TRANSPORT MEANS 2021
Sustainability: Research and Solutions

PROCEEDINGS OF THE 25th INTERNATIONAL SCIENTIFIC CONFERENCE
PART I

October 06-08, 2021
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,
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PREFACE

25th international scientific conference TRANSPORT MEANS 2021 due to the COVID-19 pandemic in the world, for the second time was organized as a virtual event on 06-08 October, 2021. 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 and 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.

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Prof. V. Ostaševičius
Comparative Study of Diesel and Compressed Natural Gas (CNG) Engine

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Abstract

Gradually progressing emission limitations as well as emerging bans on the use of diesel-powered engines, especially in urban areas, encourage the search for alternative means of powering them. This paper presents a comparative study of a diesel engine in its original variant and after conversion to run on compressed natural gas (CNG). During the conversion from the mechanical side the compression degree was lowered by replacing the pistons. The timing phases from the original variant were left. An additional power system with sequential gas injection and ignition system was installed. Tests on an engine dynamometer in the full load characteristics and performance mode confirmed the consistency of values, with local differences of 3.36% to the disadvantage of CNG power supply. Analysis of the composition of exhaust gases showed an increase in the analyzed components of HC, CO₂ and NOₓ when powered by CNG, with no CO content in both power supply variants. The tests were preliminary in nature, and optimization of the CNG supply control system is expected at a later stage.

KEY WORDS: mechanical engineering, combustion engines, alternative fuel supply, CNG, research

1. Introduction

Current emission regulations known as GreenHouse Gases (GHGs) [1] pose a major challenge to internal combustion engines used in transportation. From 2020, CO₂ emissions in the Worldwide Harmonized Light-Duty Vehicle Test Procedure (WLTP) vehicle type approval test must not exceed 95 gCO₂/km [2]. Subsequent legislation envisages CO₂ emission reductions of 15% in 2025 and 37.5% in 2030 [3]. Additionally, the emerging proposals concerning the shape of the Euro 7 emission standard [4-6] will most probably exclude the use of the combustion engine as the only source of vehicle propulsion. It will become necessary to use hybrid drives in various configurations with combustion engines [7-9] or electric drives [10, 11]. Apart from the legislation on engines used in transport, engines for off-highway and working machines are a separate issue [12, 13].

Legislation applies to brand new engines, whereas in the transport sector there is a large number of engines already in operation. In long-distance transport, in vans and trucks and in working machines, diesel engines are the basic source of propulsion. Efforts are being made in various ways to eliminate this type of propulsion system, for example in urban areas [1], which is why these engines are often converted to run on alternative fuels. The most popular alternative fuels are: Liquefied Petroleum Gas (LPG), Compressed Natural Gas (CNG), and Liquefied Natural Gas (LNG) [14-16]. The use of hydrogen (H₂) in vehicle powertrains promises to be very promising [15, 17] Alternative fuels that are possible for use in propulsion sources are included in a number of legal norms such as the European Union Directive (2014/94/EU) [18], Alternative Motor Fuels Act (AMFA), Corporate Average Fuel Economy (CAFE), and GHGs [19].

Conversion of a diesel engine to run on alternate fuel can be done in two ways. First, a dual-fuel engine can be created, where leaving the minimum diesel dose to initiate auto-ignition an additional portion of fuel can be supplied in the form of LPG, CNG or H₂ gas [20-22]. The second method is the introduction of structural changes in the engine together with the transition from auto-ignition to foreign ignition with only alternative fuel [23, 24]. It should be pointed out that the change of the operation mode from self-ignition to external ignition, especially in the case of diesel engines operating in the lower speed range, causes a change in their flexibility [25]. The change of the engine operation mode entails differences in exhaust emission. Alternate power supply reduces particulate matter (PM) emissions, but HC, CO and NOₓ emissions are not always lower [26, 27].

In the further development of conversion methods for diesel engines to run on alternate fuels, especially CNG, several strategic aspects must be taken into account. Mainly the early prediction of whether the engine has any chance at all of stable operation under load when switching to another ignition system. As is well known, spark ignition (foreign) engines are high speed and their operation is stable above 1500 rpm. Further, can the moment of inertia of diesel engine provide stable operation in spark ignition mode below 1000 rpm. On the functional side, the friction resistance in the working nodes [28, 29], the possibility of using piezoelectric drive in the gas injectors [30], or the extension of diagnostic systems within the engine [31] should also be considered. The final analysis ultimately has to relate cost-effectiveness to conversion costs [32].

The aim of this study is to evaluate the conversion of a diesel engine to run on CNG fuel in the variant of
mechanical modification and change of ignition system. To the group of analyzed parameters external indicators such as power and torque as well as ecological ones including selected components of exhaust gases were chosen. The tests were carried out on an engine dynamometer in the full load characteristics and performance mode, taking into account the fact that differences occur at partial loads.

2. Object of the Research

The subject of the research was a Steyr engine. Table 1 presents the basic technical data of the tested engine in its original version, i.e. fueled with diesel oil.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>- model</td>
<td>WD615.69 / R6 / 12V</td>
</tr>
<tr>
<td>- engine displacement</td>
<td>9.726 cm³</td>
</tr>
<tr>
<td>- max. power at engine speed</td>
<td>247 kW at 2200 r./min</td>
</tr>
<tr>
<td>- max. torque at engine speed</td>
<td>1350 N·m at (1100-1600) r./min</td>
</tr>
<tr>
<td>- bore</td>
<td>126 mm</td>
</tr>
<tr>
<td>- stroke</td>
<td>130 mm</td>
</tr>
<tr>
<td>- compression ratio</td>
<td>16:1</td>
</tr>
<tr>
<td>- minimum specific fuel consumption</td>
<td>193 g/(kW·h)</td>
</tr>
<tr>
<td>- respect to emission</td>
<td>Euro 2</td>
</tr>
<tr>
<td>- fuel</td>
<td>diesel</td>
</tr>
</tbody>
</table>

When converting the engine to run on CNG, it was decided to lower the compression ratio. This was achieved by replacing the pistons, which reduced the compression ratio from 16:1 to 11.5:1. The change of the compression ratio entailed changing the pressure at the end of the compression stroke from the initial $28 \times 10^5$ Pa to $13 \times 10^5$ Pa. The CNG supply system was implemented using an additional fuel system with multi-point sequential gas injection based on the STAG 600 MF controller. The STAG 600 MF controller controlled both the fuel dosing and the moment of spark appearance on the spark plug, as the engine after conversion operates in the foreign ignition mode. The engine timing phases were not corrected.

3. Research Methodology

A SuperFlow SF-902 water-braked dynamometer was used in the tests, and a Maha MGT-5 analyser was used to evaluate the exhaust gas composition. An AFR controller based on a Bosch 4.9 probe cooperating with a STAG 600 MF engine controller enabled evaluation of the combustible mixture ratio.

The tests were carried out in the engine full load characteristics and performance cycle, where at the power supply level set at 100%, the dynamometer controlled the load in an automatic cycle so as to obtain successive set points of the rotational speed measurement.

Basic technical data of the measurement equipment have been presented in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement device</th>
<th>Range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation speed: $n$, r./min</td>
<td>SuperFlow SF-902</td>
<td>0 - 9,000</td>
<td>±1</td>
</tr>
<tr>
<td>Torque: $T$, N·m</td>
<td>SuperFlow SF-902</td>
<td>0 - 1,627</td>
<td>±0.25%</td>
</tr>
<tr>
<td>Power: $P$, kW</td>
<td>SuperFlow SF-902</td>
<td>0 - 1,119</td>
<td>±0.25%</td>
</tr>
<tr>
<td>Air-fuel ratio: $\lambda$, -</td>
<td>STAG 600 MF + Bosch 4.9</td>
<td>0.650 – 10.119</td>
<td>0.001</td>
</tr>
<tr>
<td>Oxygen, O₂, %</td>
<td>Maha MGT-5</td>
<td>0 – 25.00</td>
<td>0.1</td>
</tr>
<tr>
<td>Carbon monoxide: CO, %</td>
<td>Maha MGT-5</td>
<td>0 – 15.00</td>
<td>0.06</td>
</tr>
<tr>
<td>Carbon dioxide: CO₂, %</td>
<td>Maha MGT-5</td>
<td>0 – 20.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Hydrocarbons: HC, ppm</td>
<td>Maha MGT-5</td>
<td>0 – 20000 (hexan),</td>
<td>12</td>
</tr>
<tr>
<td>Nitrogen oxides: NOₓ, ppm</td>
<td>Maha MGT-5</td>
<td>0 – 5000</td>
<td>32 – 120</td>
</tr>
</tbody>
</table>

4. Results and Discussion

Analyzing the power and torque variation shown on the engine full load characteristics and performance (Fig. 1), slight differences are evident. The advantage of CNG power supply occurs in the range (1300-1500) r./min, amounting to a maximum of 3.36%. On the other hand, at a rotational speed of 1900 r./min, the CNG power supply causes a decrease in the values of the analyzed parameters by 3.04% compared to the base power supply.
An important parameter in CNG fueling is the composition factor of the combustible mixture $\lambda$ [37]. Monitoring the variation of this parameter determines the corrections of gas dose. Fig. 2 shows the variation of the value depending on the engine speed. The CNG-fueled engine showed lower values $\lambda$ (by about 0.2) with a similar character of variability. In the case of the $O_2$ content in exhaust gas (Fig. 2), the diesel engine maintained the same value of about 7.9%, while the CNG-fueled engine showed significant oscillations (4.3 - 20.8), especially in the range (700 - 1000) r./min. This is most likely due to the fact that the spark ignition (foreign) engine, which was obtained after conversion to CNG power, has a problem with stable operation below a speed of 1000 r./min. In general, spark ignition engines are high speed engines, where the speed range at which we can load it completely should rarely be lower than 1500 r./min.

In the case of CO emissions, they were not recorded for both diesel and CNG fuels (Fig. 3). $CO_2$ emissions for diesel (baseline) fueling remained at 8.4%, while for CNG fueling they ranged between (10.1 - 7.3)% with a tendency to decrease as speed increases.

HC and NOx emissions on diesel (baseline) power were fixed at 13 ppm and 1511 ppm (Fig. 4). With CNG fueling, HC emissions varied, several times higher than with diesel fueling, borderline reaching 288 ppm. At this point, it should be pointed out that the exhaust gas analyzer referred HC to hexane when fueled with diesel, while when fueled with CNG to methane, which could be the reason for the differences.

The NOx emissions were very irregularly arranged. Up to 1400 r./min values were higher than diesel (max. 3322 ppm), above 1400 r./min values were lower than diesel (min. 491 ppm).
Summarizing the presented test results, it was found that conversion of diesel engine to CNG fuel and mode of operation as spark ignition gives:

- local differences of 3.36% in the values of external indicators, i.e. power and torque;
- decrease in the coefficient of composition of the combustible mixture, on average by almost 8%, while the O₂ content;
- in the exhaust gases increased on average by 7.2%;
- increase in HC emissions, on average by as much as 1329%;
- increase in CO emissions, on average by only 0.7%;
- increase in NOx emissions, by an average of 24%.

It is noted that the nature of the changes in O₂, HC and NOx under CNG fueling varies greatly, which is not reflected under base diesel fueling.

5. Conclusions

The method of converting a diesel engine to run on CNG, presented in the article, confirmed the applicability of this type of treatment. The presented research was based on the simplest way of conversion, where an additional gas supply system was installed and pistons were changed in order to lower the compression ratio. A very important aspect of the conversion in this case was omitted, i.e. changing the timing phases, which are different for spark-ignition and diesel engines. The attempt made has shown the feasibility of converting the diesel engine to CNG fuel in the minimum investment variant. The engine full load characteristics and performance are very close to each other with both power systems giving a local difference of only 3.36% to the disadvantage of the CNG power system.

The combustible mixture ratio analysis showed an average decrease of almost 8%, with the exhaust gas analyzer reporting an approximate 7.2% increase in O₂ content in the exhaust gas. Analysis of the other components of the exhaust gas showed an average increase of 1329% in HC, 7.7% in CO₂, and 24% in NOx, with no CO content recorded. Significant variation in the nature of changes in the content of O₂, HC and NOx in exhaust gases was observed when CNG was powered, which was not the case when diesel was powered.

It should be noted that the research was preliminary in nature, where in a further stage it will be focused on optimizing the control method of the CNG power system.

Acknowledgment

This research was financed through subsidy of the Ministry of Science and Higher Education of Poland for the discipline of mechanical engineering at the Faculty of Mechanical Engineering Bialystok University of Technology WZ/WM-IIM/4/2020.

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Prediction of Liquefied Natural Gas Ageing at Klaipėda FSRU Terminal Independence

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Abstract
In this paper liquefied natural gas (LNG) ageing and boil-off gas (BOG) issues are being analyzed for Floating Storage and Regasification Unit (FSRU) Independence. An analysis is conducted in order to propose practical recommendations to control of various technological operations in the large-scale LNG terminal. It was determined that the composition of primary cargo, LNG holding time, management of boil-off gas, and LNG-free tank volume has the main impact on liquefied natural gas ageing.

KEY WORDS: LNG, LNG ageing, boil-off gas, FSRU, Wobbe index.

1. Introduction
Due to highly advancing technologies in liquefied natural gas industry, LNG is being widely used in energy industry and marine transport. LNG value is increasing significantly in global market due to low greenhouse gas emissions to the atmosphere [1]. Usage of LNG as a fuel is a great alternative in shipping – sulphur oxides and particulate matters are fully removed from the exhaust gases [2]. Furthermore, usage of LNG as a fuel reduces nitrogen and carbon oxides emissions [3].

LNG is easily and effectively transported globally due to its exclusive physical and chemical characteristics [1]. The main issue in usage of LNG is to reduce loss of LNG and to prevent hazardous conditions occurrence in LNG storage tanks. For these reasons it is necessary to predict changes of LNG composition and to manage evaporation of LNG during different technological operations on FSRU [4].

Ageing of LNG is a change in the composition of liquefied natural gas as well as in chemical and physical properties during its long-term storage.

The objective of this work was to evaluate impact of technological operations on LNG ageing and management of boil-off gas during its storage on FSRU terminal Independence.

2. Methodology
The object of this work was the FSRU type large scale LNG terminal Independence (Table 1).

Table 1

<table>
<thead>
<tr>
<th>Characteristics of the FSRU LNG terminal Independence [5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
</tr>
<tr>
<td>Builder</td>
</tr>
<tr>
<td>Launched</td>
</tr>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Beam</td>
</tr>
<tr>
<td>Propulsion</td>
</tr>
<tr>
<td>Speed</td>
</tr>
<tr>
<td>Total capacity of LNG tanks</td>
</tr>
<tr>
<td>Max LNG filling level</td>
</tr>
<tr>
<td>Min operational LNG heel level</td>
</tr>
<tr>
<td>Max LNG load rate</td>
</tr>
<tr>
<td>Max LNG regasification rate</td>
</tr>
</tbody>
</table>
3. Results and Discussions

In this analytical part results of the variation of the composition of LNG, the factors that affect the changes in the composition of LNG, changes in physical properties of LNG, evaporation and ageing of LNG on FSRU are presented.

Variation of LNG composition during the regasification process (Fig. 1). It is important to analyse this dependence in order to understand the effect of the change of LNG-free volume in the tank on the change of methane content in LNG. The selected period for the further analysis was chosen 31 calendar days. On the first day of the cargo storage, the loading of LNG into the tank from the incoming gas carrier was completed. During the storage of this cargo, no technological processes were carried out, however the evaporated gas was removed from the tank and burned. On the 23rd day the regasification process from the tank was started.

The level of LNG in the tank on the first day of cargo storage was 78% (36713.81 m$^3$) as well as the percentage of methane in LNG was 92.11 mol. %. For the first 23 days, LNG was just stored, no technological processes were carried out, except boil-off gas burning. During this period, the percentage of methane in LNG changed insignificantly – from 92.11 to 92.054 mol. %. Meanwhile, on the 23rd day of cargo storage, regasification process was started and lasted until the 31st day. The tank filling level decreased up to 8% (3804.6 m$^3$) and the percentage of methane in LNG changed from 92.11 to 92.00 mol. %.

Thus, from the data presented in the Fig. 1, we can state that the content of methane in LNG starts to change more intensively with the start of the regasification process. This is explained by the increasing LNG-free volume above LNG, which promotes more intense evaporation of methane [6].

Dependence of LNG temperature variation on the methane content in the LNG (Fig. 2). On the first day of cargo storage, the LNG temperature was minus 159.91 °C as well as methane content in LNG was 92.11 mol. %. It was observed that as the LNG warms, the percentage of methane in the LNG decreases proportionally. During the first 23rd days of cargo storage, the temperature of LNG increased up to minus 158.40°C (1.51°C). Meanwhile, during regasification process, the temperature of LNG began to rise faster. From day 23 to day 31, the LNG temperature increased up to minus 156.87°C. During this period LNG warmed 1.53°C in just 8 days. In comparison, during the first 23 days of cargo storage, LNG warmed by only 1.51°C, and during the entire LNG storage period (31 days), LNG warmed to 3.04°C. Thus, as the volume of LNG in the tank decreases, the evaporation of methane and the heating of LNG intensifies. LNG warmed up faster at a lower LNG volume in the tank due to the lower relative area between the LNG contact surface and the tank walls.

![Fig. 1 Variation of LNG composition during the regasification process](image-url)
Fig. 2 Dependence of LNG temperature variation on the methane content in the LNG

Dependence of LNG density variation on the methane content in the LNG (Fig. 3). It is necessary to monitor and forecast the changes of LNG density in order to prevent cargo rollover in the tank when accepting new cargo, during LNG transfer between the tanks, and for a long-term storage of LNG [7].

On the first day of cargo storage, the density of LNG was 445.54 kg m\(^{-3}\). Within the next 23 days, it increased up to 447.48 kg m\(^{-3}\), or 1.94 kg m\(^{-3}\).

On the last day of the cargo storage before the arrival of new cargo of LNG, a density of 448.461 kg m\(^{-3}\) was recorded. During 31 days of LNG storage, it became 2.921 kg m\(^{-3}\) heavier.

Thus, the change in density can be observed as a function of the change in the percentage of methane. Without regasification, the percentage change of methane in LNG is slower, leading to a slower increase in the density of LNG.
With the start of the regasification process, the LNG-free volume of the tank will increase, which will accelerate the evaporation of methane.

**Dependence of LNG temperature variation on the vapour pressure in the tank (Fig. 4).** During LNG storage BOG are released and increase the pressure in the tank. As a result, the evaporation of LNG intensifies, and the content of methane in LNG begins to change more intensively. The pressure in the tanks of FSRU vessels must never exceed 0.7 bar. If this pressure is exceeded this value, the BOG is removed through the emergency exhaust valves to the spark plug. In order to avoid the formation of overpressure in the tank and the loss of a methane content in LNG, it is necessary to analyse and predict the dependence of the LNG temperature on the pressure in the tank [8].

![Fig. 4 Dependence of LNG temperature variation on the vapour pressure in the tank](image)

From the Fig. 4, it can be observed that as the pressure in the tank increases, the LNG temperature increases too, because LNG absorbs energy that is transferred through the tank walls [9]. On the 18th day of the cargo storage, the BOG was started to be removed from the tank more intensively, which reduced the pressure in the tank from 23.97 to 11.48 kPa. Meanwhile, on the 23rd day, the regasification of the LNG was started, which resulted an increase of the LNG-free volume in the tank. Due to this, the pressure above the LNG started to decrease, but as the LNG volume decreases, the evaporation in the tank intensifies and the area of direct contact of LNG with the tank walls decreases, causing them to heat and evaporate more intensively.

Thus, during the 31 days of analysis, the temperature of LNG changed from minus 159.91 to minus 156.87°C, and the pressure above the LNG ranged from 11.48 to 26.01 kPa. The Fig. 4 shows the effect of pressure on the LNG temperature: as the pressure in the tank increases, the LNG temperature increases too; as the pressure decreases, the LNG temperature increases more slowly. It could be stated that the pressure regulation in the tank is an important factor in monitoring LNG ageing process [4].

**Dependence of nitrogen content in the LNG variation on the LNG temperature (Fig. 5).** It is necessary to analyse this dependence in order to better understand the changes of the methane content in LNG after partial or total evaporation of nitrogen.

The more intense change of nitrogen in LNG is explained by the lower boiling point of nitrogen (minus 196°C), which results that nitrogen evaporating faster and more intensely than methane. On the first day of the cargo storage, the percentage of nitrogen in LNG was 0.586 mol. %. With the start of the regasification process, it is noticeable that the change in the percentage of nitrogen in LNG has slowed down. This can be explained that nitrogen evaporated more intensively from the upper LNG layer during the first 22 days. With the start of LNG regasification and the increase of LNG-free volume in the tank, the change of methane content in LNG intensified. During the 31 days of cargo storage, the percentage of nitrogen in LNG decreased up to 0.263 mol. %.
From the analysis of these data, it could be stated that the evaporation of most of the nitrogen from the upper LNG layer will intensify the evaporation of methane in LNG. In this way, by observing the change of the nitrogen content in LNG, it is possible to predict when the methane begins to evaporate more intensively and thus contribute to the management of the LNG ageing process.

**Dependence of Wobbe index variation on the methane content in the LNG (Fig. 6).** This index is a measure of the interchangeability of fuel gases and their relative ability to deliver energy.

On the first day of cargo storage, the value of the *Wobbe index* was 54.5901 MJ/m$^3$. During the 23 days of LNG storage, the value of the *Wobbe index* increased up to 54.7043 MJ/m$^3$. The change of methane content in LNG has the...
greatest impact on the change in the value of this index, as methane makes up over 90 mol. % of LNG and evaporates more intensively than other components [10]. During the rest of the period the value of the Wobbe index of LNG increased up to 54.7361 MJ/m³. From the Fig. 6, it could be stated that the value of the Wobbe index directly depends on the percentage of methane in LNG. As the percentage of methane in LNG decreases, the Wobbe index increases, because methane evaporates faster and more intensely than other LNG components. Furthermore, as the percentage of methane decreases, LNG becomes richer [11].

4. Conclusions

It has been found that content of the methane in LNG slightly changes during LNG storage and start more intensively during regasification process due to the increasing LNG-free volume in the tank. In addition, BOG formation in the tank impact on the increasing the density of LNG, as well as increasing the risk of LNG stratification and the rollover during long-time LNG storage.

It has been found that the temperature of LNG is directly affected by the pressure in the tank: as the pressure increases, the LNG temperature increases too.

It has been found that the evaporation of most of the nitrogen intensifies the evaporation of methane of LNG. In addition, it has been found that the change of the content of nitrogen in LNG is not significantly affected by the change in LNG temperature, as the boiling point of nitrogen (-196 °C) is much lower than methane (-162 °C).

It has been found that the value of the Wobbe index directly depends on the composition of LNG: as the content of methane in LNG decreases, the content of other components in LNG (ethane, propane, butane) increases, resulting in an increase of the Wobbe index.

It is recommended to proceed regasification from only one tank until heel level has been reached in order to minimize increment of overall cargo tank LNG-free volume. During the long LNG storage time it is recommended to recirculate LNG in close loop in order to homogenize LNG and to prevent occurrence of different density LNG layers and to minimize rollover risk. Moreover, if there is no possibility to utilize boil-off gas, it is recommended to condensate it by recirculating LNG in close loop and by filling LNG to the cargo tank from the top filling line.

References

Properties Study of the Harmonized Shape Transition Sections of the Railway Track Curves

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Abstract

This study is based on the calculative modelling results of functionally significant kinematic points at levels $H$ of the rail track + vehicle system (RT+V system from here on) on its harmonized transition sections (TS from here on) of the railway curves with a variable cross slope track $i(l)$ and with a variable axis curvature $k(l)$. The integrative quality characteristics results of the RT+V system obtained by applying this method investigated for dependence on predetermined values of movement design speed $V$, the radius of curvature $R$, the external rail elevation above the internal rail (the cant) $D$ with a track width $S = 1520$ mm, and with constant harmonization of the system properties with elevation level raised above the rail top level (RTL from here on) by $H_{LG} = 2200$ mm. The lengths $L$ and the parameters $Z$ and $U$ of various TS shapes were established in the harmonization process of the RT+V system interaction properties. They were modified and predetermined in accordance with the summary of all the above-mentioned parameters. The goals and the results of this harmonization process differed from the requirements of presently recognised regulations. Therefore, this research includes an assessment study of the possibility to use harmonized TS shapes in the design of curves of ordinary, high-speed and super high-speed railway tracks.

KEY WORDS: cross-slope transition, transition section length, properties harmonization level, track twist

1. Introduction

In a practical aspect, the term "harmonization" means the process of achieving the highest performance efficiency of the RT+V system within the TS by coordinated interaction of deterministic properties of all its components. From the objectives formalized in [1], it is concluded that its results are mainly influenced by TS length $L$. Its influence on the function of non-compensated lateral acceleration (NCLA) $a(l)$, effective within the TS of the curve at the design vehicle level $H_{LG}$, is illustrated in the example with the following values of system parameters: movement speed $V = 200$ km/h, curvature radius $R = 2000$ m and cant $D = 150$ mm. For these values and for the lengths $L$ varying in the range of $100 \text{ m} \leq L \leq 420$ m, distribution diagrams were constructed for functions $a(l)$ and $\psi(l) = da / dt$ (see Fig. 1, a and Fig. 1, b). The values of these functions were calculated at the level $H_{LG}$ using the analytical dependencies of the multi-factor deterministic kinematic model (MDKM) described in [2].

![Fig. 1 Distribution diagrams of integrative quality characteristics of the RT+V system with fixated track curvature at different lengths L of TS shapes with non-identical half-sine functions k(l) and i(l): a - distribution diagrams of NCLA a(l); b - distribution diagrams of NCLA change rate $\psi(l) = da / dt$; c - distribution diagrams of extrema functions $\psi_{max}(L)$ and $\psi_{min}(L)$](attachment:image.png)

From the distribution diagrams shown in Fig. 1, it is concluded that for the given parameter values of the RT+V system in this example, within the specified boundaries of the length range $L$, there is a special point $G$ (see Fig. 1, c), which separates the integrative properties of the RT+V system in two qualitatively different sets. In the given example, the length of the TS corresponding to this point is $L_G = 210$ m. The first combination of the RT+V system integrative properties with TS lengths $L < L_G$ is characterized by low-frequency oscillation values of NCLA function $a(l)$ and its derivative $\psi(l) = da / dt$. Field observation of the acceleration vibrations, as well as the medical examination of the passengers and carriage attendants in Japan established that it is at this kind of frequencies ranging from 0.5 Hz to 1 Hz, they...
caused discomfort and motion sickness [3]. From the distribution diagram of the extrema functions $\psi_{\text{max}}(L)$ and $\psi_{\text{min}}(L)$, follows that the difference between them within each of the TS $s$ dramatically increases as their lengths $L < L_G$ decrease (see Fig. 1, b and Fig. 1, c). As a result, this increases the unevenness of transverse accelerations and forces, which result in a swinging effect of the moving vehicle along such a TS. Dashed lines of the distribution diagrams $a(l)$, $\psi(l)$, $\psi_{\text{max}}(L)$ and $\psi_{\text{min}}(L)$ which correspond to such an unacceptable quality of movement are drawn in black and orange colours in Fig. 1.

The second combination of the RT+V system integrative properties, secured at TS lengths of $L \geq L_G$, is characterized by a smooth and strictly monotonous transition of NCLA functions $a(l)$ values, which excludes undesired oscillations. As the TS lengths increase $L \geq L_G$, their diagrams become more like the diagrams of half-sine curvature functions $k(l)$ of their trail axle or its slope transition $\dot{n}(l)$. The diagrams of functions $\psi(l) = da / dt$ that have already become unimodal are subject to a similar transformation (see Fig. 1, b). This characterizes the essence of intermittent transition of RT+V systems performance to a new quality, which occurs at point $G$ at the length of their TS $L = L_G$. In this particular example, $L_G$ equals 210 m. With a slight increase in TS lengths $L > L_G$, an undesirable increase in the values of unimodal functions $\psi(l)$ maxima are observed. In this example, it is attributable to TS with the lengths of $L = 210$ to 260 m. As the TS lengths increase further above 260 m, the functions $\psi(l)$ corresponding maxima will steadily decrease.

Taken into consideration those specific properties, the subjects of this study were the geometric and functional properties of RT+V systems with TS lengths rounded to 1 m, $L = L_G \pm 0.5$ m. Additionally to transitioning to a whole new quality at such lengths, a synergistic effect occurs, which could be "measured" either by TS length reduction $\Delta L$, or by an increase of passenger comfort $\Delta \psi_{\text{max}}$ (see Fig. 1, c). In this concrete example, it amounts to $\Delta L = -154$ m and $\Delta \psi_{\text{max}} = -0.022$ m/sec$^2$. In relative terms, this amounts to ~42% of TS length with similar passenger comfort and +12% to the level of comfort at the lowest levels of $L \geq L_G$. The semi-linear distribution NCLA diagram $a(l)$ and the "unimodal" distribution diagram of its change rate $\psi(l)$, which characterize the kinematics of vehicle points at the $H_{LG}$ level, when the vehicle moves along a TS of harmonized shape with a length $L_G$, are drawn in Fig. 1, a and 1, b as red lines. To a certain extent, the result of this harmonization and other variants of sets of values of parameters of RT+V systems considered below are also influenced by the values of the so-called parameters $Z$ and $U$. However, explaining them is not relevant to the essence of this study. Therefore, they will not be mentioned afterwards.

According to a systemic analysis, these, and other quality characteristics quantities of the RT+V system are relevant only for these specific combinations of parameter values, which are considered within its scope. Realistically, there can be many more other variants. To reduce the number of variants without affecting the value of this study results, the possibility change track gauge $S$ and the design level of harmonization $H_{LG}$ were excluded. This determined the choice of values for other partially related with $H_{LG}$ functionally significant levels of the design vehicle. These include the following: RTL $H_{RTL} = 0$ mm, axle box level $H_{LB} = 460$ mm, mass centre of the empty cargo vehicle $H_{CG} (\text{empty}) = 1600$ mm, mass centre of the passenger vehicle $H_{CG} = 1800$ mm and the vestibular system elevation of the modal passenger $H_{VS} = 2200$ mm. The values of these parameters were considered in calculation process of their respective NCLA distribution diagrams $a(l)$ and $\psi(l)$ which are dependent on the considered variant of the assessed set of predetermined parameter values of the RT+V system. One of the objectives of this assessment was to identify specific regularity features established in the process of the lengths $L_G$ harmonization and the dependent integrative properties of the RT+V system. They were considered when assessing the possibility of the harmonized TS shapes usage in the curves design of ordinary, high-speed and super high-speed railway.

2. Substantiation of the Variation Range of the Investigated TS Shapes Values

The aforementioned railway types were considered when selecting the four design speeds: 100, 200, 300 and 400 km/h. In each of them, six discrete values of cant $D$ were considered (25, 50, 75, 100, 125 and 150 mm). Each pair with a unique combination of possible $V$ and $D$ values got correspondent 10 variants of radius $R$ of the curve circular part. Their values were calculated subjectively with the condition to ensure maximum values of NCLA $a_{\text{max}}$, with a step variation of 0.1 m/sec$^2$ at given values of $V$ and $D$ in the range: 0.1 m/sec$^2$ to 1.0 m/sec$^2$. Thus, the number of unique combination variants of the parameter values for the investigated RT+V systems amounted to 240 variants.

The passenger comfort priority in each of the variants was ensured at the expense of equal levels of $H_{LG}$ and $H_{VS}$. TS lengths $L_G$ calculated for $H_{LG} = H_{VS}$ ensured almost linear NCLA distribution diagrams $a(l)$ and a trapezoidal form distribution diagrams of NCLA change rate $\psi(l)$ that are consistent with passenger comfort at minimum value extremum of the characteristic $\psi_{\text{max}}$ in their central part. Therefore, at all other levels of the carriage located below $H_{VS}$, the distribution diagram shapes $\psi(l)$, maintained the required smoothness and monotonal symmetry, became more unimodal. Consequently, the extrema $\psi_{\text{max}}$ typical to these levels increased, as the positive difference between $H_{LG}$ and these levels respectively increased. In the absence of functions $\psi(l)$ oscillations at the carriage levels located below $H_{VS}$, this is not critical. A typical for all the RTV- system variants considered in this analysis, is the example of regularity characteristics properties for a system harmonized with values: $V = 200$ km/h, $D = 150$ mm, $R = 2000$ m, $a_{\text{max}} = 0.624$ m/sec$^2$, $H_{LG} = H_{VS} = 2200$ mm and $L_G = 210$ m (see Fig. 2, a).

If the HLG level becomes lower, the length of thee harmonized TS shape LG is shortened. But at the same time, the quality of movement at all other functionally significant levels of the vehicle HLG deteriorate (see Fig. 2, b). Consequently, the lengths LG of the TS shapes investigated in this analysis that harmonized at HLG = HVS, should be considered minimal.
3. Analysis of the TS Shapes Properties that are Harmonized without any Limitations

The geometric and functional properties of are RT+V systems with harmonized TS shapes at the first stage of this study were represented by their length $L_G$, their passenger comfort characteristics $\gamma_{\max}$ and the necessary for this arrangement displacement of their circular curves $p$. A total of 720 values of these parameters were calculated in accordance with previously justified 240 variants parameter values of the RT+V system, and they were represented by points for these three systems in rectangular coordinates $(L_G, a_{\max})$, $(a_{\max}, \gamma_{\max})$ and $(a_{\max}, p)$. When plotted on the diagrams, all points coordinates which were calculated with the same cant $D$ value, were self-organized into groups, which were well approximated by polynomial trend functions with high approximation accuracy $R^2 \approx 1.0$ (see Fig. 3).

According to these results, the non-linear regularities of conditional functions $L_G(a_{\max})$ that are calculated at $D = 150$ mm, differ significantly from vertical lines of functions diagrams $L_{\min} = V \cdot D / \gamma$. They traditionally limit the clothoid TS forms minimum lengths, depending on the so-called wheel lifting speed $\gamma$ at cant $D$ for the entire range of design speeds $V$. A diagram of one of these functions at $\gamma = 28$ mm/sec is drawn as punctuated black line (see Fig. 3, a). All thought, the differences of other minimum length half-sine TS shapes determined in [4] with respect to proportionality coefficients given, would be even greater. Unlike functions $a_{\max}(L_G)$, functions $\gamma_{\max}(a_{\max})$ and $p(a_{\max})$ are invariant to speed $V$. This indicates that regardless of the design speed $V$ value, passenger motion discomfort $\gamma_{\max}$ will increase proportionally to the growth of the design NCLA value $a_{\max}$ and proportionally inversely to the design value of the cant $D$. But at the same time, the displacement of circular curves $p$ will increase proportionally to $D$ and proportionally inversely to NCLA $a_{\max}$.

For the entire combination subset of variants predetermined values of system parameters $V, R$ and $D$ represented in coordinate systems: a - $L_G, a_{\max}$; b - $a_{\max}, \gamma_{\max}$; c - $a_{\max}, p$.

For the entire combination subset of variants predetermined values of system parameters $V, R$ and $D$, which ensure the design NCLA values $a_{\max}$ within the range from 0.1 m/sec$^2$ to 0.7 m/sec$^2$, the passenger motion discomfort indicator
\[ \psi_{\text{max}} \] will not exceed 0.5 m/sec\(^2\). The necessary displacements \( p \) of these curves’ circular parts, that are required for the arrangement of TS, will fall within the range of 0.025 m to 0.925 m. They constitute approximately a \( \frac{1}{2} \) of the displacement values \( p \) required for the arrangement of clothoid TS with similar radii and lengths.

4. Additional Parameters Control of the Harmonized TS Shapes

The ideal properties of functions regularities \( a(l) \) and \( \psi(l) \) acquired at the level \( H_{L|G} = H_{TS} \) throughout the entire length \( L_G \) of harmonized TS shapes (see Fig. 1, a and 1, b), as well as their significantly important values of geometric and functional parameters (see Fig. 3, b and 3, c), show their significant superiority compared to the previously known technical TS shapes variations. Nevertheless, when justifying the possibility and the scope of their application, two important circumstances should be considered. The first circumstance is conditioned by the indirect nature of quality criterion for harmonization of RT+V systems. Its achieving level is quantitatively assessed by residual dispersion \( \varrho \), which could have corresponded to a strictly linear function of NCLA function \( \psi(l) \) or how close the diagram of the NCLA function \( \psi(l) \) is to become linear, by connecting its initial \((a(0) = 0)\) and final \((a(L_G) = a_{\text{max}})\) values. This also ensures maximal convergence of the level “plateau” of the function \( \psi(l) \) with its absolute, but practically unattainable minimum \( \psi_{\text{MIN}} \), which could have corresponded to a strictly linear function of NCLA \( a(l) \). This minimum is shown by a green punctuated line and denoted as imaginary in the diagrams shown in Fig. 2.

But all these indirect indicators cannot guarantee permissible compliance norm of passenger comfort indicator \( \psi_{\text{max}} \leq \psi_{\text{lim}} \). Therefore, those subsets of systems parameter values, which do not ensure the required comfort of movement, should be identified in accordance with the given criterion \( \psi_{\text{lim}} \) in the process of their harmonization. Thus, in the example, from the diagram shown in Fig. 3, b, follows that at any design speed of movement \( V \), the maximal level of discomfort allowed \( \psi_{\text{lim}} = 0.4 \text{ m/sec}^2 \) will not be exceeded in curves with harmonized TS shapes with values: \( D = 25 \text{ mm} \) and \( a_{\text{max}} \leq 0.6 \text{ m/sec}^2 \); \( D = 50 \text{ mm} \) and \( a_{\text{max}} \leq 0.73 \text{ m/sec}^2 \); \( D = 75 \text{ mm} \) and \( a_{\text{max}} \leq 0.85 \text{ m/sec}^2 \); \( D = 100 \text{ mm} \) and \( a_{\text{max}} \leq 0.93 \text{ m/sec}^2 \); \( D \geq 125 \text{ mm} \) and \( a_{\text{max}} \leq 1.0 \text{ m/sec}^2 \).

The second circumstance is conditioned by representing the vehicle in the MDKM as a dimensionless design point on the vertical axis cross-section of its body, which traditionally has no length [2]. With a significant variation in the lengths \( L_G \) and relative constancy of real vehicles lengths, situations may acquire when track twist conditioned by its transition type \( \varrho(l) \) creates a threat to the movement safety. For example, derailment due to unloading of diagonally opposite wheels. The indicator of the current track twist \( \varrho(l) \) depends on track gauge \( S \) (mm), the current value of its cross-slope function \( \varrho(l) \) and the half - length of its assessed basis \( b(m) \):

\[
\tau(l) = \frac{S \left[ l(l+b) - l(l-b) \right]}{2b}.
\]  

From Eq. (1), it is concluded that the maximum track twist \( \tau_{\text{max}} = \text{MAX}[\tau(l)] \), assessed within the TS range \( 0 \leq l \leq L_G \) at half-sine transition type \( D \) will be observed in its middle, i.e., at \( l = L_G/2 \). Those subsets of system parameters values, which do not ensure the compliance to the condition \( \tau_{\text{max}} \leq \tau_{\text{lim}} \), could be identified similarly as in the previous case. So, as in the example, from the diagram shown in Fig. 4, a, it is concluded that at a design movement speed of \( V = 100 \text{ km/h} \), the predetermined limit of track twist \( \tau_{\text{lim}} = 2 \text{ mm/m} \) can be exceeded in the centre of harmonized TS shape curves, calculated in accordance to: \( D = 150 \text{ mm} \) and \( a_{\text{max}} \geq 0.22 \text{ m/sec}^2 \); \( D = 125 \text{ mm} \) and \( a_{\text{max}} > 0.3 \text{ m/sec}^2 \); \( D = 100 \text{ mm} \) and \( a_{\text{max}} > 0.4 \text{ m/sec}^2 \); \( D = 75 \text{ mm} \) and \( a_{\text{max}} > 0.55 \text{ m/sec}^2 \); \( D = 50 \text{ mm} \) and \( a_{\text{max}} > 0.82 \text{ m/sec}^2 \). At \( V = 100 \text{ km/h} \) and \( D = 25 \text{ mm} \), and also in all other cases where \( V \geq 200 \text{ km/h} \) and \( D \leq 150 \text{ mm} \), the condition \( \tau_{\text{max}} \leq \tau_{\text{lim}} \) will be observed in all curves with TS shapes harmonized for \( a_{\text{max}} \leq 1.0 \text{ m/sec}^2 \).

![Fig. 4](image)

Fig. 4 The subset of track twist functions Values \( \tau_{\text{max}}(V, D, a_{\text{max}}) \) of the investigated RT+V systems with harmonized TS shapes (a), and an application example of functions \( \tau_{\text{max}}(L_G) \) and \( L_G(H_{L|G}) \) to harmonize the RT+V system at \( V = 100 \text{ km/h} \), \( D = 150 \text{ mm} \), \( a_{\text{max}} = 0.6 \text{ m/sec}^2 \) subjected to the condition \( \tau_{\text{lim}} = 2 \text{ mm/m} \) (b)
For other values of parameter’s $S$, $H_{LG}$, $\psi_{lim}$ and $\tau_{lim}$, an acceptable combination of values of design parameters for curves $V$, $R$ and $D$, ensuring the required quality and efficiency performance of harmonized RT+V systems, should be established by calculation. Achieving these targets outside the acceptable range of the parameter’s values $V$, $R$ and $D$ is associated with a significant increase in TS lengths $L > L_{G}$ and the necessary displacements $p$ that are required for their construction. From the diagrams shown in Fig. 3, b and Fig. 4, a, it is concluded that the value combinations of the of curve parameters $V$, $R$ and $D$ of ordinary railway tracks with a design movement speed $V = 100$ km/h and less, are more susceptible to these limitations to a great extent. This could be explained by the fact that as $V$ decreases, the portion of the constant length of the conditional vehicle $2b$ increases in the decreasing TS lengths $L_{G}$. From the abscissas values in the diagram shown in Fig. 3, a, it follows that TS lengths $L_{G}$ harmonized for various speeds $V$ are related to each other in the same way as these speeds are. Therefore, at low design speeds of movement, critical combination of large cant $D$ and short lengths $L_{G}$ arise, at which the maximum value of track twist $\tau_{max}$ could exceed its permissible limits $\tau_{lim}$. Therefore, in such case, in addition to the conditioned limitation on $\tau_{max} \leq \tau_{lim}$ another condition limitation on $\psi_{max} \leq \psi_{lim}$ may be forced. The range of predetermined values of parameters $a_{max}$ and $D$ that are acceptable for the harmonization of TS at $V = 100$ km/h, $\tau_{lim} = 2$ mm/m and $\psi_{lim} = 0.4$ m/sec$^3$ is shown in Fig. 5, a.

Fig. 5 Combinations of predetermined values of parameters $V$, $R$ and $D$ that are acceptable based on conditions $\tau_{max} \leq \tau_{lim}$ and $\psi_{max} \leq \psi_{lim}$, and the dependent upon them TS diagram lengths $L_{G} (a_{max}, D)$, harmonized at $V = 100$ km/h and $H_{LG} = 2200$ mm (a), and the corresponding values of $\psi_{max} (a_{max}, D)$ (b) , also the displacements $p (a_{max}, D)$ (c)

Fig. 6 Combinations of predetermined values of parameters $V$, $R$ and $D$ that are acceptable based on the condition $\psi_{max} \leq \psi_{lim}$ and the diagrams of TS lengths $L_{G} (V, a_{max}, D)$ that are dependent on them, harmonized at $V = 200$ km/h and $H_{LG} = 2200$ mm (a), and the corresponding to them values $\psi_{max} (a_{max}, D)$ (b) also displacements $p (a_{max}, D)$ (c)
As the design movement speed and the lengths $L_G$ increase, the relevance of the condition $\tau_{\text{max}} \leq \tau_{\text{lim}}$ decreases drastically. The combinations range of predetermined parameter values of $V$, $R$ and $D$ that are acceptable for the harmonization of TS at $200 \leq V \leq 400$ km/h, $\tau_{\text{lim}} = 2$ mm/m and $\gamma_{\text{lim}} = 0.4$ m/sec$^3$ is shown in Fig. 6, a. The diagram lines of $L_G (V, \alpha_{\text{max}}, D)$ and the corresponding parameter values $\gamma_{\text{max}} (\alpha_{\text{max}}, D)$ and $\rho (\alpha_{\text{max}}, D)$ which were obtained during the harmonization of RT+V systems with the combinations of predetermined values of parameters $V$, $R$ and $D$ that were unacceptable for predetermined limits $\tau_{\text{lim}}$ and $\gamma_{\text{lim}}$ are shown in Fig. 5 and Fig. 6 with chain-dotted lines with one dot (for limits on $\tau_{\text{lim}}$) and chain-dotted lines with crosses (for limits on $\gamma_{\text{lim}}$). In such cases, the specified limits $\tau_{\text{lim}}$ and $\gamma_{\text{lim}}$ will be maintained at the expense of excess TS length $L > L_G$ with unimodal shapes of functions $\psi(l)$ at the level $H_{\text{VS}}$, which are conditioned by the harmonization of the RT+V system at $H_{LG} >> H_{\text{VS}}$.

5. Conclusions

The results of calculation modelling of RT+V systems performance substantiate the expediency and high efficiency by using harmonized TS shapes in curves design of ordinary, high-speed, and super high-speed railway tracks. High-level safety and movement convenience properties are achieved by substantiated and reasonable correspondence of their main design parameter values of the curves $V$, $R$ and $D$ with predetermined limits $\tau_{\text{lim}}$ and $\gamma_{\text{lim}}$. Therefore, property interactions of the RT+V system at the level $H_{\text{VS}}$ could be harmonized at the appropriate design level $H_{LG} = H_{\text{VS}}$ with the minimum TS length $L_G$, that is optimal for its exploitation purposes.

Considering other risk factors, for example the so-called yawing of vehicles on curvilinear track sections [5], could be justified by accumulated results obtained from exploited curves with harmonized TS shapes. But there are no theoretical prerequisites at this moment. This opinion is based on the fact of a significant increase in the smoothness of conjugation of tracks with such TS shapes with adjacent sections of the track. So, for example, in comparison with the traditional clothoid TS forms, the orders of smoothness of these conjugations are increased from $G^0$ to $G^3$ in the vertical projection plane, and from $G^2$ to $G^6$ in the horizontal plane.

References


Impact of Station Modernisation Projects on Railway System Resilience

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Abstract

Throughout almost two hundred years of history of railway transport, its role has undergone considerable changes. After many years of intensive development, a period of line closedowns ensued, and only recently have some of these lines been rebuilt or modernised. Simplifications of track layouts made at railway stations should be considered not only in the financial context, but also taking into account the role of the station as an element of critical infrastructure in the process of building railway system resilience. The article describes an index developed by the authors, enabling an estimation of changes in the track layout, which accounts for the number of routes served, possible route courses, and the number of available platforms. Next, the manner of calculating the index is presented, based on an example of two track layout versions at the Sława Wielkopolska station.

KEY WORDS: resilience; railway infrastructure; railway station

1. Introduction

Throughout almost two hundred years of history of railway transport, its role has undergone considerable changes. Initially, trains caused fear and resistance, however, after just several decades, they virtually dominated passenger and freight transport in Europe. It was not until the second half of the 20th century that the situation started to change, as railway transport began losing the contest with road and air transport. Many railway lines were put out of use, some of them completely dismantled. However, the recent years have seen a new interest in railways and the once-abandoned infrastructure is being rebuilt (e.g. Riisipere-Haapsalu in Estonia) or thoroughly modernised (e.g. Szklarska Poręba Górna-Harrahov on the Polish and Czech border). During projects of this type, the historic route is frequently retained with simplified station systems or even all turnouts disassembled – with stations changed into railway stops.

Financial reasons certainly motivate the modification of station systems, as there is no point in maintaining a freight infrastructure at stations from which no cargo has been shipped for many years. On the other hand, railway networks are considered to be an example of critical infrastructure, crucial to maintaining the essential social functions, as well as people’s health, safety, security, and material or social well-being [7]. The decommissioning of critical infrastructure elements can therefore lead to issues with the performance of the above-mentioned functions in emergency situations, such as derailments or overhead line damage. Ways of determining the most important elements of a railway network are the subject of numerous scientific research projects in China [3, 6] and Central Europe [2], among others.

This article was prepared based on the graduate thesis of the first co-author. Its purpose is to present an index for estimating the effect of changes to the layout of the station on its potential in the process of building railway system resilience – which is understood here as extending performance when surprise events challenge system boundaries [5]. Chapter 2 includes a description of an example railway station and defines the manner of determining the resilience index. Chapter 3 presents the procedure of determining the index for different station track layouts. Chapter 4 contains the final remarks and conclusions.

2. Materials and Methods

2.1. Sława Wielkopolska Station

From the beginning of the 19th century until World War I, the western regions of Poland belonged to the Kingdom of Prussia, where railway transport played an important role. The first train connection to Poznań was established in 1848 and within the next 30 years, the city became an important railway junction enabling travel in six directions. The following years brought about an expansion of the main network with local lines added. One of them is the current line 356, which comprises sections of the old lines built between 1895 and 1908. Many stations along this line originally functioned as junctions (Fig. 1), but at present, a considerable number of lines have been put out of service or even physically dismantled.
In the years 2011-2013, a thorough modernisation of line 356 between Poznań and Wągrowiec was carried out. Its scope included railroad surface and subgrade replacement, as well as the adaptation of passenger infrastructure to the current requirements [4]. The modernisation made it possible to increase train speed from 60 to 120 km/h and brought about a threefold increase in passenger traffic [1]. Another significant aspect of the project consisted in the redevelopment of the stations located along the line. Some of them were dismantled, others had the track layout remodelled, including permanent cutting-off of unused railway lines running towards Janowiec Wielkopolski and Damasławek.

The only station where trains still travel in more than two directions from time to time is Sława Wielkopolska. It is located about 30 kilometres away from Poznań and apart from line 356, it also serves line 377 departing from Gniezno. Opened in 1914, the line was closed down in 2000 and reactivated after seven years on account of the fuel depot in Rejowiec near Stawiany. Trains carrying fuel run from Gniezno, but the Stawiany-Sława section is also passable and occasionally used when rolling stock travels to the service depot in Wągrowiec. The diagrams of the Sława station before and after the modernisation are provided in Figs. 2 and 3.

2.2. Station Resilience Index

The article assumes that the effect of a station on railway system resilience can be compared using the $R$ station resilience index developed by the authors. It is defined as the arithmetic mean of the $R_i$ coefficients for the routes served by the given station:

$$ R = \frac{1}{n} \sum_{i=1}^{n} R_i, \quad (1) $$

Therefore, the first stage in determining the $R$ station resilience index consists in identifying all the possible routes, understood as an ordered pair, where:

- the first element indicates the direction of entering the station,
- the second element indicates the direction of departing from the station,

whereas in both cases, the names of the terminal railway line points are provided. It should be noted that an origin-destination route is also identified when the journey would require manoeuvring due to the track layout. Subsequently, the index is determined for each route using the following formula:

$$ R_i = d_i \cdot p_i, \quad (2) $$

where $d_i$ – the number of possible route courses for trains of the given origin-destination route; $p_i$ – the number of platform edges along these route courses.

3. Results

The revitalisation of the Sława Wielkopolska station has not deprived it of the junction station status and it is still possible to travel from there towards Bydgoszcz Główna, Poznań Wschód, and Gniezno Winiary – which gives a total of 6 possible origin-destination routes. As the information contained in the database maintained by railway enthusiasts indicates [8], the modernisation work has considerably changed the track layout at the station. Originally (Fig. 2), it had
5 tracks – three main tracks and two sidings. By the main tracks, designated with numbers 1, 3, and 5, three single-edge platforms were located. Railway signals, warning shields, and turnouts were operated from the command and dependent signal box. Railway signal designations make it possible to recreate the possible train route courses.

Fig. 2. Simplified diagram of the Sława Wielkopolska station before the modernisation

Trains passing through the station when travelling from Poznań to Bydgoszcz have three possible route courses through tracks number 1, 3, and 5, whereas those travelling to Gniezno – only two route courses: through tracks 3 and 5. Trains running from the Bydgoszcz Główna station towards Poznań can enter tracks 1 and 5; the railway signal at track 3 cannot display a signal that allows running in a reverse direction. For the same reason, the trains from Gniezno to Poznań can only use track number 5. Trains from Gniezno to Bydgoszcz and back can enter tracks 3 or 5. In all these cases, the number of available platforms is equal to the number of possible route courses. Track number 2 is not taken into account because it is not intended for train traffic – together with track number 4 leading towards the bay platform, it constitutes the freight section of the station. The information provided here, including the indices calculated using formulas (1) and (2), is listed in Table 1.

During the modernisation carried out in the years 2011-2013, track 2 was put into operation in regular train traffic, but at the same time, track 5 was removed together with the key turnout between tracks 1 and 3 from the Poznań/Gniezno side (Fig. 3). This decision has considerably limited the possibilities for the use of track 3, especially as it does not have any platform edge. In the course of the modernisation, the station was covered by the ETCS L1 LS system supervision and old signal boxes were dismantled.

Fig. 3 Simplified current diagram of the Sława Wielkopolska station

After the modernisation, only two possible route courses are provided at the station for trains from Poznań to Bydgoszcz and back, which run on tracks number 1 and 2, which were equipped with platform edges. In the case of the route from Bydgoszcz to Gniezno and back, only one route course is possible (on track number 3), but it does not have access to a platform edge. Trains from Poznań to Gniezno and from Gniezno to Poznań cannot be operated – it would require running from/to track number 3 using manoeuvring. The information on the characteristics of the Sława Wielkopolska station after the modernisation is compiled in Table.

<table>
<thead>
<tr>
<th>Route</th>
<th>Before modernisation</th>
<th>After modernisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of route courses $d_i$</td>
<td>Number of platform edges $p_i$</td>
</tr>
<tr>
<td>Poznań Wschód – Bydgoszcz Główna</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bydgoszcz Główna – Poznań Wschód</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Poznań Wschód – Gniezno Winiary</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Gniezno Winiary – Poznań Wschód</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Gniezno Winiary – Bydgoszcz Główna</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Bydgoszcz Główna – Gniezno Winiary</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Index by formula (1)</strong></td>
<td><strong>4.33</strong></td>
<td></td>
</tr>
</tbody>
</table>
The calculations performed (Table 1) indicate that after the modernisation, the station is characterised by a lower resilience index, and so its effect on railway system resilience has decreased. This result is consistent with intuition and takes into account the fact that passenger service at the Sława Wielkopolska station would need to be suspended should a detour to Poznań on line 377 via Gniezno be introduced.

4. Conclusions

Chapter 2 and 3 present a proposed method of calculating the index illustrating the potential of typical stations in the process of building railway system resilience. In its proposed version, the index makes it possible to compare several variants of station track layouts from the point of view of the ability to manage passenger traffic in case of railway system service disruptions. Despite the fact that the index is calculated on the basis of just two station features – the number of possible route courses and the number of platforms – the results obtained for small and medium junction stations are consistent with intuition.

In the case of larger junction stations, where several track groups can be distinguished, the algorithm described here can yield results which are too optimistic. The issue is the presence of bottlenecks, which are small infrastructure fragments (single turnouts, short track sections) connecting individual track groups. Their failure may effectively prevent railway traffic from running on a considerable part of a station or even result in the need to cancel trains on certain routes. One of the methods of taking this phenomenon into consideration is to specify the definition of the number of route courses $d_i$ in formula (2) more precisely, so that all the route courses running through a bottleneck would only be included once in the resilience index calculation.

During work on the definition of the resilience index, many other aspects of station operation were taken into account, such as the number of trains served, platform access way layout or track lengths. The latter suggestion would be vital in the case of station resilience estimation for freight transport.

Acknowledgement

The research work was financed with the budget subsidy for the support and development of research potential for the Faculty of Civil and Transport Engineering at the Poznan University of Technology.

References

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Safety of Pneumatic Brake Systems of Rolling Stock

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Abstract

Traffic safety is one of the priorities of the railways. Automatic braking systems must ensure the timely stop of a train in the event of a threat to traffic safety. In turn, devices for monitoring the operation of automatic brakes must ensure that the possibility of the influence of the human factor is prevented and that means for stopping the train are automatically used in the event of the driver's inaction.

The paper discusses devices that ensure safety when using pneumatic brakes on the railway rolling stock, as well as aspects of their application. Some possible risks of emergencies when driving a train are considered. Description of single-pipe and twin-pipe air braking systems is given. The importance of Safety Management System (SMS) as a preventive tool in the event of the possible impact of the human factor on traffic safety is noted.

KEY WORDS: air brake systems, railway rolling stock, safe management system.

1. Introduction

The braking system must ensure that the speed of the train is reduced, it is maintained on the descent and the train stops without exceeding the permissible braking distance, as well as the immobility of a stationary train [1]. The main known devices providing control over the operation of the automatic braking system are the brake pipe break alarm (BPBA) - a system that monitors the spontaneous decrease in pressure in the brake pipe (BP) and an electro-pneumatic valve (EPV) - which provides automatic application of the brakes if the driver does not confirm vigilance [2]. The BPBA is triggered by a short-term decrease in pressure in the BP, including in case drop of the pressure, which is not actuating the brakes, which is signaled by a signal lamp on the driver's control panel.

Thus, widely used on rolling stock, brake system safety devices that control the presence of compressed air in it provide a train stop or a warning to the driver about an unacceptable pressure drop in the BP [3], which occurs in the event of equipment malfunction or improper actions of the driver, which in turn leads to a decrease in pressure in the BP, as well as cases of depletion of BP when using a single-pipe brake system of the train and improper brake control.

2. More Information

On most 1520 mm track gauge locomotives the pressure in the feed pipe (FP) is controlled only according to the readings of the FP manometer, which should be in the range of 7.5-9 bar, depending on the series of locomotives and equipment settings [4]. In the event of a compressor shutdown, the pressure drop in the FP to the level of the charging pressure in the BP (5.0 bar) occurs on average in 2-3 minutes, this time depends on the length of the composition and the density of the BP, the leaks from which are replenished from the FP [5].

By monitoring the identified violations for 5 years, the authors of the study found that at the freight railway undertakings with 25 to 30 locomotives, on average, during the year, there are 2-3 cases of pressure decrease in the PM, which entailed a decrease pressure in TM. These, in turn, are due to a malfunction of the pneumatic pressure regulator when using a mechanically driven compressor, or a pressures witch in case of an electrically driven compressor. Cases of violation of the rules for operating the brakes are also detected, leading to depletion of the brake line - for example, repeated braking without provising the necessary time between braking applications, 1-2 cases per year.

3. Result and Discussion

3.1. Pressure Control Methods in FP

Next, we will consider measures to prevent the above violations. Monitoring the pressure drop in the FP on most types of traction rolling stock of 1520 mm track gauge carried out only by the driver's observation of the FP manometer, with light or sound alarm indication not being provided by the design [5]. To solve this problem, it is technically possible to connect a pressure switch sensor that monitors the pressure drop in the FP Fig. 1.
Additionally, a signal lamp is installed on the driver's console, which can be supplemented with a buzzer. Connection pneumatic part of the sensor is carried out by connecting to the FP fittings on the approach to the locking device, and the electrical part for powering the signal lamp to the on-board network of the locomotive. When the pressure in the FP falls below 7 +/- 0.1 bar, the pressure switch of the sensor is triggered, closing the contacts in the signal lamp circuit, the lamp turns off when the pressure reaches more than 8 +/- 0.1 bar (this range can be adjusted individually, in accordance with compressor on and off setting).

The principle of operation of the sensor is based on comparing the forces created by the pressure or the pressure difference of the controlled medium on the sensitive system and the forces of elastic deformation of the setpoint spring and the return zone.

Device actuation - contact closure occurs when the controlled pressure reaches the value set on the adjustment scale. The return of the contacts of the switching device to its original position occurs when the pressure of the medium changes by an amount equal to the value of the return zone.

For use on tractive rolling stock, the sensor-relay (pressure switch) must be resistant to ambient temperatures from minus 50 to plus 70°C at relative humidity up to 80% and IP64 Class degree of protection against dust and water ingress.

### 3.2. Depletion of BP

Depletion of BP is a serious threat to traffic safety, this problem is especially relevant in the case of using a single-pipe train braking system. The operation of such systems is described in [6, 7]. A diagram of a single-pipe brake system is shown in Fig. 2. and is the most common one.
The brakes are controlled by the DBV driver's valve by reducing the pressure in the brake pipe of the train. The distributor valve, responding to a decrease in pressure in the brake pipe, passes air from the auxiliary reservoir (AR) to the brake cylinder. The release of the brakes, as well as the replenishment of the AR, is carried out by increasing the pressure in the brake line using the DBV, thus, this scheme provides for the need of the time delay between repeated braking in order to recharge the auxiliary reservoirs of the wagons in the train.

As already mentioned, violation of the rules for the operation of brakes, namely, frequent braking without exposure the time required to replenish the air reserves in the auxiliary reservoirs of the wagons, can lead to depletion of brakes with a subsequent decrease in the braking effect, since the full pressure in the brake cylinders, required to stop a train at the calculated stopping distance or to hold a stopped train in place, will not be provided.

In the design of a twin-pipe circuit Fig.3 provides for independent power supply of the auxiliary reservoirs of the rolling stock, this scheme eliminates the possibility of depletion of BP during frequent braking without time exposure.

The operation of the brakes is preserved, compressed air is pumped in by compressor C and accumulates in the main reservoirs (MR) of the locomotive, then from the FP through the DBV driver's valve, air enters the brake pipe, from which the air distributor is powered. Additional supply to the reserve tank is carried out through the feeding line through the OV check valve, preventing the escape of air from the reserve tank when the cars are disconnected.

The advantage of the twin-pipe brake system is the constant supply of the auxiliary reservoirs of the wagons directly from the feeding line, which ensures the replenishment of the auxiliary reservoir at the beginning of braking, as well as more accelerated release of the brakes, since all the air directed through the DBV into the BP is directed to charge the working chambers of the air distributor.

However the necessity for two pipelines is a disadvantage for locomotive hauled trains due to lack of interoperable rolling stock with such equipment and bit more decomplicated operational procedures. However, it is a case for the multiple unit trains, where the FP is already provided along the train.

4. Conclusions

Together with technical solutions to improve traffic safety in railway transport, preventive measures aimed at the timely detection of certain incident precursors and, in particular, with the operation of brakes are important - this is enhanced control in relation to drivers with the less than one year experience, using movement registration systems and braking systems, and the corresponding checks and revisions regulated in the Safety Management System (SMS), established by railway undertakings.

Key aspects of SMS are shown in paper [8, 9]. Fulfillment of SMS requirements for supervision and risk assessment allows timely detection of possible precursors to incidents.

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Road Safety at Intersections and Roundabouts: A Case Study

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Abstract

The aim of this paper is to familiarize the reader with a case study of road safety assessment at two basic types of intersections: crossroads and roundabouts. The paper first describes the individual shapes of intersections and then introduces two sites where in the past crossroads were rebuilt into roundabouts because of road safety and traffic flow fluency. From the statistics of traffic accidents registered since 2007, data on the number and severity of all traffic accidents registered in the given locations since that year were obtained. By means of a mutual comparison of these data, it was possible to find out whether or not the measures based on the changes in the shape of the intersections were really effective in terms of road safety. With reference to the above, the final part of the paper outlines other ways of achieving higher road safety at such important road constructions.

KEY WORDS: crossroads; roundabout; accident rate; road safety; vector traffic map

1. Introduction

The safety of all road users today is one of the main pillars of modern society. In addition to safe vehicles (active and passive safety elements) and safe behaviour of road users, the fact that the construction and traffic structure of a road can itself reduce or eliminate a wide range of security risks is very often neglected. Examples include an oversized road layout (the speed of vehicles increases with lane widths), insufficient visibility due to improper routing and irregular road maintenance (vegetation), inappropriate road surroundings (solid obstacles, perpendicular culverts), and the absence of self-explanatory principle of the road (a psychological right of way at intersections over the one given by traffic signs, a sudden change of direction beyond the horizon without proper warning, inappropriate lateral inclination of the road in directional curves, etc.). This article deals with the issue of traffic safety at intersections. First, the individual patterns of intersections are presented and then, on the basis of two concrete examples from practice, the impact of their construction adjustment on the road safety in the given locations is assessed according to data from police statistics.

2. Intersections

According to [1], an intersection can be defined as a place where roads intersect or meet in the ground plan view and at least two of them are interconnected. Connections of house entrances, non-public parking areas, entrances to reserved land, connection of field and forest roads are not considered as intersections. In comparison to interchanges, the intersection of roads takes place only at one height level. For this reason, there is also a higher accident rate and less traffic flow [2].

2.1. A Classification of Intersections

As already mentioned in the introduction of this article, intersections are divided according to their ground plan. The total of six basic patterns includes crossroads, T-junction, Y-junction, staggered junction, multi-leg junction and roundabout. (see Fig. 1).

![Fig. 1 Patterns of intersections [3-5]](image-url)
Level intersections are further divided according to type into intersections without a determination of the right of way (right-hand rule applies here), with a determination of the right of way (priority determined by vertical and horizontal traffic signs), and those controlled by traffic lights. Depending on the degree of traffic regulation, the intersections can be simple (not regulated by building adjustments or traffic signs), partially regulated (some traffic directions are partially regulated by building adjustments or traffic signs), and regulated, where the possible traffic movement of all traffic flows is determined by building adjustments and traffic signs [3-5].

2.2. Roundabouts

As shown in Fig. 1, roundabouts are level intersections and are based on the fact that vehicles entering the intersection first turn right and then move along the roundabout towards the desired exit to which they turn right. A characteristic feature of traffic at these intersections is that they are organized in such a way that the vehicle at the entrance has to give way to vehicles on the roundabout. If roundabouts were organized in the opposite way, the capacity of the roundabout would inevitably decrease rapidly and the accident rate could be expected to increase [6-8].

Roundabouts can have several categories (design characteristics), as shown in Table 1 below.

<table>
<thead>
<tr>
<th>Basic categories (design characteristics) of roundabouts [6]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mini</strong></td>
</tr>
<tr>
<td><strong>Built-up area</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Non-urban area</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

3. A Case Study – Sites under Assessment

The main reason for converting crossroads, T-junctions and multi-leg junctions in some problematic locations to roundabouts today is the fact that the number of traffic accidents is decreasing as a result of the movement of vehicles at a lower speed on a roundabout with a small radius. The absolute number of traffic accidents is lower and they are also less serious [9-11]. In order to prove this claim on a concrete practical example, two locations were identified (site I located in a non-urban area, site II in a built-up area), where in the past the pattern of the crossroads/T-junction was changed to the roundabout and at the same time, all traffic accidents that occurred before and after this change (rebuilding) were assessed.

3.1. Site I (Non-Urban Area)

It is the intersection of road II/141 with road II/145 in the South Bohemian Region in the Czech Republic. In the past, there was only a T-junction which was in June 2010 replaced by crossroads because of the relocation of road II/145 between villages Běleč and Husinec. After its opening, however, there were often traffic accidents including one frontal collision after which one of the drivers died, and other six accidents with physical injuries to road users. For this reason, the entire intersection was rebuilt into a roundabout in spring 2016. Fig. 2 shows all traffic accidents registered in police statistics since 2007 in this location and Table 2 lists these accidents in terms of date, type and their consequences.
### Table 2

**List of all traffic accidents in Site I**

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Date</th>
<th>Type</th>
<th>Dead</th>
<th>Seriously injured</th>
<th>Slightly injured</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T-junction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19. 4. 2007</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>19. 7. 2007</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1. 10. 2008</td>
<td>frontal</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>14. 9. 2010</td>
<td>side</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>27. 1. 2011</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20. 6. 2011</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>24. 9. 2011</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>17. 10. 2011</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>14. 8. 2012</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>12. 9. 2012</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2. 11. 2012</td>
<td>from behind</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td><strong>22. 7. 2013</strong></td>
<td>frontal</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>20. 10. 2013</td>
<td>other</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>26. 7. 2014</td>
<td>side</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>31. 10. 2014</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>16. 12. 2014</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>20. 12. 2014</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1. 11. 2015</td>
<td>side</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td><strong>Cross Roads (since VI/2010)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28. 6. 2017</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>18. 11. 2017</td>
<td>frontal</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### 3.2. Site II (Built-Up Area)

It is a junction of road I/29 with local roads (Obchodní and Průběžná streets) including the connection of the exit from road I/20 in Písek in the South Bohemian Region in the Czech Republic. In the past, there was originally only a T-junction without the connecting lane of the exit, but was replaced in January 2008 by the crossroads due to the connection of the fourth branch of the crossroads leading to the shopping zone (Průběžná street). After its opening, however, there were often traffic accidents and congestion, and therefore in June 2016 the entire intersection was rebuilt into a roundabout, which also included the implementation of the connecting lane transferring the transit traffic from road I/20 to road I/29. Fig. 3 shows on the map all traffic accidents recorded in police statistics since 2007 at this location, and Table 3 shows the date, type and consequences of these accidents.
Fig. 3 Statistical evaluation of accident rate for Site II: a – the intersection; b – connecting lane [12]

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Date</th>
<th>Type</th>
<th>Dead</th>
<th>Seriously injured</th>
<th>Slightly injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-junction</td>
<td>8. 6. 2007</td>
<td>side</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1. 6. 2007</td>
<td>from behind</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>21. 6. 2007</td>
<td>from behind</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
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4. Discussion

As can be seen from Tables 2 and 3, the number and severity of traffic accidents in Site I and Site II was indeed reduced due to the rebuilding of the intersections in both assessed locations. To date, only two traffic accidents with only material damage to vehicles without consequences on life or health of their participants have been recorded in Site I after rebuilding of the crossroads to the roundabout. In total, the accident rate of the given place was reduced by approximately 87%. Similarly, only two traffic accidents with material damage to vehicles without consequences on life or health of their participants have been recorded in Site II after rebuilding of the crossroads to the roundabout. In total, the accident rate in this area was reduced by about 82%. On the basis of this evaluation, it can be concluded that the implementation of roundabouts where the accident rate is increased is desirable and beneficial in terms of road safety.

On the other hand, of course, it is necessary to mention the fact according to [13-15] that any such conversion of one intersection pattern to another carries a number of previous expert opinions and traffic-engineering analyses (models and assessments). An incorrectly designed intersection pattern without the knowledge of traffic-engineering characteristics (density, traffic volumes, vehicle speed, traffic flow pattern, etc.) may result in a situation where a
relatively safe location becomes a dangerous place with a negative impact on accident rate, capacity, traffic flow, and the safety of all its participants; therefore, each such proposal must be considered individually.

5. Conclusion

As mentioned in the previous chapter, it is not possible to generalize the benefits of converting all crossroads into roundabouts; however, there are a number of other factors affecting our decision-making process that must be taken into account and that we must bear in mind. There are, of course, other ways to improve the traffic safety situation at intersections, such as supplementing vertical traffic signs with a reflective base or fitting light signalling devices; the question is only the financial demands of the implementation of a design measure and especially its effect on traffic safety, which is, unfortunately, verified only after some time since the change in the construction and traffic layout of the intersection was realized and since the new layout was exposed to the actual traffic load in normal traffic.

Acknowledgement

This manuscript was supported within solving the research project entitled “Autonomous mobility in the context of regional development LTC19009” of the INTER-EXCELLENCE programme, the VES 19 INTER-COST subprogramme.

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Validation of a Multi-Body Human Model for Efficient Rear Impact Simulations

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Abstract

In this study, a 50th percentile male human model which was developed using multi-body dynamics approach, is validated by using data from JARI (Japanese Automobile Research Institute) rear impact sled tests conducted with 12 male volunteers in normal driving posture on a rigid seat without head restraint and seatbelt. This human model was previously validated at a sled impact speed of 8 km/h. In this paper, the human model is further validated at a sled impact speed of 6.2 km/h using newer experimental data. This human model can be used to investigate whiplash associated disorders in road traffic accidents. The results indicate that the presented biofidelic human model can be successfully and efficiently used in rear impact simulations so as to develop safety systems.

KEYWORDS: human model, whiplash, rear impact, validation

1. Introduction

In road traffic accidents involving rear impacts, whiplash is a common disorder resulting in pain and discomfort in the head-neck system of an occupant. Whiplash occurs as a consequence of the relative motion of the head with respect to the upper torso. In order to simulate rear impacts, it is required to have biofidelic human models. Efficient simulations can be obtained by using multi-body modelling approach.

The human models in the literature for crash safety are either multi-body (MB) or finite-element (FE) models. A hybrid modelling technique is also applied which involves different human-body parts modelled by using either MB or FE approach [1]. FE models are more detailed than MB models since they provide stress and strain information on human body parts. Therefore, FE models are more suitable for studying injury mechanisms at the tissue level. MB models are simpler in architecture but they are computationally much more efficient. MB models can simulate cheaply the global responses i.e. the kinematics of human body parts and the resultant forces and moments acting at the joints in a crash scenario. Hence, MB models can still predict the level of injury risk and be used in parameter variation analyses including control system design during the development stages of safety systems.

In the crash safety community, the Total Human Model for Safety (THUMS) and the Global Human Body Model Consortium (GHBMC) are the two state-of-the-art FE human body models [2]. These two models require some complicated transformation procedures to represent different sizes, ages and postures. There are also human models for specific types of impact such as the BioRID II dummy (Biofidelic Rear Impact Dummy) [3-6]. One such model was presented by Himmetoglu et al. [3, 4] which was shown to simulate successfully the rear impact response of a 50th percentile male in a standard automotive posture with a seatback angle of 20 deg from the vertical. This paper presents an extended validation of the human model by Himmetoglu et al. [4] using newer volunteer test data [7] including improved geometry for the human body parts.

2. Rear Impact Volunteer Test Procedure

The experimental data to validate the 50th percentile male human body by Himmetoglu et al. [4] is obtained from Sato et al. [7]. The obtained data corresponds to Test Series 1 (with sled pulse 1). The details of this experimental test procedure is given in a recent study by Himmetoglu et al. [8] and repeated here for completeness. In these tests, a rigid seat with no head restraint and seatbelt, was fixed to a sled which was let to slide downward on inclined rails with an angle of 10 deg from the horizontal, as depicted in Fig. 1. The seatback angle was 20 deg from the vertical. The hydraulic damper at the bottom end of the rails decelerated the sled and produced a crash pulse which is typical of low severity rear impacts. The impact velocity of the sled just before it contacted the damper, was 6.2 km/h which led to a delta-V (change of velocity) of 8.1 km/h and a peak acceleration of 27 m/s² for the sled. The volunteers were told to relax prior to the impact. In this Test Series 1 (with sled pulse 1), there were 12 male volunteers having a mean age of 24.8 with a standard deviation of 4.2, a mean height of 175 cm with a standard deviation of 2.7 cm, and a mean weight of 70.8 kg with a standard deviation of 5.24 kg.

Video target markers and accelerometers were secured to the head and T1 (the first thoracic vertebra) to record the displacements and accelerations. Four coordinate systems (i.e. frames) are utilised in the tests as indicated in Fig.1 and Fig. 2. The sled coordinate system (frame) which is fixed to the sled, is denoted by $F_0$ and its $x_0$ axis is horizontal (i.e. parallel to the ground). The head anatomical frame which is attached to the head at the head centre of gravity (C.G.), is denoted by $F_1$ and its $x_1$ axis is parallel to the Frankfort line [3,7]. The T1 accelerometer frame is denoted by $F_2$ whose $z_2$ axis is on the skin lying on the T1 spinous process. A biaxial accelerometer is attached to the T1 accelerometer frame.
The T1 anatomical frame is denoted by $F_3$ and its origin is defined as the centre of T1 which is estimated as the midpoint of the T1 and sternum skin target-markers. The $z_3$ axis of frame $F_3$ passes through the occipital condyles (O.C.) at the initial posture of the head-and-neck.

3. The Properties of the Human Model

Since whiplash is associated largely with the neck, a biofidelic head-and-neck model is indispensable. In the development of the human model, the head-and-neck section was first modelled and validated at two different sled impact speeds [3, 4, 8] using the multi-body dynamics software MSC VisualNastran 4D. The head-and-neck section was then integrated into the rest of the body as shown in Fig. 3. Details about the human model and the contact model were documented by Himmetoglu et al. [4]. The geometry of the human model [4] is improved here in this paper based on the results of a project done in the Mechanical Engineering Department of Hacettepe University [9] which also benefited from the research of UMTRI (University of Michigan Transportation Research Institute) throughout the years. The human model is derived from a male aged 30 with a stature of 175 cm and a BMI (Body Mass Index) of 24 kg/m².

The human model is basically composed of rigid bodies connected by rotational springs and dampers which are nonlinear in nature, as shown in Fig. 4 and Fig. 5. The rotational springs and dampers in the torso are located at the anatomical locations of T3 (third thoracic vertebra), T5 (fifth thoracic vertebra), T11/T12 (between eleventh and twelfth thoracic vertebrae) and L3/L4 (between third and fourth lumbar vertebrae). The stiffness and damping properties of the intervertebral joints (i.e. the joints between each pair of vertebrae) in the cervical spine are denoted by "Neck" in Fig. 4 and Fig. 5. The stiffness variations given in Fig. 4 show the resistive torque for a given amount of intervertebral angular displacement. The stiffnesses in Fig. 4 are in agreement with those of the BioRID II dummy [6]. The dampers are modelled using viscous damping coefficients which vary with time. These time varying damping coefficients produce approximately the effects of dynamic stiffening behaviour in the soft tissues and active muscle contraction. The variation of the damping coefficients with respect to time are in accordance with the variation of the muscle electromyography (EMG) signals observed in volunteer tests [10-13] thus these time varying damping coefficients simulate active muscle response. Passive spring and damper elements are used at the joints associated with the limbs. Passive spring and damper elements simulate passive resistance at the joints which corresponds to the resistance of the soft tissues around the joints without any voluntary or reflex muscle contraction.
4. Validation of the Model

In order to validate the human model against the experimental data [7], the crash pulse measured in the volunteer tests is applied to the sled at time zero when the sled contacts the damper. At time zero, the sled and all bodies in the human model are given the same initial velocity which corresponds to a downward velocity of 6.2 km/h along the rails.

The responses of the human model are compared with those of the volunteers in the figures given below. In these tests, there were also female volunteers. In these figures, male and female volunteers’ response corridors (mean ± one standard deviation (SD)) are shown in blue and red colours, respectively. The response of the human model is shown by the dashed lines. The reported volunteer responses pertained only to the head-and-neck of the volunteers [7]. Fig. 6 and Fig. 7 show the T1 accelerations recorded by the accelerometers in frame $F_2$. Fig. 8 and Fig. 9 present the head C.G. displacements with respect to the sled expressed in the sled frame $F_0$. Fig. 10 and Fig. 11 show the head C.G. accelerations (with respect to the ground) expressed in the head anatomical frame $F_1$. 

Fig. 4 Rotational stiffness [4]

Fig. 5 Rotational viscous-damping coefficients [4]

Fig. 6 T1 $x$-acceleration

Fig. 7 T1 $z$-acceleration

Fig. 8 Head C.G. $x$-displacement wrt sled

Fig. 9 Head C.G. $z$-displacement wrt sled

Fig. 10 Head C.G. $x$-acceleration

Fig. 11 Head C.G. $z$-acceleration
Fig. 12 T1 x-displacement wrt sled

Fig. 13 T1 z-displacement wrt sled

Fig. 14 Head rotation wrt sled

Fig. 15 T1 rotation wrt sled

Fig. 16 Head wrt T1 rotation

Fig. 17 The motion of the human model during impact
Fig. 12 and Fig. 13 present the displacements of the centre of T1 with respect to the sled expressed in the sled frame $F_s$. Fig. 14 and Fig. 15 show the angular displacements of the head and T1 with respect to the sled around the $y_0$-axis of the sled frame. Fig. 16 presents the head angular displacement with respect to T1 around the $y_0$-axis of the sled frame. The motion of the human model at 50 ms intervals is given in Fig. 17.

5. Discussion and Conclusions

This paper presents a 50th percentile male multi-body human model which was validated previously by using volunteer data from JARI (Japanese Automobile Research Institute) rear impact sled tests performed at an impact speed of 8 km/h. In this study, the presented human model is validated again using the same experimental setup in which 12 male volunteers were exposed to sled tests at an impact speed of 6.2 km/h. In these tests, the volunteers assumed a normal automotive driving posture and placed on rigid seats without any seatbelt and head restraint.

The results indicate that there is a good agreement between the human model and volunteer kinematic responses since the model responses are within the response corridors (mean ± one standard deviation (SD)) of male volunteers shown in blue colour. However, there are some differences between the model and volunteer responses regarding head C.G. accelerations. The head C.G. accelerations in the model do not exactly follow the pattern seen in volunteer responses especially for head C.G. accelerations but the order of magnitudes of these responses are similar. It should be noted that in comparison to displacements, it is difficult to estimate accelerations using such human models since the human body is a complex system. Although the approximations involved in modelling lead to small differences between the model and real human displacements, these discrepancies are amplified in the calculation of accelerations as accelerations are the derivatives of displacements. The differences observed in the head accelerations also affect the upper neck forces and moments at the occipital condyles (O.C.) hence they are not included in this paper. Besides, the presented figures involve volunteer response corridors corresponding only to mean ± one standard deviation, thus there are certainly other volunteer responses outside of these corridors.

The presented bioidetic model provides fast computation of human response in rear impacts. Some of the mechanical properties of the model are based on the well-known BioRID II dummy but the rotational springs and dampers in the model are tuned to provide more bioidetic response. The model has the capability of simulating active muscle response by using simple rotational dampers. These dampers can be easily tuned for varying degrees of active muscle response once relevant volunteer data is available. This multi-body human model is very efficient for long crash simulations which involve the pre-crash phase of the accident. Hence, the model is a valuable design tool for the optimisation of safety systems and associated control system design.

The presented model is a very useful tool to design seats and head restraints which are the main restraints that protect occupants in rear impacts. It can be argued that the human model is only validated for low speed impacts which do not cause any injury to the volunteers. First, it must be pointed out that it is not ethically possible to perform experiments on humans that would risk their health. What's more, the objective of building this human model is to design seats for occupant protection. At higher impact speeds than the ones in the volunteer tests, the developed seat will make the occupant face a lower severity impact with the aid of crash energy management techniques. In other words, with a well-designed seat system, occupants will not be exposed to higher loadings than those in the volunteer tests. Therefore, the presented human model is suited for seat design.

Acknowledgement

The author thanks Mr. Oğul Can Üçbaş for his efforts in processing the 3D geometry of the human model presented in this study.

References


Computational Evaluation of the Compression Ratio Impact on External and Economic Indicators of a Piston Pneumatic Engine

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Abstract

The article presents an evaluation of the compression ratio impact on external and economic parameters of a pneumatic engine. The analysis was computational, basing on a mathematical model created from mechanical and pneumatic parts. The object of analysis was a two-stroke engine based on an internal combustion engine. In the engine intake system, a solenoid valve was mounted enabling to regulate the dose of air supplied to the cylinder. The exhaust system remained unchanged from the combustion original. Calculations were conducted in two variants, with varying compression ratio, inlet valve opening and opening time of the inlet solenoid valve. As a result of the performed calculations, it was found that the compression ratio range (4...6):1 provided the best results, and the analysed engine is able to generate 3.74 N·m at 500 r./min. Appropriate control of the time and timing of solenoid valve opening allows to reduce air consumption even by a half.

KEY WORDS: mechanical engineering; drive sources; pneumatic engine; modelling

1. Introduction

The work on the application of the pneumatic engine as a source of propulsion dates back to the 19th century [1]. Initially, attempts were made to use it for powering a car [2], then a tram [3] and a locomotive [4]. Having regard to the current [5] and future [6] restrictions on the emissivity of propulsion sources used in transport, further development of alternative power sources, also including pneumatic engines [7], should be predicted in the long term. The carbon footprint associated with the manufacture and use of the propulsion source [8] is also important. Pneumatic engines, due to the lack of combustion in the cylinder, allow for achieving longer oil change intervals, do not require cooling as well and can provide cool air for use in the air conditioning system [9]. Nevertheless, there remains a problem with the energy intensity of air compression and the method of vehicle refuelling [10], the usage of multi-stage compressors [11], or a way to inspect safety valves [12]. In order to ensure safety, a compressed air tank should comply with all approval requirements before introduction into service [3].

Pneumatic engines are built from scratch as new designs based on solutions used in reciprocating internal combustion engines, as for instance the MDI company's engine with a modified crank system [3]. Unconventional engines are also built, including the Di Pietro engine, which combines a vane engine with a Wankel engine [13], or the engine based on the solution of a scroll compressor [14, 15]. Pneumatic engines are also attempted to be used in hybrid drives [16], where energy is stored as a pressurized fluid.

Many research studies concentrate on pneumatic engines based directly on internal combustion engines. Through appropriate modifications of two-stroke [17-19] and four-stroke [20, 21] engines, it is possible to obtain a pneumatic engine in a simple manner. A number of theoretical [22, 23] and experimental [24] studies on the operation of a reciprocating pneumatic engine can be found in the literature. In the mechanical part, the mathematical models are based on the description of a piston machine using classical mechanics [25, 26]. In the flow (pneumatic) part, it describes the flow through the inlet and outlet valve and the compression and expansion process in a variable volume chamber (cylinder) based on fluid mechanics equations [27].

The purpose of the study was to determine the impact of compression ratio on the external and economic indicators of a pneumatic engine. The study was theoretical in nature, based on a simplified mathematical model consisting of mechanical and pneumatic parts. The object of analysis was a two-stroke pneumatic engine built through a conversion of an internal combustion engine.

2. Object of the Modelling

As a modelling object was chosen pneumatic engine which is a modification of two-stroke internal combustion engine JAWA 50 [18]. The basic technical data of the engine have been presented in Table 1.
Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>- engine type</td>
<td>1 cylinder, pneumatic, two-stroke</td>
</tr>
</tbody>
</table>
| - timing system (throughput): inlet (Fig. 1, a) / outlet (Fig. 1, b) | max($\mu A$)$_{in}$ = $12.7 \times 10^{-6}$ m$^2$  
max($\mu A$)$_{out}$ = $238.4 \times 10^{-6}$ m$^2$ |
| - displacement (volume)                        | $V_{max} = 5.479 \times 10^{-5}$ m$^3$     |
| - bore                                         | $D = 40 \times 10^{-3}$ m                  |
| - stroke                                       | $S = 43.6 \times 10^{-3}$ m                |
| - connecting rod length                        | $L = 100 \times 10^{-3}$ m                |
| - weight of the components involved in the reciprocal motion | $m_A = 0.142$ kg                           |
| - substitute mass of the part of the connecting rod rotating on radius of the $x$-th crank | $m_B = 0.140$ kg                           |
| - crankshaft mass moment of inertia            | $J_L = 0.140$ kg-m$^2$                    |

In the cylinder filling system (inlet timing) of the analysed engine, a solenoid valve was used for which the opening and closing times were assumed on the same level $3 \times 10^{-3}$ s (Fig. 1, a). In the cylinder emptying system (outlet timing) the original exhaust port was retained (Fig. 1, b).

3. Mathematical Modelling

In the course of creating a mathematical model describing the operation of a pneumatic engine, the following simplifying assumptions were made [17, 18]:

1. In the mechanical part: a perfectly stiff system without the influence of elastic vibrations and losses, in which the pressure course depends on timing as well as the input/output pressure difference and the position of the piston.
2. In the pneumatic part: the working medium (air) was treated as an thermodynamically ideal gas both locally and in the entire cross-section, flowing without internal friction and heat exchange with the surroundings at perfectly airtight connections, and its state in a given volume depends on time at a constant temperature value.

Based on that, a schematic diagram was created, as presented in Fig. 2.

![Fig. 1 Courses: a – inlet process as a time function; b – outlet process as a crankshaft angle degrees](image)

![Fig. 2 Scheme of the mechanical and pneumatic parts: $p$ – pressure; $T$ – temperature; ($\mu A$) – throughput; $V$ – volume; CA – crankshaft angle degrees; $R$ – crank radius; $L$ – length of the connecting rod; $\omega$ – angular crankshaft speed; indexes: $air$ – the air; $c$ – cylinder; $in$ – inlet; $out$ – outlet](image)
The dependence of engine torque ($T_r$) of a single-cylinder two-stroke engine (Fig. 2) with respect to the crankshaft rotation angle (CA) was described [17, 18]:

$$T_r = R A_p S p_c(CA) - R^2 m_A S (\cos(CA) + \lambda \cos(2 \text{CA})) \omega^2$$  \hspace{2cm} (1)

where

$$S = \frac{\lambda \sin(2 \text{CA})}{2 - \lambda^2 \sin^2(CA)} + \sin(CA); \quad \omega_0 = \sqrt{\frac{2T_r \Delta CA}{J_E}}$$  \hspace{2cm} (2)

and $A_p$ – piston area; $\lambda$ – the connecting rod coefficient $L/R$; MIT – mean indicated torque (mean value of $T_r$); $J_C$ – the crankshaft mass moment of inertia; $m_B$ – the replacement mass of the part of the connecting rod rotating on radius $R$ of the x-th crank.

The pressure change in the cylinder (Fig. 2) was described using the lumped method [17, 18]:

$$\frac{dp_{in}}{dt} = \frac{\kappa R T_{air}}{V_c} \left( m_{in} - m_{out} \right) \frac{dV_c}{dt}$$  \hspace{2cm} (3)

where

$$m_{in} = G_{in} = \frac{(\mu A)}{\sqrt{RT_{air}}} (p_{in} \psi_{max} a p_{in} - p_{c})$$

$$m_{out} = G_{out} = \frac{(\mu A)}{\sqrt{RT_{air}}} (p_{c} \psi_{max} a p_{c} - p_{a})$$  \hspace{2cm} (4)

where $R$ – gas constant; $\kappa$ – adiabatic exponent; $\psi_{max}$ – maximum value of the function St` Venant and Wantzel; $a$ – constant parameter value of Metlyuk-Avtushko function.

In Table 2, the flow parameters and the values of the flow function parameters used in the course of the simulation are presented.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>- inlet pressure</td>
<td>$p_{in} = 10 \times 10^5$ Pa</td>
</tr>
<tr>
<td>- atmospheric pressure</td>
<td>$p_a = 1 \times 10^5$ Pa</td>
</tr>
<tr>
<td>- air temperature</td>
<td>$T_{air} = 293.15$ K</td>
</tr>
<tr>
<td>- adiabatic exponent</td>
<td>$\kappa = 1.4$</td>
</tr>
<tr>
<td>- gas constant</td>
<td>$R_e = 297.15$ J/(kg K)</td>
</tr>
<tr>
<td>- max. value of the St` Venant and Wanzel function</td>
<td>$\psi_{max} = 0.587$</td>
</tr>
<tr>
<td>- factor of the Metlyuk-Avtushko function</td>
<td>$a = 1.13$</td>
</tr>
</tbody>
</table>

The differential equation Eq. (3) was solved numerically by the trapezoidal method combined with reverse differentiation. For the purposes of the subsequent steps in solving the equation, the inlet valve and outlet port throughputs were searched for using a 2nd degree polynomial interpolation. The outlet port in every calculations was permanently associated with the CA, while the inlet valve operation was variable, depending on the adopted calculation variant. The calculation procedures have been written in the Matlab-Simulink code.

Boundary condition of simulation have been presented in Table 3.

<table>
<thead>
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<th>Parameter</th>
<th>Value</th>
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<tbody>
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<td>- crankshaft angle degrees</td>
<td>$CA = 0$ deg</td>
</tr>
<tr>
<td>- displacement of pistons</td>
<td>$x = 0$ m</td>
</tr>
<tr>
<td>- volume of cylinder: combustion chamber</td>
<td>$V_c = V_{min}, m^3$</td>
</tr>
<tr>
<td>- pressure in cylinder</td>
<td>$p_r = f(T_r, \omega)$ – mean from 10 times, Pa</td>
</tr>
<tr>
<td>- timing system</td>
<td>$((\mu A)<em>{in}$ and $((\mu A)</em>{out}$ – variants (Fig. 1), $m^2$</td>
</tr>
</tbody>
</table>

Each time before the proper simulation, calculations were carried out for 10 work cycles, assuming $p_c = p_a$ at the beginning and on this basis from the last cycle were defined the boundary conditions of the pressure in cylinder at the start. It was caused by the fact that in the different variants adopted for the calculations, a change in the initial pressure in the cylinder was required.
4. Results and Discussion

In the modelling, the variation of compression ratio (CR) was assumed in the range of (2, 3...12):1. Calculations were performed for each CR in the specified range with regulations according to Table 4. In Variant I, calculations were carried out with a constant duration time of the impulse forcing the opening of the inlet solenoid valve $t_{imp} = 15 \times 10^{-3} \text{ s}$. When defining the variability of the inlet valve opening (IVO), the guidelines presented in the study [18] were followed, where such a necessity was indicated. It should be noted that the maximum IVO value measured against the top dead centre (TDC) hereinafter referred to as before the top dead centre (BTDC) has the limitation in the form of the necessity of closing the outlet port. In Variant II, additionally, a variability of $t_{imp}$ was introduced in order to reduce air consumption. In this case, in addition to the maximum IVO, particularly at higher rotational speeds, the $t_{imp}$ value is important to prevent entering of the air directly into the exhaust port without being used for energy purposes (torque generation).

<table>
<thead>
<tr>
<th>$n$, r./min</th>
<th>IVO, deg BTDC</th>
<th>$t_{imp} \times 10^{-3}$ s</th>
<th>IVO, deg BTDC</th>
<th>$t_{imp} \times 10^{-3}$ s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variant I</td>
<td>Variant II</td>
<td></td>
<td></td>
<td></td>
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<td>500</td>
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<tr>
<td>3000</td>
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<td>80</td>
<td>7</td>
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<tr>
<td>3500</td>
<td>100</td>
<td>15</td>
<td>100</td>
<td>6.50</td>
</tr>
</tbody>
</table>

According to [18], using 6:1 as a level of CR provides satisfactory results (Fig. 3, a). At a rotational speed of 1000 r./min for Variant I, the MIT value is the highest (3.04 N·m). However, in the higher rotational speed range it is advisable to use CR = 4:1. At 3500 r./min and CR > 7:1 the engine demonstrates a problem with torque generation. The constant $t_{imp}$ value in Variant I results in a systematic increase in $G$ as the rotational speed increases, what highlights the problem with the increase in the mass of air flowing through the outlet port without being used for energy purposes (Fig. 3, b). In addition, at CR = 12:1 and $n = 3000$ r./min as well as at 10:1 from 3500 r./min reverse flows become apparent because the compression pressure exceeds the supply pressure.
In Variant II (Fig. 3c and d), at differentiation of \( t_{imp} \), the MIT value reaches a maximum amounting to 3.74 N\( \cdot \)m at \( CR = 7:1 \) and \( n = 500 \) r./min. However, it should be noted that the \( t_{imp} \) in this case was increased to \( 25 \times 10^{-3} \) s. Reducing the \( t_{imp} \) as the rotational speed increased resulted in a lower decrease in MIT above 2000 r./min. The values of \( G \) only in the range (500…1000) r./min are slightly higher than those of Variant I, while at higher rotational speeds are significantly lower (at 3500 r./min by half). The occurrence of reverse flows in Variant II was only found at a rotational speed of 3500 r./min and a CR above 7:1. On this basis, it must be concluded that the CR range of (4…6):1 is the most appropriate for the analysed engine. Conducted analyses have demonstrated the analogy of the control of the pneumatic engine with regard to the internal combustion engine, especially with spark ignition (SI) [28]. In a SI engine it is necessary to control both the mass of the combustion mixture and the ignition advance angle. Similarly, in a piston pneumatic engine, it is necessary to control the mass of supplied air as well as the moment of its application. Specifically, the tests conducted in Variant II indicated the necessity of controlling the opening time of the inlet solenoid valve as well as the moment of its opening with respect to TDC. A way of increasing the precision of air dosage through the solenoid valve is to use a piezoelectric drive [29]. In addition, the range of rotational speeds in which the engine generates its maximum torque is below the values obtained in the combustion operating mode. The pneumatic engine is not capable to operate stably above 3000 r./min. Therefore, the conventional adaptation of an internal combustion engine to a compressed air supply without the possibility of controlling the supply parameters cannot meet the expectations, especially economic ones, i.e. relating to air consumption with maintaining the external parameters [30]. The possibility of smooth control of the compression ratio would be a certain way in the development of piston air engines.

5. Conclusions

The article presents a mathematical model of a pneumatic engine. The object of the analysis was a two-stroke engine based on an internal combustion engine. An important aspect of this engine was the mounting of a solenoid valve in the air supply system enabling the control of the opening time (in effect, the supplied air mass) as well as the moment of its application. The exhaust system remained unchanged from the original. The mathematical model consisted of two parts. On the one hand, the mechanical part (piston machine) was described using classical mechanics, on the other hand, the pneumatic part was described using the lumped method. The solution was sought by numerical methods using dedicated software.

The simulations were aimed to evaluate the effect of compression ratio (CR) on torque and mass airflow in the engine. The calculations were conducted in two variants, in the compression ratio range (2, 3…12):1. In Variant I, apart from the compression ratio, the inlet valve opening was subject to changes, while in Variant II, additionally as a variable was set the time of the impulse forcing the opening of the inlet solenoid valve. In Variant I, the maximum value of average torque in the cycle was 3.04 N\( \cdot \)m with a compression ratio of 6:1 and a rotational speed of 1000 r./min. However, in the higher rotational speed range, an increase in air consumption was observed, most likely caused by the open exhaust port. In Variant II, the maximum of the average torque was 3.74 N\( \cdot \)m with a compression ratio of 7:1 and a rotational speed of 500 r./min, however with a 60% longer opening time of the inlet solenoid valve. In both considered variants, reverse flows were found resulting from higher compression pressure in the cylinder relative to the supply pressure, especially at 3000 r./min, and a compression ratio above 7:1.

Conducted simulations have shown the necessity of controlling the air dosage in the pneumatic engine. The issue concerns not only the mass of the dose delivered per cycle but also the moment of its occurrence in relation to the top dead centre. For the investigated type of engine, the most efficient external and economic parameters were obtained with a compression ratio in the range (4…6):1.

Acknowledgment

This research was financed through subsidy of the Ministry of Science and Higher Education of Poland for the discipline of mechanical engineering at the Faculty of Mechanical Engineering Bialystok University of Technology WZ/WM-IIM/4/2020.

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Environmental Sciences Europe 32: 125.


Perspectives of High-Speed Train Traffic in Ukraine at the Stage of Integration with the European Network

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Abstract

The extension concept of the high-speed network for Eastern European countries has been formulated the implementation of which will allow integrating the railways of Ukraine into a high-speed network of Europe. Based on the analysis of long-term tasks, the following issues are subject to the rationale: the implementation of speed (161-200 km/h) and high-speed (250-350 km/h) train traffic in Ukraine, transition to a new track, which in its parameters will ensure the implementation of high-speed train traffic, the use of rolling stock with the tilting of car bodies, constructing the European standard gauge. Based on the results of scientific developments, the authors outlined the ways to solve the problem concerning the designing route of the high-speed network and the creation of a high-speed network in Ukraine, with regard to the geopolitical, topographical, and other conditions.

KEY WORDS: railway; train traffic; high-speed network; Net Present Value; the reconstruction of the railway.

1. Introduction

Most European countries for over three decades successfully solve the problem of national passenger traffic based on a substantial increase in travel speed on specially built lines [1-6]. The extension concept of the high-speed network (HSN) for Eastern European countries has been formulated the implementation of which will allow integrating the railways of Ukraine into a high-speed network of Europe.

According to the country's national transport strategy approved by the Cabinet of Ministers of Ukraine for the period up to 2030, which defines the priorities of the industry development, until 2025 it is planned to provide conditions for faster passenger train service between regional centers from 160 up to 200 km/h, and up to 2030 – from 250 up to 350 km/h. It is also expected a faster delivering the valuable cargo at a speed of up to 350 km/h, and providing conditions for faster delivery of containerized freight – up to 200 km/h [7].

According to the Strategy for the development of railway transport of Ukraine, the reconstruction of existing and construction of new railways in Ukraine should be carried out in two stages. Implementation of the first stage will ensure the introduction of high-speed traffic between Kyiv and the major regional centers. The task of the second stage is to create a network of high-speed highways with technical-operational parameters that provide the motion of high-speed expresses at a speed of up to 300-350 km/h. The implementation of high-speed traffic on the territory of Ukraine, together with speed lines Kyiv-Lviv, Kyiv-Odesa, Kyiv-Kharkiv, Kyiv-Dnipro will ensure a single network of speed railways, it will be attractive to users, which in turn will increase the number of transit passengers on the European Union–Ukraine–Asia direction. Obviously, the lower limit for HSN is the maximum speed of 250 km/h, which in transport corridors with a length of 600–800 km will provide travel time no more than 4 hours.

For the realization of the above-mentioned programs, Ukraine together with Italy is starting the preparation of economic and technological feasibility (ETF) for the implementation of high-speed railway in Ukraine. The realization of a national project at the state level will not only change the railway sector but also positively affect the economic state in a number of regions; it will greatly expand the capacity of existing spheres of production and launch new ones.

The leading European company Italferr is involved in the development of ETF for the European standard gauge Odesa-Kyiv-Lviv. Italian technical assistance can be expressed in the transfer of technology for Ukraine to build a railway track for more than 160 kilometers per hour, as well as high-speed trains "Pendolino" series, operated in Italy. Their main feature is the tilting of car bodies when passing curved tracks. This allows not to slow down cornering speed, as in the case of conventional trains, and level the action of centrifugal force. Such trains are capable of speeds of up to 250 kilometers per hour.

The length of a high-speed railway can reach 900 km. It will pass somewhere about the following route: Ukraine-Poland border - Lviv - Kyiv - Odesa. At the same time, Kyiv - Odesa section, if it is re-built "from greenfield" by the shortest option, will have a length of about 450 kilometers. Theoretically, at the length of sections Kyiv - Odesa and Kyiv
- Lviv approximately 450 kilometers each, this would enable to overcome the distance from the capital to Odesa or Lviv in two-three hours.

As it is known, in the world the most common is 1435 mm track gauge (4 feet and 8.5 inches). This track is used by 60% of the railways in the world, in particular the railways of North America, China, and Europe (excepting the Commonwealth of Independent States (CIS), Baltic States, Finland, Ireland, Spain, and Portugal).

In Ukraine, 1520 mm track gauge is now operated and currently on the border with Poland, Slovakia, Hungary, and Romania is the largest number of break-of-gauge points (about 15).

The national transport strategy states that main cities must be linked by the European standard gauge. The technical group has been developed the cost issue for the construction of the high-speed European standard gauge on the triangle Kyiv-Vinnitsa-Odesa-Lviv, where Vinnytsia would be the center of train departure. According to this project, the cost of infrastructure works, stations and depots facilities, as well as the purchase of rolling stock will be about $ 18 billion ($ 20 million/km).

Earlier, France has announced the renovation of the electric locomotive park and the creation of a high-speed network. The current Memorandum does not exclude this, since the production of Italian high-speed trains "Pendolino" class is controlled by the French Corporation "Alstom".

It was planned that in 2021 the work on the construction project for a railway network of the European standard would start in Ukraine, where trains from Western countries are able to move. The full integration of the Ukrainian railway with the European network is planned up to 2025. Kyiv, Kharkiv, Lviv, and Odesa will be the main cities, from which trains will drive abroad. According to a new project, trains will move at a speed of 300 to 350 kilometers per hour. The new route will significantly reduce the travel time to the capital.

Based on the analysis of long-term tasks, the following issues are subject to the rationale:
- the implementation of speed (161-200 km/h) train traffic in Ukraine;
- transition to a new track, which in its parameters will ensure the implementation of high-speed (250-350 km/h) train traffic;
- the use of rolling stock with the tilting of car bodies;
- constructing the European standard gauge, Odesa-Kyiv-Lviv route.

In this paper, the authors tried to expand the overview of single questions.

2. Alternative Options for the Implementation of Speed and High-Speed Train Traffic

2.1. Measures to Implement Passenger Train Traffic with Speeds of 160-200 km/h on the Kyiv-Lviv, Kyiv-Odesa Routes

When solving the tasks of the first stage, the reconstruction of the railway line is considered as an integrated system consisting of devices and structures which due to the imperfect technical condition, can restrict the travel speed of trains in each particular section. Therefore, there is a need to know the allowable speed of trains for each barrier point on the railway, as well as the parameters of devices, for which the railway should be rebuilt to realize these speeds [8-12].

Table 1 shows the summarized results of conducted traction calculations on Kyiv - Lviv route for three technical states: option 1 – an initial state of a railway, option 2 – reconstructing a plan of a line, option 3 – reconstructing a plan and changing turnouts on the interstations for train handling with higher speeds.

<table>
<thead>
<tr>
<th>Train type</th>
<th>Option 1</th>
<th></th>
<th></th>
<th>Option 2</th>
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<th></th>
<th>Option 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Travel time, min.</td>
<td>Average speed, km/h</td>
<td>Travel time, min.</td>
<td>Average speed, km/h</td>
<td>Travel time, min.</td>
<td>Average speed, km/h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger</td>
<td>787</td>
<td>96</td>
<td>767</td>
<td>98</td>
<td>767</td>
<td>98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercity+</td>
<td>617</td>
<td>122</td>
<td>564</td>
<td>134</td>
<td>530</td>
<td>142</td>
<td></td>
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</tr>
<tr>
<td>Pendolino</td>
<td>599</td>
<td>126</td>
<td>542</td>
<td>139</td>
<td>504</td>
<td>150</td>
<td></td>
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</tr>
</tbody>
</table>

The required capital investments for performing works on modernization of infrastructure and reconstructing a plan of a line are presented (Fig. 1) in the form of the following components:
1. Track works: replacement of turnouts, reconstruction of main tracks, reconstruction of station necks, capital repairs to the roadbed and artificial structures, construction of overpasses, etc.
2. Overhead contact system, traction and district substations: reconstruction of the overhead contact system at running lines and stations, reconstruction of traction substations and sectioning points, construction of new traction substations, reconstruction of power supply devices, etc.
3. Reconstruction and modernization of automation and telemechanics devices: equipment with new automatic block systems and automatic cab signaling (ACS), reconstruction of electrical centralized control of turnouts, construction of fiber-optic link, etc.
4. Construction and reconstruction of passenger facilities at running lines and stations: railway stations, foot bridges, platforms, etc.
Total costs amounted to UAH 75.510 billion, or UAH 74.8 million/km, or EUR 2.5 million/km, which was taken for the subsequent assessment of design decisions.

2.2. Application of Rolling Stock with the Tilting of Car Bodies

In the literature on the control technique for a tilt angle of railway car bodies (up to 8.6°) it is stated that using this technique is possible to reduce the travel time by almost 30% [13, 14]. This statement cannot be considered final, because the determining factor for a possible reduction in the passing time of rolling stock is, first of all, the radii of the circular curves, the length of the transition curves, as well as the actual cant of the outer rail. Short transition curves of a railway track and length of rail cant often do not allow to provide high speed of movement on sections consisting of adjacent curves directed both in one and in different sides [15].

As evidenced by the results of calculations, a greater speed gain (up to 30-40%) may be in curves with a radius of up to 1200 m. In curves with radii of 1500 m and more, the speed increases by an average of 25% compared to existing trains (Fig. 2).

2.3. Designing the New Track to Provide Traffic by High-Speed Transport

The main criteria for choosing the direction of the track were based on a balanced consideration of such fundamentally important requirements as maximum reduction of HSN length, ensuring optimal technical, operational, and construction performances of the line (reduction in a number of curves, large artificial structures, earthworks volumes, demolition of buildings, etc.) reducing the area of occupied lands, ensuring regulatory environmental and sanitary requirements in the area of HSN impact [16-18].

The route of the line was laid with a deviation from the shortest direction only in difficult topographic conditions, as well as to get around residential areas, historical parks, large reservoirs, etc. It was taken into account that the approach of HSN to the existing railway will save money on the construction of technological connections between them, HSN itself (due to cheaper delivery of materials, equipment on the existing line, organization of work across a broad fronts, the maneuverability of labor and material resources), as well as reduce construction time.

The amount of investment into high-speed lines includes the costs of land alienation, earthworks and construction works, the cost of artificial structures (bridges, overpasses, viaducts, etc.), a permanent way, power supply, signalling and communication systems. The averaged percentage ratio of expenses that are being included in the cost of HSN construction in Ukraine is shown in Fig. 3.

With some generalization, authors can adopt a conceptual model of high-speed train traffic development in Ukraine, based on the application of French experience in organizing high-speed passenger service as more optimal for conditions of Ukraine on the totality of all its features and characteristics. This approach involves the construction of a new electrified double-track railway specialized for the movement of high-speed passenger transport and faster delivery of containerized freight and valuable cargo. At the same time, high-speed trains can go on the existing line Odesa-Kyiv-Lviv in order to serve them at existing passenger stations, but trains of the existing railway are prohibited from entering the high-speed track. Travel time is 1.5-2.0 hours, route speed is about 270 km/h.

3. Assessing the Effectiveness of Design Decisions

The implementation of large-scale investment projects (new construction, reconstruction of railways), which involve high investment costs and the need to take into account a large number of factors, requires the use of appropriate methods of assessing the effectiveness.

The basis for assessing the effectiveness of the project is the following principles: consideration of the option (project) throughout the calculation period, positivity and maximum effect, allowance for the time factor, the impact of
inflation, uncertainties, risks, etc..

The preliminary assessment is based on methods [19-21]:
- Guide to Cost Benefit Analysis of Investment Projects;
- Guideline of Organization for Economic Co-operation and Development (OECD); DAC Criteria for Evaluating Development Assistance;

According to the methods, the assessment can be performed on six indices. Let's focus on the most common NPV (Net Present Value of Discounted Cash Flow) – net discounted income, which is the difference between total income and all types of expenses, with regard to the time factor.

To compare the options: for the reconstruction of the existing railway, the implementation of rolling stock with the construction of the European standard gauge, and the implementation of high-speed traffic in Ukraine, the authors developed a model for predicting and assessing the effectiveness of railway transportation, taking into account all costs by NPV index [22, 23]:

\[ NPV = f \left( D, KI, KL, KV, C_s, CS, \eta, t \right), \]  (1)

where \( D \) – predictive annual revenues to be received as payment for cargo and passenger transportation on domestic and international railway service; \( KI \) – predictive investments for the reconstruction of the railway infrastructure and the border station, providing transportation and technological operations with cargo; \( KL, KV \) – predictive annual investments in the purchase of locomotives and cars, respectively; \( C_s, CS \) – predictive annual operating costs for transportation and costs that depend on the type of technological operations and the time spent by cars at the break-of-gauge points; \( \eta \) – discount rate; \( t \) – number of the target year.

The International Rail Transit Tariff (RTT) was used to determine freight charges, which are applied for cargo dispatch, as well as for transportations through border and port stations.

The developed model allows us to investigate and predict the revenues that JSC "Ukrzaliznytsia" will receive from transportation using the above options for different levels of prediction and traffic volumes in the future.

The analysis of the results showed that at the cost of reconstruction for the railway infrastructure Odesa-Kyiv-Lviv (1010 km) 2.5 million euros/km (see Item 1), the organization of high-speed traffic can be economically justified with annual freight traffic volumes of 10-15 million tons (Fig. 4) and volumes of passenger traffic 15-20 pairs of trains per day.

To determine the most optimum compromise of high-speed passenger and specialized freight transportation on the new route, various combinations were considered, including passenger traffic at \( n = 10…30 \) train pairs per day, specialized freight at \( G = 10…30 \) million tons per year.

The issue of choosing the track gauge when designing a new Odesa-Kyiv-Lviv railway remains relevant. The choice of 1520 mm or 1435 mm track gauge for use on the Ukrainian network is one of the most important issues.

Each option has both positive and negative factors (Tables 2 and 3).

During the construction of the European standard railway with the implementation of rolling stock with the tilting of car bodies, the net present value depends on the volume of freight and passenger traffic and the cost of 1 km of the new railway (Fig. 5). As follows from the chart, the greatest economic effect and in the shortest possible time can be achieved at the volumes of specialized freight traffic of 20-25 million tons per year and passenger traffic of 25-30 pairs of trains per day. According to the results of traction calculations on Kyiv-Odesa and Kyiv-Lviv routes, the delivery time will be about 2 hours excluding the time for stops at a route speed of about 220 km/h.
Factors affecting the choice of 1435 mm track gauge

<table>
<thead>
<tr>
<th>Positive factors</th>
<th>Negative factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The possibility of purchasing rolling stock or technology for its manufacture from leading companies, which will shorten the time for HSN putting into operation</td>
<td>1. Increasing the cost of construction due to the need to arrange connecting tracks between the speed line and the existing network</td>
</tr>
<tr>
<td>2. Crossing borders without wasting time and the possibility of entering European countries</td>
<td>2. Rising prices due to the construction of stations and platforms for passengers service</td>
</tr>
<tr>
<td>3. The possibility of manufacturing domestic rolling stock with the participation of foreign firms</td>
<td>3. Increasing the cost of construction due to the need to arrange specialized depots serving rolling stock</td>
</tr>
</tbody>
</table>

Factors affecting the choice of 1520 mm track gauge

<table>
<thead>
<tr>
<th>Positive factors</th>
<th>Negative factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The possibility of high-speed train traffic on conventional railways to enter large cities</td>
<td>1. Significant costs for the creation of high-speed rolling stock, which prolongs time for HSN putting into operation</td>
</tr>
<tr>
<td>2. The possibility of using existing passenger facilities and devices</td>
<td>2. Increasing operating costs for prevention and repair of rolling stock</td>
</tr>
<tr>
<td>3. Less wear in urban areas due to the limited number of connecting tracks for entering large cities</td>
<td>3. Reduction of the high speed effect due to passengers transfer or change of rolling stock bogies</td>
</tr>
<tr>
<td></td>
<td>4. Complications in the organization of train traffic</td>
</tr>
</tbody>
</table>

During the construction of the Ukrainian standard railway with the implementation of high-speed rolling stock of the TGV POS type, the net present value also depends on the volumes of freight and passenger traffic and the cost of 1 km of the new railway (Fig. 6). As follows from the graph, the greatest economic effect and in the shortest possible time can be achieved with the volumes of special freight traffic 25-30 million tons per year and passenger traffic 25-30 pairs of trains per day. According to the results of traction calculations, the delivery time of passengers on the sections Kyiv-Odesa and Kyiv-Lviv will be about 1.5 hours excluding the time for stops at a route speed of 280 km/h.

Fig. 5 The period when there is a net present value depending on the volumes of freight and passenger traffic during the construction of a new railway with 1435 mm track gauge

Fig. 6 The period when there is a net present value depending on the volumes of freight and passenger traffic during the construction of a new railway with 1520 mm track gauge

4. Conclusions

Researchers believe that the choice of the future track gauge for Ukraine is a more operational and political issue than the financial one. At the first stage, it is assumed to build a new double-track, electrified, designed for a high-speed passenger rolling stock with 1520 mm track gauge and separate technological connections of it with an existing general network of railways. At the same time, high-speed trains will enter existing stations, but conventional trains will be prohibited to go on the high-speed track.

Based on the results of scientific developments (domestic and foreign), the authors outlined the ways to solve the problem concerning the designing route of HSN and the creation of a high-speed network in Ukraine, with regard to the geopolitical, topographical, and other conditions.

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Study of the Influence of a Semi-Trailer Technical State on Handling and Maneuvrability

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Abstract

The practice of operating the semi-trailer truck and the performed studies show that the movement of the semi-trailer truck can depend significantly on changes of design and conditions in some cases, as well as on changes of the geometric parameters of the trailed links chassis of a semi-trailer. The article presents the results of experimental studies of assessment of the impact of interruption of technical conditions of a semi-trailer on a vehicle movement. It was determined that the rear axle skew, the displacement of the hitch point, and the presence of wheels brake retarding of a semi-trailer cause the greatest change of a vehicle movement trajectory.

KEY WORDS: semi-trailer truck, tractor, angle obliquity, articulation angle, interruption

1. Introduction

The advent of modern powerful tractors has led to a significant increase of the maximum speed of semi-trailer trucks. As a result, the semi-trailer truck driving becomes even more complicated and requires the special attention and professionalism of a driver. Controllability of a semi-trailer truck is characterized as the ability of a driver-driven tractor operating as a part of the semi-trailer truck, as well as its trailer links, to maintain the movement along a given trajectory with minimal adjustments and to change it at the request of the driver using the tractor controls [1-3].

The practice of operating vehicles and the performed studies show that the nature of the semi-trailer truck movement can significantly change in the number of cases depend on changes of some design and operational factors - the number of its links, the load location, the air pressure in tyres, the clearance in a towing hitch, the speed, road conditions, as well as the interruption of the geometric parameters of the trailed links chassis of a vehicle, etc. [3-13].

As the experience of operating the semitrailer trucks shows, an interruption in the state of the running gear and the braking system of the trailer links as a result of road accidents lead to large material damage and severe social consequences [14-20].

In connection with the facts mentioned above, an urgent task is to obtain the quantitative data characterizing the controllability of the semi-trailer truck and to conduct an analysis that allows to assess the controllability of the semi-trailer truck depending on the interruption of the technical state of the chassis and the brake system of the trailer links based on experimental studies. These interruptions include clearances in the towing device, air pressure in tyres, axle displacement and obliquity, uneven braking torques along the sides of the trailer link.

2. Subject of the Research and an Applied Equipment

The subject of the research consists of an experimental vehicle (Fig. 1) of category O2 consisting of a tractor and a two-axle trailed link - a semi-trailer. An UAZ-425D vehicle was used as a truck. A trailer link is attached to the vehicle frame of which by a hinge linkage device. A trailer link is a semi-trailer, which consists of several modules: two frame modules and two bogie axle modules. The design and dimensions of the semi-trailer truck are taken into account within the theory of a similarity using the main characteristics [21].

![Fig. 1 A scheme of the experimental vehicle](image-url)
The experimental vehicle is equipped with a measuring and recording equipment including a control panel, a magneto-electric oscilloscope, sensors and hydrometers. Wire sensors - circular potentiometers with a resistance of 1.0 kOhm of the PTP-1 and PTP-2 type - were used as sensors for the tractor steering wheels angle and the semi-trailer articulation angle. Using brackets, the sensors are attached to the steering joint shaft and the towing hitch (Fig. 2).

![Fig. 2 Sensors: a – for the tractor steering wheels angle; b – for the semi-trailer articulation angle](image)

The equipment control panel and the recording device (oscilloscope) are located at the operator's workplace, which is located in the tractor compartment. The trajectory of the semi-trailers is fixed on the supporting surface by a water stream with a diameter of less than 1 mm using hydraulic markers (Fig. 3), which are installed on a tractor and semi-trailer (Fig. 4 a, b). The installation correctness of the hydraulic markers was checked by aligning the trajectories of the characteristic points of the semi-trailer truck links, which were recorded during straight-line movement. Each of the described sensors is connected via the control panel. Before the tests start, necessary maintenance works were performed on the tractor and the semi-trailer; during the testing process and, moreover the operation of the systems and mechanisms of the semi-trailer truck was constantly monitored. All sensors were calibrated before road tests.

![Fig. 3 A set of hydrometers for a tractor unit and a trailer link](image)

![Fig. 4 Installation of hydraulic markers on: a – the semi-trailer cargo platform; b – the articulated joint for connecting the trailer with the tractor](image)
3. Program and Research Methodology

The test program provides the quantitative data characterizing the controllability of the semi-trailer truck and takes into account the variation of its parameters by the axle obliquity, displacement of the hitch point, changes of tyre pressure and braking moments on wheels of the semi-trailer.

The tests were carried out on a flat, dry asphalt surface. The manoeuvres were carried out along a circular route, which included two sections: straight (12 m long) and curved (90° right turn with a radius of 10 m).

The movement along the route was carried out at a constant speed of 1.388 m/s (5 km/h). The races for each test were repeated three times. The provided test method allows to obtain calibration and characteristics of the deviation of the trajectory when failures of the technical conditions of the semi-trailer link are modelled.

Axle obliquities varied from 0° to $3^\circ\ 30'$ clockwise and counterclockwise along different axes of the semi-trailer link, and the hitch point displacement had values of 50, 75, 100 mm to the left and right of the tractor axis. The air pressure of tyres of the trailed link was of 0.7 and 0.5 according to the determined values by the standard on the right and left sides. Braking along the sides of the trailed link was by 10%, 15%, and 20% less than the norm on the right and left sides.

4. Results of the Semi-Trailer Truck Road Test

The results of analyses of the semi-trailer truck road tests show the influence of the technical condition interruptions of the trailer link on the change of the trajectory of the semi-trailer truck, which correspond to the change in the nature of the movement and affect the controllability and manoeuvrability of the semi-trailer truck.

The results of modelling interruptions of the technical condition on the controllability and manoeuvrability of the semi-trailer truck when driving on a straight section and when cornering show that the rear axle obliquity on a straight section has a greater effect on the deviation of the trajectory of the semi-trailer (Figs. 5-14, an asterisk in the figures shows the average deviation trajectory of the trailed link during calibration).

Fig. 5 Deviation of the trailed link trajectory when the semi-trailer truck is moving on a straight section with axes obliquity to the right (clockwise)

Fig. 6 Deviation of the trailed link trajectory when the semi-trailer truck is moving on a straight section with axes obliquity to the left (counter-clockwise)

Fig. 7 Deviation of the trajectory of the trailed link when the semi-trailer truck is moving on a section with a 90° curve with an axes obliquity to the right (clockwise)

Fig. 8 Deviation of the trajectory of the trailed link when the semi-trailer truck is moving on a section with a 90° curve with an axes obliquity to the left (counter-clockwise)
By analysing all the graphs, one can note the greater sensitivity of the trailed link to interruption of parameters when driving on a straight section. The maximum deviation of the trajectory of the trailed link causes obliquities of the rear axle (by 21.7 times) and displacement of the hitch point (by 7.5 times).

5. Conclusions

The analysis of experimental studies of the influence of the technical state of trailed links on the movement
nature of the semi-trailer truck showed that the greatest influence on the change of the trajectory of the trailed link from all interruptions of the geometric parameters of the running gear and the brake system is felt when it moves on straight sections. The axle obliquities during cornering has practically no effect on the change of the trajectory of the trailed link (the maximum change is of 1.12 when the rear axle is oblique). The average deviation of the trailed link trajectory in the presence of an obliquity of the front axle increases the trajectory of the trailed link by 10.4 times, in the presence of obliquity of the rear axle - 16.1 times. With the maximum obliquity of the front axle, that values were increased 14.1 times, with the maximum obliquity of the rear axle - 21.7 times. Axle obliquities lead to the increased fuel consumption and tyre wear. The left and right displacement of the hitch point of the trailer link from the tractor axis increased the deviation of the trajectory of the trailer link by an average of 5.8 times. When the vehicle moves in a curve, the displacement of the hitch point changed the trajectory of the trailed link by an average of 1.45 times. The decrease of the tyre pressure when it moves on a straight section, the trajectory of the trailed link was changed by 1.5 times on average. When it moves in a curve, the change of the tyre pressure did not practically change the trajectory of the trailer link. The braking of the wheels of the trailed link on a straight section caused a deviation of the trajectory of the trailed link by 2.6 times, while driving in a curve only - by 1.2 times.

Acknowledgement

This publication was issued thanks to supporting the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 0362021: Implementation of modern methods of computer and experimental analysis of properties of vehicle components in the education of future vehicle designers.

References

Application of Logistic Information Flow in Customs Clearance of Cargo at Marshalling Station

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Abstract

Large marshalling stations are the important element in the logistic chain linking the consignor and consignee. As a rule, such stations are located near large loading or unloading facilities, where cargo arrive under customs control. The problems in processing of carriage documents related to the customs formalities of cargo at marshalling stations are considered. In connection with the imperfection of the existing technology, the operating personnel at the station are forced to work irregularly due to delays in the processing of customs documents, and this significantly increases the idle time of wagons and reduces the rationality of use of the rolling stock. Currently, there is the urgent task of how quickly and efficiently to process the customs formalities of cargo at the marshalling station using logistic technologies for processing of information flow. Two main approaches to organization of work on the processing of carriage documents are compared: traditional and logistic. In the course of comparing of the variants, the main reasons of unproductive downtime in the processing of customs cargo carrying from Latvia to foreign countries by sea transport are identified. To predict the operations associated with the processing of carriage documents, it is proposed to use the dynamic model, which is based on scheduling theory in the form of the solution to the problem of the type “Flow shop” (flow line). Recommendations are given for optimization of the technological process of operation at the marshalling station to reduce time and financial costs. It is proposed to introduce the modern logistic and information technology in order to ensure the efficiency of operation of the marshalling station. It is concluded that modern logistic information systems can improve the productivity of station operation.

KEY WORDS: logistic information flow, marshalling station, customs clearance, scheduling theory, wagon downtime

1. Introduction

The marshalling station is the element of the macrological system that provides communication between the links of the logistics chain. The main function of the marshalling station in the transportation process is the processing of wagons flows and the formation of trains in the optimal mode, in order that the staying of the wagon at the station have been minimal in time and technologically justified. It is part of the physical movement of material flows between participants in the supply chain. Such movement of goods along the logistics chain ultimately allows delivering any cargo to the end customer to the place of further processing or consumption [1]. At marshalling stations the material flow is the cargo (or the container) loaded into the wagons, namely reprocessed wagon flow, which is accordingly divided into transit without processing, transit with processing, local. As a rule, when carrying out multimodal transportation, it is necessary to comply with customs formalities (declaration and customs clearance of cargo), which arises in connection with the movement of cargo across the customs border, as well as in the event of the change of the customs procedure. Today, it can occur at base or transfer marshalling stations, which, as a rule, are located near the state borders of the country [2].

In most logistics systems, material flows are accompanied by logistics information flows. Their relationship is obvious, as processing of information is at the heart of the management process of material flows. The content of the logistics information flow typically reflects all data of material flow with the certain degree of accuracy.

Currently, at marshalling stations, the main reliable logistic information flow for processing of customs, carriage and other documents is mainly the paper information carrier. Document flow in this form is cumbersome and routine. The urgent task is to ensure the transition of the document flow accompanying transport services to the electronic form of information carriers, ensuring maximum efficiency in the implementation of customs formalities of the cargo. Similar complex systems have already existed, for example, on Ukraine railways in the form of automated freight management system of Ukrzaliznytsia (ACK ВП У3-Е) that is uniform.

To maintain the competitiveness of railway transport, it is planned to introduce the electronic system of preliminary information on the performance of customs formalities, as today, the issue of the development of railway transport is relevant, by increasing its innovative potential and susceptibility to technological innovations in general [3].

2. Problems of Processing of Carriage Documents

Currently, when processing of customs formalities for cargo at marshalling stations, the corresponding paper
documents are drawn up. In this case, the marshalling station is usually the transfer or base station, at which the consignee is obliged to settle all formalities with the cargo, which is under customs control. For this, there is the principal’s service, the function of which is to establish relationships between the departments of customs, the consignee and the railway, to determine the sequence and conditions for the technological process of the station.

At present, in connection with the optimization process at the base marshalling station, the uniform principal’s centre for customs clearance of cargo is being created on the Latvian Railway. In connection with the introduction of the new technology of operation of the principal’s centre, the volume of both additional shunting work and the volume of paperwork has increased.

At the base marshalling station, when passing through customs clearance, cargo of foreign origin are imported into Latvia in one of three possible ways [4]:
1. when the recognized consignee (or the customs service) carries the responsibility and performs the following customs procedure, after which the cargo is unloaded into the free zone;
2. when the customs service carries the responsibility and performs the following customs procedure, after which the cargo is unloaded to the customs warehouse or to the place of temporary storage, but at the same time the consignee has concluded the agreement with the railway for customs formalities;
3. when the customs service carries the responsibility and performs the following customs procedure, after which the cargo is unloaded to the customs warehouse or to the place of temporary storage, but at the same time the consignee with the railway hasn’t concluded the contract for customs formalities.

According to the first and second methods, in accordance with the new technology for customs clearance of cargo, the principal informs all consignees that the cargo have arrived at the base marshalling station and consignees need to settle all customs formalities. After that, the consignee provides the statement in which he certifies that the cargo will be unloaded in one of the possible ways: in the free zone, the customs warehouse or at the temporary storage place. Before unloading the cargo, it is necessary to draw up the documentation, pay taxes and other mandatory fees. After all this, the goods office issues the cargo to the consignee. Now he has the right to perform any actions with cargo: transport, sell, store or consume.

According to the third method, exactly the same scheme of document flow is used as in the first and second methods, only in this case additionally the general form statement is drawn up for the customs cargo and the wagon has the idle time for as long as the consignee will have performed the following customs procedure. After then he will have provided the import declaration or document of pre-customs clearance at principal’s centre. This standard customs clearance procedure takes several hours. However, sometimes during the check, non-standard situations arise, because of which there is the risk and this period can increase up to 3 days. Such provoking factors include the lack of permissive documents from the authorized agency, incorrect filling or drafting of documents submitted for the customs officer.

In the implementation of the technological process of operation for the marshalling station, there are the number of organizational and technological problems associated with the clearance of customs formalities for cargo. In accordance with the technological process, after the arrival of the freight train, the processing time for customs cargo takes 60 minutes. However, due to manual processing of carriage documents, this rate can exceed by about 10 minutes and more up to one hour. As a result, wagons have unproductive idle time. In 60% of cases, additional downtime is more than 30 minutes.

When the third method is used, after the full clearance of delay for the customs cargo, the wagon with this cargo is sent to the specialized sorting track, where it stands the idle time until customs formalities are settled. After settling these formalities, when the consignee has provided all the necessary documents and paid taxes and other mandatory fees, this wagon is sent to the required sorting track. This is usually done through the hump. Thus, these wagons are re-sorted through the hump. The statistical analysis of the hump operation has showed that since the 1st of August 2020, with the introduction of the new technology, the coefficient of repeated sorting has increased from 0,073 to 0,128.

Thus, one of the reasons for the unproductive downtime of wagons and the increase of shunting work is that the consignee does not have full information in advance about the arriving cargo.

3. Comparison of Two Main Approaches to Organization of Work on Processing of Customs and Carriage Documents

There are two main approaches to organizational operation on the fulfillment of customs formalities during cargo clearance: the traditional and logistic approach with the participation of the single operator for customs clearance of cargo [1].

With the traditional approach to material flow management, each link in the logistics chain has its own management system, focusing on its own goals and performance criteria. At the marshalling station, the output reprocessed wagon flow (material flow) of each previous link in the logistics chain is the input for the next link. The resulting wagon flow of the entire logistics chain is the output flow of the last link. Wagon flow parameters are determined as the result of independent control actions carried out sequentially in each link of the logistics chain. Therefore, from the point of view of general management goals, they are random.

Another characteristic feature of traditional systems is the fragmentation of the management functions of the logistics system for different services of the station (wagon and locomotive depot, service of movement and cargo), which are involved in the transportation process. At the same time, the vector of goal-setting of the system and
subsystems has the different orientation, the direct goals of these services and may not coincide with the goal of rational organization of the wagon flow at the marshalling station as a whole.

At the same time, the task of management of the through discontinuous wagon flow is not posed or solved. As a result, the indicators of this flow (cost, processing of wagon flow, quality of transport services, etc.) at the exit from the chain, as a rule, are far from optimal. Therefore, for effective management of material flows, it is necessary to apply the logistic approach.

Thus, with the traditional approach, there is no single function of management of the through-material flow. The coordination of the logistic links in matters of the promotion of information and finance is low, since there is no one to coordinate their actions. Fig. 1 shows the processing of wagon flow using the traditional approach.

![Fig. 1 Traditional approach to organization of work on the processing of customs and carriage documents at transfer and base marshalling station](image)

With the logistic approach, control actions are applied to separate phases of the movement of wagon flow from the side of the single logistic subsystem of management. These control actions are formulated based on the general goals and performance criteria of the logistics chain under study. As a result, the parameters of the wagon flow become predictable and controllable, and the advancement of the wagon flow along the logistic chain begins to be carried out taking into account the criterion of the minimum cost of time and money.

Thus, with the logistic approach to organizational operation of the marshalling station, the new participant in the technological process has appeared - the single principal centre for customs clearance of cargo. The presence of such centre may create the opportunity to synchronize the movement of wagon flow, information and to achieve optimal performance of the station. Fig. 2 shows the processing of wagon flow using the logistic approach. Comparing the traditional and the logistic approaches based on preliminary customs clearance using logistics technology “Just In Time” (JIT), the following differences can be seen in Table.

![Table Comparison of the traditional and logistic approaches to the organization of work on the processing of customs and carriage documents](table)

<table>
<thead>
<tr>
<th>No.</th>
<th>Comparative parameters of system</th>
<th>traditional Approach</th>
<th>logistic Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Flexibility</td>
<td>Minimum flexibility</td>
<td>High flexibility focused on service of consignee</td>
</tr>
<tr>
<td>2.</td>
<td>Method of processing on customs formalities</td>
<td>Scattered drawing up and lack of the single operator</td>
<td>Unified end-to-end processing of document</td>
</tr>
<tr>
<td>3.</td>
<td>Scheme of interaction of participants</td>
<td>Consistent</td>
<td>Sequential-central</td>
</tr>
<tr>
<td>4.</td>
<td>Time of fulfilment of technological operations for processing documents</td>
<td>Determined by the current course of the technological process</td>
<td>Minimal investment of time</td>
</tr>
<tr>
<td>5.</td>
<td>Time to perform shunting work</td>
<td>Increased number of shunting half-run due to repeat sorting</td>
<td>Minimum number of shunting half-run to be performed</td>
</tr>
<tr>
<td>6.</td>
<td>Wagon-hours of idle</td>
<td>Increased unproductive downtime of wagon</td>
<td>Unproductive idle of wagons strive to a minimum</td>
</tr>
<tr>
<td>7.</td>
<td>Relations with consignees</td>
<td>Individual, often antagonistic goals</td>
<td>General goals aimed at reducing downtime of wagon</td>
</tr>
<tr>
<td>8.</td>
<td>Quality of service of consignees</td>
<td>“Acceptable quality” with the lowest cost</td>
<td>Highest quality implying joint solving of problems</td>
</tr>
<tr>
<td>9.</td>
<td>General approach</td>
<td>Focus on cost reduction</td>
<td>Orientation on service of consignees</td>
</tr>
</tbody>
</table>

The fundamental difference between logistic and traditional approach is as follows:
- allocation of the single function for processing of customs and carriage documents;
ensuring the technological integration of individual links of the logistics chain into the single system at the macro- and microlevels.

![Single Principal Centre for Customs Clearance of Cargo](image)

Fig. 2 Logistic approach to organization of work on processing of customs and carriage documents at transfer and base marshalling station

4. Mathematical Modelling of Operation for the Marshalling Station with the Logistic Approach

From the point of view of management, any marshalling station should be considered as one large marshalling system, which is characterized by the task – continuous passage of the reprocessed and transit wagon flow with the lowest financial costs, which mainly depend on the wagon-hours of idle time of transit wagons with reprocessing and the volume of shunting work. To accomplish this task, the shunting dispatcher of the marshalling station predicts the use for each “line” of the train schedule for each direction and prioritizes the disassembling of trains with the closing wagon groups on the marshalling hump in order to form and dispatch the freight train on time in accordance with the plan formation and schedule of trains. Thus, the quality of operation of the marshalling station is characterized by the function of average daily costs and is solved as the dynamic programming problem with the target function [5]:

$$E_{\text{av.d.}} = \sum_i B_i e_i^{\text{w-h}} + 12 \sum_j \sum_f M_{ij} r_{ij} e_{\text{shunt}} + E_a \rightarrow \min,$$

where $i$ – index of category of wagon flow (empty, loading with normal, regular, high-speed or guaranteed mode of delivery by the certain date); $B_i$ – wagon-hours of standing within the marshalling station for wagons of the $i$-th category; $e_i^{\text{w-h}}$ – cost of wagon-hour of idle time for wagon of the $i$-th category, Eur; $j$ – index of variant the work of shunting locomotive (each variant is characterized by the series of locomotives, the number of employees of the locomotive and shunting crew); $M_{ij}$ – number of locomotives operating according to the $i$-th variant on the $f$-th technological line (hump, draw-out track, district of industrial track served by the station); $r_{ij}$ – number of shifts of their work per twenty-four hours; $e_{\text{shunt}}$ – cost of 1 hour of locomotive operation according to $j$-th variant, Eur.; $E_a$ – costs in the field of organization of train work and transfer traffic associated with train delays due to non-acceptance by the marshalling station, Eur.

In formula (1), the element can be represented as the sum of wagon-hours of downtime in the receiving park, the sorting park and the departure park. Obviously, non-negativity constraints must be imposed on the components of the objective function.

Mathematical models in transport logistics are explained in sources [6, 7], but in which are not considered the mathematical models that can be based on the scheduling theory. The example of calculating of wagon-hours is considered in receiving park of the marshalling station, applying the scheduling theory.

Namely, in the receiving park, the processing of carriage documents related to the customs clearance of cargo takes place. To determine the wagon-hours in the receiving park, the mathematical model based on the scheduling theory is used. The set of technological operations for processing of the $j$-th train set ($j$-e requirement) and the set of performers who perform the $i$-th technological operation ($i$-th job) are given. The problem can be formalized in the general form, where the total duration of all operations for processing of the freight train (duration of work) is calculated by the following formula [8]:

$$B_j = \sum_{j=1}^{n_j} t_{ij} + \sum_{j=1}^{n_j} u_i W_{ij}$$

where $t_{ij}$ – duration of performance of the technological operation; $u_i$ – weighting coefficient that determines the priority of the operation; $W_{ij}$ – waiting time for the start of the technological operation $ij$, namely, time interval between the end of the $(j-1)$-th and the beginning of the $j$-th technological operation for the $i$-th work.
The wagon-hours of downtime, which consist of technological operations, is considered in the receiving park: time for processing of carriage documents $t_{rec.p}^{pr.doc}$, inspection of the train in technical and commercial terms $t_{rec.p}^{pr.tech-com}$, and disassembling of the train from the hump $t_{rec.p}^{disas.tr}$. Due to the creating of the queue for processing train sets, there is waiting time for the start of processing of carriage documents $W_{rec.p}^{pr.doc}$, waiting time for the beginning of the inspection of the train in technical and commercial terms $W_{rec.p}^{pr.tech-com}$, and waiting time for the beginning of the disassembling of the train from the hump $W_{rec.p}^{disas.tr}$.

As a rule, the reprocessed wagon flow has the different structure - empty or loaded one, and when processing of this wagon flow in the receiving park, both the processing of carriage documents and the technical and commercial inspection of the train take place in parallel. Therefore, when processing the loaded train, the limiting operation, as a rule, will be the processing of carriage documents, and when processing the empty train, on the contrary – inspection of the train in technical and commercial terms. Thus, the wagon-hours of idle time in this park will be determined as the Boolean variable according to the following formula (3).

$$B_i^{rec.p} = \max \left\{ t_{rec.p}^{pr.doc} + t_{rec.p}^{pr.tech-com} + t_{rec.p}^{disas.tr} + W_{rec.p}^{rec.p} + W_{rec.p}^{disas.tr} ; \right\}$$

$$B_i^{rec.p} = t_{rec.p}^{pr.tech-com} + W_{rec.p}^{rec.p} + W_{rec.p}^{disas.tr} ;$$

Formula (3) can usually be used with the traditional approach, when the processing of carriage documents occurs after the arrival of the freight train. However, with the logistic approach, formula (4) have already taken on the different form and the limiting operation will be the inspection of the train sets in technical and commercial terms.

With the help of the dynamic model, it is possible not only to reduce the unproductive idle time of wagons, but also thereby to reduce the consumption of energy and fuel for locomotives; reduce the cost of shunting work, as well as reduce the cost of transporting cargo [9].

5. Recommendations for the Application of the Logistics Information Flow

One of the main tasks of transport logistics is to find the optimal variant of decision-making for management of material flows, related information and finance to increase the company’s competitiveness. To process material flows, it is necessary to obtain preliminary information, which will come in the form of the logistic information flow. With the help of the logistics information flow, it is possible to provide preliminary customs clearance of cargo.

With the correct and efficient organization of work and with the established exchange of logistic information, any cargo can be tracked from the border point to the point of destination. In these conditions, it does not matter where the customs clearance point is, since the cargo can be cleared on the basis of the data provided already at the moment of arrival of cargo, and taxes and fees can be paid while the cargo is still in movement. This will allow in most cases to reduce to the minimum the downtime of wagons at the base marshalling station and delays in the release of cargo at the destination. In accordance with the Framework of Standards to Secure, many customs authorities ask Trader Company in advance for information about cargo arriving at the station. This gives customs authorities the additional time to conduct the risk analysis and facilitates the early release of cargo [10].

By creating the logistic information model that will contain the information about the consignee, destination station, cargo name, invoice number, wagon (container) number. This preliminary information will be obtained automatically in advance from automated systems (ACYC, C-KNIS, KPS and DKDS). Then this information will be sent electronically to the specific consignee. After informing about the arriving cargo, the consignee will fill out the application in the electronic system for processing of customs formalities for the cargo. The place of unloading of the wagon (container) and the next customs procedure will be indicated in this application. At the same time, there will be the separate problem of synchronizing of the material flow (wagons and cargo) and information flows. To solve it, it will be necessary to create the system for more accurate positioning of the location of the rolling stock with cargo. Technically, this can be implemented on the basis of GPS technologies using automatic reading of RFID tags on wagons and containers.

Depending on the situation, for example, if the cargo will be unloaded into the free zone or the consignee has drawn up the agreement with the railway for the provision of principal’s services, then the cargo is not delayed and the general form statement on the delay of the cargo, which is under customs control, is not drawn up. In this case, it is possible to issue customs formalities for the cargo in advance before the arrival of the freight train at the base marshalling station. In this case, there will be no unproductive downtime at the marshalling station.

The second situation is when the consignee does not have the agreement with the railway for the provision of principal’s services and he needs to provide the following customs procedure to the principal’s centre. For the consignee, the principal’s centre electronically will have prepared in electronic form the set of necessary documents and the invoice for payment of transportation. These preparatory operations can also be done in advance at least 2 hours [2] before the arrival of the freight train at the base marshalling station. Further to the customs service, the principal’s
centre will send the information about the arrival of wagons at the base marshalling station. This information can also be sent in advance by calculating the average length of the queue for the start of processing and registration of document for the next customs procedure in the customs service using the mathematical apparatus of the queuing theory [6, 11].

With such organization of work, it is possible to implement logistics technologies “Just In Time”. The essence of solving of the urgent problem is that it is necessary to create the new modern logistics technology for processing of “paper” customs documents, which will improve the quality of service to consignees and increase the competitiveness of railway transport.

6. Conclusions

In conclusion, of the study, it can be noted that:
1. The use of logistics technology for processing of the information flow in the clearance of customs formalities for cargo at the base marshalling station will have eliminated the reason for the increase in unproductive downtime of wagons, which is caused by:
   - laborious and time-consuming processing of carriage documents and the large amount of paperwork;
   - the increase of additional shunting work, which is associated with the repeat sorting of wagons and the formation of the train composition in accordance with the freight train formation plan.
2. The creation of logistic information system will have allowed consignees to receive in advance full information about the arriving cargo in order to settle customs formalities for the cargo in advance, before the arrival of the freight train at the base marshalling station, namely to issue the preliminary customs clearance of the cargo.
3. When comparing the traditional and logistic approaches to organization of work on customs formalities of cargo, it has been revealed that the logistic approach would improve the performance of the single principal’s centre, the quality of service for consignees and the competitiveness of railway transport.
4. The article presents the dynamic programming model that will have allowed the wagon flow at the lowest cost to process, using the logistic information flow for processing customs formalities of the cargo.
5. As a result, it has been proposed to create and implement the logistics information system for preliminary customs clearance of cargo.

Acknowledgement

We thank our colleagues from Ukrainian State University of Railway Transport who provided information on application of the logistic information flow in the customs clearance of cargo at marshalling station, as also for the valuable advice and comments on the article.

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Smart Workplace: Students’ Opinion On Being Prepared to Meeting Digitalization Challenges

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Abstract

A smart workplace is defined as a workspace that uses growing digitalization of physical objects to deliver new ways of working and improve workforce efficiency. During pandemic, a lot of physical workplaces shifted into remote mode; the idea of smart workplaces became relevant for different industries and business models. Transportation and warehousing business are based on 96% of small and medium business companies, so in the transportation industry one of the ways to optimize business resources is to shift traditional workplace to the smart workplace. The competences of future professionals able to work in smart workplace in transportation industry were investigated by applying the multi-dimensional model of competences categorized in three planes of layers: plane one – inner-interaction competences of the person (self-awareness, cognitive), plane two – outer-interaction competences allowing the person to connect and interact with the environment (soft, hard and digital), plane three – functional competences as related to the characteristics of the environment in this case – transportation industry. The objective of the paper is to present results of the investigation about the students’ readiness to meet the recent challenges in transportation industry and their expectations from the labor market in relation to the changes.

KEYWORDS: smart workplace, competences of future professionals, model of competences, digitalization in transportation, digital competences

1. Introduction

The changes in industries, labor market and education in a post-COVID-19 pandemic situation boosted intensive transformational processes for the adapting new methods and technologies, so the future workforce should be prepared not only to use them professionally and socially but also in the context of new smart professions demand in the smart market. The transformation fosters the need to investigate the smart workplace that is defined as a workspace that uses growing digitalization of physical objects to deliver new ways of working and improve workforce efficiency. During pandemic, a lot of physical workplaces shifted into remote mode and the idea of smart workplaces became relevant for different industries and business models. The transportation and warehousing business structure are based on 96% small and medium business companies, so one of the business resources optimization tasks is to shift traditional workplace to the smart workplace. From point of view of the competencies of future professionals, the model of T-shaped professional [1] the Tuning methodology, exploring competences as generic and subject-related [2], and the RHAM (Reference human-centric architecture model) [3] were considered to develop multi-dimensional model of competences for the purpose of the investigation of the digital readiness of Lithuanian Maritime Academy’s students to work at smart workplace in the future maritime transportation industry.

The competences of future professional able to work in smart workplace in transportation industry were investigated by applying the multi-dimensional model of competences of future professional categorized in 3 planes of layers: plane one – inner-self competences of the person (self-awareness, cognitive), plane two – competences allowing the person to connect and interact with the environment (soft, hard and digital), plane three – characteristics of the environment in this case – transportation industry. The research methodology included exploratory research based on the concept analysis of the smart workplace and competences of future professional in maritime transportation industry applying the quantitative and qualitative analysis of the students’ survey data.

It is important to note, that this research could be continued by investigating the challenges of the whole education systems which have to be transformed into the hybrid educational models related to the changes in workplace conception in the maritime transportation industry. As implications for further research the investigation of the lecturer’s perceptions on understanding of current issues and preparedness in providing needed educational activities could be suggested including institutional readiness for the training of future professionals in maritime industry.

2. Smart Workplace Concept under the Influence of Industry 4.0 Combined within the Pandemic Conditions in Maritime Education and Training and Multi-Dimensional Model of Competences

Development of digitization of global supply chain influenced the need of automation and robotics of business processes and formed the challenges for the whole education systems. In addition, the remote working conditions under the pandemic situation in the global market induced the intensity of digitization, so the educational systems were strongly
impacted and had to implement qualitative changes. Scientific literature analysis reveals this influence on the basis of relationship between Industry 4.0 and Education 4.0 which are related to smart workplace conception. As the Benešova and Tupa [4] found out the emerging technologies have huge effect on the education of qualified and highly educated employees who will be able to control Industry 4.0 technologies integrated into supply chain processes and also these changes will increase the needs of collaboration within the higher education institutions and scientific organizations. A smart workplace is defined as a workspace that uses growing digitalization of physical objects to deliver new ways of working and improve workforce efficiency. During pandemic the idea of smart working places became extremely relevant for different industries and business models. In this context, the smart workplace will connect technologies, services and people into the unified cyber – physical system (CPS), consisted of Internet of things, Internet of services and Internet of people, where the main relationships of machine-machine, human-machine and human-human will be implemented through the huge amount of big data [5] and the “smart production” and “smart services” will become the result of effective working at “smart workplace” [6]. So, the skills and qualifications of the workforce will become the key to success of a highly innovative factory; consequently, the higher education has to be ready to meet these tendencies. In the report on Future jobs [7] similar tendencies were identified: the most adaptable five technologies until 2025 will be the cloud computing, big data analysis, internet of things, the cybersecurity and artificial intelligence. Several CPS, such as autonomous cars, intelligent systems, smart cities and artificial intelligence applications which drive this shift under the uncertainty conditions will result in mass unemployment where the workers in specific areas will be less needed or will lead to new jobs not imagined today being required, and these insights allow justify deeper the challenges of smart workplace in the modern education principles and policies [8]. By resuming the formation of smart workplace, it could be stated that the industrial changes called Industry 4.0 are based on the development and integration of CPS which influenced the changes of education called Education 4.0 which should transform the traditional education systems by meeting the conception of smart workforce dependent on the technological progress which is described by human relationship within the machines in processes and workplace equipment.

Going to the explanations of required competences and their structure in preparation to work at smart workplace it is important to make analysis of digitization processes in global supply chain which is similar to any business process in every area of activities. As Benešova and Tupa [4] found out, the various stages of implementation of Industry 4.0 (Fig. 1) divide future competences in two well balanced groups of competences constructed from technical and social competences used in the automation of processes. It is important to note, that the conception of smart work starting from the first stage of Industry 4.0 with the assumption of realized stage 0, which is the fundamental structure of Industry 4.0 implementation. The main prerequisite for business process automation is the required known data and parameters for the digitization and digital competences to find and to process them. The scientific findings on the smart workplace could be described as workplace where the specialists are working within the digital environment, operating and communicating through the specialized platforms having possibilities to work independently, creatively and be able to make decisions based on the data represented in digital tools. As it is showed in Fig. 1, each next stage is based on implemented previous stage and different types of competences could be identified. And according to the conception of smart workplace the RHAM model (Reference human-centric architecture model) [3] combines self-awareness and cognitive, as inner-self interaction competences, with the soft (social), hard (technical) and digital competences, as outer-world interaction competences, to describe the characteristics of the effective future specialist in demand.

Transportation industry and particularly, maritime transport sector, also is shifting to smart transport business processes. These changes more intensively influence education and training, so the new approach is required for the training of specialist in the maritime transport sector. Because a lot of researchers work together with the shipbuilders and producers of ship control systems including the companies of telecommunication to implement in real practice the idea of fully or partially autonomous ships. These tendencies in the market create possibilities to develop idea of the digital readiness which is consisted of basic digital attitudes, knowledge and skills required to implement main routine actions in professional and also household area. But the digital readiness has diverse meanings in literature [9], it also,
can be interpreted differently, but in context of this research the readiness is explained as individuals’ competences of adapting and utilizing digital technologies to acquire the maximum benefits from those technologies individually and organizationally starting their utilization at the background level of digitization.

Industry 4.0 is strongly related to the concept of smart workplace because it requires well developed general communication and social competences, including critical and system thinking, and also well-developed specific competences consisted of the process knowing (technical) in its virtual environment competences which are the technical and digital competences. It is important to know, that for future professions is very important for each specialist to be digitally prepared for the periodical transition of workplace to more and more smartness in the future. In order to investigate the questions: What kind of professional is best suited to adapt to the continually changing environment? What types of competences and how many of them do the future professionals need? How to educate future specialists in transportation industry to be efficient in using smart workplace opportunity? - the three models of describing competences were analyzed for the purpose of the research: T-shaped professional [1], RHAM (Reference human-centric architecture model) [3], Generic/transferable and subject-related competences model according to Tuning methodology [10].

The multi-dimensional model of competences (Fig. 2) was developed integrating 5 core groups of competences related to the person and 4 groups of competences related to the industry:
- Plane one: two of layers of competences (self-awareness and cognitive) are considered mostly as inner-individual competences of a person, such as understanding of individual consciousness and emotions and understanding of physical world and self by mental inner processes.
- Plane two: three layers of competences (soft, hard and digital) are considered as connecting inner and outer-world, allowing the person to connect and interact with the environment - communication, work and collaboration with others and environments; performing jobs and tasks by using special tools and equipment and applying technical skills; functioning in digitally developed society by operating recent technologies and systems in particular settings.
- Plane three: four layers of competences related to functional groups of activities - characteristics of the environment in this case – transportation industry (information, communication, production and safety); they describe the work area, in which all personal competences have to be realized.

3. Methods: Resource Identification Initiative

The purpose of the investigation was achieved by applying a survey method for the data collection using the originally designed questionnaire and performing qualitative and quantitative analysis of the obtained data using content analysis method and Microsoft Excel Data analysis tools and functions for the required statistical calculations based on the score calculation methodology described below. The questionnaire was designed to obtain the opinions of the respondents regarding their preparedness to meet the recent digitalization challenges in developing digital competences and abilities to work with smart working places. The other topic under investigation was related to the perceptions of the students on the understanding of expectations from the labor market and transportation industry in relation to the changes. In the developing of the questionnaire the results of the literature analysis and personal insights of the authors were used.

The questionnaire was designed with Google Forms consisted of 272 questions divided into 6 sections and grouped to meaningful groups: 1. Socio-demographic information (5 questions); 2. The digital readiness of educational institution to prepare specialist to work with smart working places (19 questions); 3. The digital readiness of educational institution to prepare digital competences of the future specialists (18 questions); 4. Respondents’ perceptions about digital readiness competences (35 questions); 5. Respondents’ perceptions about digital readiness to work with smart working places (185 questions); 6. Respondents’ opinion about the about implementation of the idea of the smart working places in transportation (maritime) sector (10 questions). The questionnaire is reliable: the Cronbach’s Alpha coefficients of second, fourth and fifth sections of the questionnaire were bigger than 0,7 (\(\alpha_{2\text{section}} = 0,914; \alpha_{4\text{section}} = 0,981; \alpha_{5\text{section}} = 0,753\)).

The questionnaire consisted of the open-ended questions, asking the respondents to write their opinion about particular aspects of the research and close ended questions providing 8-points Likert scale responses. Four sections of questions were allocated to the assessment of the digital readiness of the educational institution and the digital readiness of the respondents themselves. The fifth block of the questions was dedicated to understand the respondents’ expectations about implementation of the idea of the smart working places in transportation (maritime) sector. For this research purposes the questions of 4\text{th} and 5\text{th} blocks were used.

For the implementation of digital readiness assessment, the main matrix of question was constructed as it presented in Table 1. It is important to note, that for the developing of questionnaire two methodologies assessing the digital readiness, such as digital readiness indexes applied in the maritime sector for the assessment of seaports [11] and digital competences profiler applied in the training field of interests [12, 9] were combined. As the smart workplace conception analysis found out that the digital readiness depends on inside and outside conditions and competences, however, from the point of view of the study programs, it is important to distinguish the organizational digital readiness for the training of required competences and personal digital readiness as the result of the education and training. But to improve the preparedness of the future professionals for the working under the digital conditions and implement required changes into the study program, the digital competences of students were measured to find out and justify the suggestions for the improvement of education and training. Student digital competences are placed in the three sections 3-5 as it presented in the Table 1. Based on the concept of that the smartness in maritime industry organizations starts from the effective data operation, so the digital readiness assessment is allocated in the area of identification main attitudes, knowledge and skills.
required for the implementation of digitization process from the first stage of its evolution until to the full smartness level. All questions are placed in the groups of attitudes knowledge and skills for the estimating the fundamental background of digital readiness competences were placed in meaningful groups and divided in groups and subgroups. But also, as it found out in the theoretically description of smart workplace, the competences also could be divided into the four functional groups described as the skills required to manage the digital information flow, to communication, in some product creation, which is the digital representing content representing and the safety ensuring, including the personal and commercial data safety (Table 1).

Matrix of digital readiness index constructed on the base of questionnaire according to the 3D competence model [13, 14]  

<table>
<thead>
<tr>
<th>DRI</th>
<th>Self-Awareness</th>
<th>Cognitive</th>
<th>Hard</th>
<th>Soft</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>DRI11</td>
<td>DRI21</td>
<td>DRI31</td>
<td>DRI41</td>
<td>DRI51</td>
</tr>
<tr>
<td>Communication</td>
<td>DRI12</td>
<td>DRI22</td>
<td>DRI32</td>
<td>DRI42</td>
<td>DRI52</td>
</tr>
<tr>
<td>Production</td>
<td>DRI13</td>
<td>DRI23</td>
<td>DRI33</td>
<td>DRI43</td>
<td>DRI53</td>
</tr>
<tr>
<td>Safety</td>
<td>DRI14</td>
<td>DRI24</td>
<td>DRI34</td>
<td>DRI44</td>
<td>DRI54</td>
</tr>
</tbody>
</table>

Colors used for the DRI visualization

| DRI score | <1,99 | <3,11 | <4,23 | <5,36 | <6,45 | <7,6 |

For the interpreting the research results, the descriptive statistics analysis was also done and the average, mean, median, skewness, kurtosis and variance indicators were calculated for the identification of most probable values within the validity criteria. So, the digital readiness was calculated by applying this formula:

\[ DRI_{k} = \frac{\sum Y_{i}}{N} \]  

where \( N \) is the natural number used for decreasing score and usually it is used 100 as the respondent’s number is less than 100, 1000 as the respondent’s number is measured in thousands and etc.; \( Y_{i} = \sum x_{ik} \) is the summing score of all respondents \( j \) and of each question \( i \) in the category \( k \in \{ \text{attitudes, knowledge, hard, soft, digital skills}; \{ \text{information, communication, production, safety}\} \} \) under these conditions:

- \( x_{i} \in [1; 8], i = 1, \ldots 185, j = 1, \ldots, 87; \)
- \( Y_{i} = 2,61 \) is the minimal score of each question which is identifying the minimal usage of supposed in the question technology or operation, and it means the minimum of skills required for the preparedness working at smart workplace;
- \( Y_{i} = 6,96 \) is the maximal score of excellence of the digital readiness.

The construction of this matrix is based on the distribution of all questions into the categories identified by their acquiring to groups of attitudes, knowledge and skills but also divided into four operational groups. Then the calculated DRI by applying the formula (1) were placed into table as it is presented in Table 1. Also, the visualization technique was applied for the distribution of all DRI by its score into the well and low developed ranges of knowledge and competences by different color. For the applying the specialized visualization technique all assessed DRI scores in each category were placed into one set which was divided into equal intervals. All DRI were placed by their meanings into the intervals and the frequency of each terminal were calculated for the evaluation of the most probable DRI level identification in the set, but mostly the equal intervals were used for the coloring of matrix elements by the selecting different colours for the different DRI score. As it showed in the Table 1 the lowest value is not valid by the minimal DRI value description, also the second interval represents extremally low competence level, so they are both until the concept of digital readiness. Based on the research results, the most part of DRI’s are placed in the range between [4,23; 6,45] and all segments require to be developed under the new elements in study programs of LMA.

For the analysis of the qualitative data in the form of the responses to open questions, the content analysis, consisting of the following procedures: 1) identification of the main issues mentioned by the respondents while answering the particular question, 2) categorizing and grouping them by assigning the most popular key words according to the theoretical 3D competence model, 3) counting the numbers of particular mentions and summarizing the outcomes, 4) developing the network diagram was applied. Ethical considerations of the research were ensured by securing the anonymity of the respondents and informing them about the aims and process of the research by the consent form ensured the research ethics. In addition, the permission from the educational institution vice-rector academics was obtained before the survey.
4. Data and Outcomes

The respondent sample included 87 students of the Lithuanian Maritime Academy, 26.4% of them were female. The majority of them (88.5%) were full-time students, the others (11.5%) used part-time and session-based modes of studies; 81.6% were state-funded, the others (18.4%) paid for the studies themselves. The median of age of the respondents (21), and the median years of studies (2) indicate that the survey population was relatively young (41% were first-year students). This characteristic of the respondents is valuable for the purpose of the research because the young people can have non-biased ideas on the research questions. The survey sample represented all study programs delivered at LMA. This could be considered as an advantage of the sample for the purpose of the current research because the survey participants represent all specialties of LMA. However, the relatively small sample of the respondents could be considered as a limitation of the research, so the outcomes and the conclusions could not be generalized, but they can be used as useful insights for further investigations.

Based on the prepared methodology the digital readiness index (DRI) was calculated for the assessment of LMA students’ preparation for the working at smart workplace as it presented in the figure 3. The quantitative research results found out that the level of attitudes and knowledge is bigger than average and it means that students understand the changes which are happening in the maritime industry, but they are not digitally ready for these challenges and also have low level of hard and soft skills for the working at smart workplace and these results are related within the qualitative analysis results where respondent talking about the digital competences of programming and usage of new technologies are not enough for the be prepared to work at smart workplace.

The results presented in Fig. 4 could be interpreted in the context of the situation that introduction about the skills and knowledge will be required in the future maritime industry need to be more detailed in the study content, because the perception of future of maritime industry also are in the low-level range (Fig. 4). And the highest self-awareness score was fixed in the perception of importance of information management in the development of future transport systems and the score of two representing factors were higher than the average of group and it means that the LMA study programs possibly are oriented into the ensuring require attitudes, knowledge and training skills work at smart workplace.

It is important to note, that the attitudes and knowledge of LMA students are in quietly high ranges of scores, but the skills have lower assessment and it possible means the requirement to include more digitization technologies of maritime industry and daily life into the study programs for better achievement of usability of the newest innovations. Results of hard skills assessment found out that the students have quietly high-level computer literacy, but the usability of more software for bigger types of data exploring such as XML, CSV (relation within the data analysis as the tools at smart workplace) or PUB, MOBI (related to the digital books and personal digital readiness) are on the lowest levels. In the comparison within the respondents understanding the maritime industry preparedness for transformation based on the innovative technologies will be applied, as it presented in the figure 4, hard skills have higher score, because the high usability of smart workplace technologies and high interests to develop it in professional activities in maritime industry. These finding implicate the requirements to develop wider hard skills required to work more intensively within the data.

Table 2

<table>
<thead>
<tr>
<th>RDI</th>
<th>Self Awareness</th>
<th>Cognitive</th>
<th>Hard</th>
<th>Soft</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>5,75</td>
<td>5,697</td>
<td>4,771</td>
<td>5,187</td>
<td>5,03</td>
</tr>
<tr>
<td>Communication</td>
<td>5,353</td>
<td>5,567</td>
<td>4,272</td>
<td>4,305</td>
<td>2,717</td>
</tr>
<tr>
<td>Production</td>
<td>5,84</td>
<td>5,194</td>
<td>4,474</td>
<td>5,473</td>
<td>3,873</td>
</tr>
<tr>
<td>Safety</td>
<td>5,545</td>
<td>5,18</td>
<td>3,821</td>
<td>4,293</td>
<td>3,542</td>
</tr>
</tbody>
</table>

But the soft skills score (Fig. 4) is less than hard skills and results’ analysis found out that the soft skills are fully dependent on the tools and software using at LMA study process and it means that the academy makes strong influence on the digital readiness of students but by using this force LMA should train the wider range of skills by developing usability of different tools and soft dependent on the situations at maritime business situations. Also, the research results
found out the low level of digital skills which are the background to be prepared for the smart workplaces: the realizing the digital skills (Fig. 3) and the applications of digital skills in the professional activities (Fig. 4) are at the same low level. And these results could be seen in the Table 2, where the DRI matrix is presented. By the resuming of DRI matrix’s results, it could be noted that the LMA students have well developed self-awareness in the context of working at smart workplace and the connectiveness if these processes also are on the high level of development. The lowest readiness finally is fixed in the area of digital competence which are required in all fields of acting at smart workplace, but also under the problematic of increased cyber-security incidents students need to be readier for the ensuring safety of themselves and organization at smart workplace.

5. Conclusions

Based on the research results and their presentation in the matrix, the following tendencies at LMA and students’ digital readiness for working at smart workplace were identified:

- Fairly high self-awareness in the field of digital readiness and knowledge about the digitalization, especially more intensively expressed in the range of students within better acceptance score, but low attitudes of digitization of maritime industry increases the need to target practical educational tasks to new tendencies in maritime industry and apply more digital innovations in practical training; mentioned actions could influence the development of the soft skills which are dependent on the communicational level and hard skills which are dependent on the technological implementational level.

- Low level of hard skills especially in the usability of different software to explore the bigger types of data or software to use digitized objects (such as the digital books); personal digital readiness is on the lowest levels in the context of high level of hard skills in the field of maritime industry. That implicates the demand to develop wider hard skills required to work more intensively within the data in the study process at LMA.

- The biggest improvement should be focused on the digital skills training oriented to maritime industry in the fields of communication, production and safety together within the digital skills development and the wider range of possibilities to integrate them in the smart maritime business should presented because the DRI for preparedness to work smartly at maritime sectors is low.

References


Development of Recommendations for Bypass of Storm Areas Based on North Atlantic Wind Repeatability Analysis

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Abstract

The work carried out an analysis of the repeatability of storm wind in the North Atlantic. On its basis, recommendations were developed on ways to bypass unfavorable areas for characteristic months of the seasons with deteriorated hydrometeorological conditions. A comparative characterization of the cost-effectiveness of voyages of the main and of the recommended routes was carried out.

KEY WORDS: analysis, repeatability, North Atlantic, bypass, storm wind, cost-effectiveness

1. Introduction

Most emergency situational seas are usually associated with dangerous hydrometeorological phenomena, in particular, with storm winds. According to the Lloyd Register for the period from 2001 to 2004. 155, 144, 144 and 142 vessels died, respectively. The main cause of death was external factors leading to a violation of the waterproofness of the hull, most often in a storm - 47.7%, 47.4%, 52.2%, 41.3% of the total for the year, respectively. For comparison, the percentage of vessels killed during these years while taking the ground ranged from 11.79 to 18.1%, in fires and explosions - from 12.5 to 20.8%, in collisions - from 10.8 to 15.3% [1]. According to the data given in article [2], for the period from 2006 to 2015. the number of dead vessels is 1231 vessels, among which 614 are deaths due to flooding (49.8%). These figures strongly indicate that the study of hydrometeorological navigation conditions (including the repeatability of storm winds) in different regions of the World Ocean is one of the important and relevant areas in improving navigation safety and reducing accidents.

2. Presentation of Studying Materials

Storm wind repeatability analysis was performed according to data [3]. From it follows:

a) in the annual course of the repeatability of storm winds in the North Atlantic, the January maximum is allocated, when there is a wind of 33 m/s or more, and the July minimum;

b) the frequency of the storm wind increases towards high latitudes;

c) below 25°N in winter and 35°N in summer, the frequency of the storm wind is 1% or less;

d) in winter months, the frequency of storm winds in the western part of the ocean is higher than in the eastern;

e) in the North Atlantic, several areas can be distinguished with maximum repeatability of storm winds, the main one is oriented from north to south from the island of Greenland, and the other is noted from October to April approximately between 35-40°N south of the peninsula of Nova Scotia and the island of Newfoundland.

That is, the weather conditions are the most favorable for navigation in July and the most dangerous in January. But vessels carry out cargo transportation throughout the year. In order to ensure the navigation safety, recommended ways of bypassing the most dangerous storm areas for the autumn, winter and spring seasons are further proposed. The baseline data of the main trade routes are taken from [4], as shown in Fig. 1. Wind repeatability at a speed of 17 m/s and 25 m/s or more was taken as a criterion for bypassing hazardous areas. For November, such routes were proposed where the wind is 25 m/s and more is no longer observed, and the wind repeatability is 17 m/s and more - less than 10%. In January, it is proposed to bypass the storm areas so that the repeatability of the wind is 25 m/s and more no longer exceeds 5%, and the wind is 17 m/s or more - 15%. In March, the frequency of storm winds decreases significantly, so the recommended routes differ slightly from the main ones. For the summer months, it is not proposed to deviate from the main routes, since the repeatability of storm winds is almost absent.

The main route from the eastern merchant coast of America to the English Channel is conventionally indicated by points "N" and "E," the route from the Strait of St. Lawrence to Gibraltar by points "M" and "G," respectively, the port of Casablanca by the letter "C" (Fig. 1). According to the above routes, schemes for bypassing storm areas in the
North Atlantic for November, January and March months are proposed.

For November, the recommended bypass routes are shown in Fig. 2 and their route points are listed in Table 1.

For January, the recommended bypass routes are shown in Fig. 3 and their route points are listed in Table 2. As can be seen from the figure, the bypass routes differ significantly from the main ones, that is explained by the increase in the territory of the repeatability of storm wind in the North Atlantic.
Fig. 3 Recommended ocean routes to bypass storm areas in the North Atlantic in January

Table 2

<table>
<thead>
<tr>
<th>Point Number</th>
<th>N (New York) - E (English Channel)</th>
<th>M (Montreal) - G (Gibraltar)</th>
<th>M (Montreal) - E (English Channel)</th>
<th>M (Montreal) - C (Casablanca)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northern Latitude</td>
<td>Western Longitude</td>
<td>Northern Latitude</td>
<td>Western Longitude</td>
</tr>
<tr>
<td>1</td>
<td>40° 39'</td>
<td>074° 03'</td>
<td>48° 20'</td>
<td>069° 16'</td>
</tr>
<tr>
<td>2</td>
<td>40° 25'</td>
<td>073° 46'</td>
<td>49° 08'</td>
<td>067° 24'</td>
</tr>
<tr>
<td>3</td>
<td>40° 30'</td>
<td>068° 42'</td>
<td>49° 27'</td>
<td>065° 47'</td>
</tr>
<tr>
<td>4</td>
<td>45° 00'</td>
<td>055° 00'</td>
<td>49° 20'</td>
<td>064° 13'</td>
</tr>
<tr>
<td>5</td>
<td>40° 00'</td>
<td>050° 00'</td>
<td>48° 03'</td>
<td>060° 55'</td>
</tr>
<tr>
<td>6</td>
<td>40° 00'</td>
<td>030° 00'</td>
<td>45° 00'</td>
<td>055° 00'</td>
</tr>
<tr>
<td>7</td>
<td>45° 00'</td>
<td>015° 00'</td>
<td>40° 00'</td>
<td>050° 00'</td>
</tr>
<tr>
<td>8</td>
<td>49° 11'</td>
<td>006° 39'</td>
<td>40° 00'</td>
<td>030° 00'</td>
</tr>
<tr>
<td>9</td>
<td>—</td>
<td>—</td>
<td>39° 21'</td>
<td>023° 55'</td>
</tr>
<tr>
<td>10</td>
<td>—</td>
<td>—</td>
<td>38° 29'</td>
<td>017° 54'</td>
</tr>
<tr>
<td>11</td>
<td>—</td>
<td>—</td>
<td>37° 18'</td>
<td>012° 04'</td>
</tr>
<tr>
<td>12</td>
<td>—</td>
<td>—</td>
<td>35° 57'</td>
<td>006° 26'</td>
</tr>
</tbody>
</table>

For March, the recommended bypass routes are shown in Fig. 4 and their route points are listed in Table 3. As can be seen from the figure, the bypass routes are already more reminiscent of the trajectories of the main ones, which is connected with a decrease in the territory of the repeatability of the storm wind in the North Atlantic.

Fig. 4 Recommended ocean routes to bypass storm areas in the North Atlantic in March

As a result of the calculations of the repeatability of storm winds in the North Atlantic, recommendations have been developed for bypassing likely storm areas with the following characteristics for each of the months of the season, except summer.

For November, the route changes are:
1) for route N-E, it is proposed to follow east to point J, where there is a change in course to the northeast with
an intermediate point K, after which the route leads to the western approach to the English Channel;
2) for route M-G, it is proposed at point H to continue to the southeast, instead of the northeast, and only at
point I to change the course east to point J, after which to continue to the western approach of Gibraltar;
3) for the route M-E and M-C, similar recommendations for changing the following a route are offered, as was
completed for the routes N-E and M-E.

Route points of recommended storm squares bypass routes in the North Atlantic in March

<table>
<thead>
<tr>
<th>Point Number</th>
<th>N (New York) - E (English Channel)</th>
<th>M (Montreal) - G (Gibraltar)</th>
<th>M (Montreal) - E (English Channel)</th>
<th>M (Montreal) - C (Casablanca)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Northern Latitude</td>
<td>Western Longitude</td>
<td>Northern Latitude</td>
<td>Western Longitude</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>1</td>
<td>40° 39’</td>
<td>074° 03’</td>
<td>48° 20’</td>
<td>069° 16’</td>
</tr>
<tr>
<td>2</td>
<td>40° 25’</td>
<td>073° 46’</td>
<td>49° 08’</td>
<td>067° 24’</td>
</tr>
<tr>
<td>3</td>
<td>40° 30’</td>
<td>068° 42’</td>
<td>49° 27’</td>
<td>065° 47’</td>
</tr>
<tr>
<td>4</td>
<td>40° 02’</td>
<td>055° 00’</td>
<td>49° 20’</td>
<td>064° 13’</td>
</tr>
<tr>
<td>5</td>
<td>40° 00’</td>
<td>050° 00’</td>
<td>48° 03’</td>
<td>060° 55’</td>
</tr>
<tr>
<td>6</td>
<td>40° 00’</td>
<td>030° 00’</td>
<td>43° 20’</td>
<td>054° 55’</td>
</tr>
<tr>
<td>7</td>
<td>49° 11’</td>
<td>015° 00’</td>
<td>40° 00’</td>
<td>045° 00’</td>
</tr>
<tr>
<td>8</td>
<td>—</td>
<td>—</td>
<td>40° 00’</td>
<td>035° 00’</td>
</tr>
<tr>
<td>9</td>
<td>—</td>
<td>—</td>
<td>39° 52’</td>
<td>030° 32’</td>
</tr>
<tr>
<td>10</td>
<td>—</td>
<td>—</td>
<td>37° 51’</td>
<td>017° 15’</td>
</tr>
<tr>
<td>11</td>
<td>—</td>
<td>—</td>
<td>35° 57’</td>
<td>006° 26’</td>
</tr>
</tbody>
</table>

For January, the route changes are:
1) for route N-E at point A, it is proposed to take a course to the northeast in order to pass the local maximum
formed south of Newfoundland, then at point B, on the contrary, turn southeast to point D. In the future, it is
recommended to go the eastern course and only at point F turn to the northeast again and follow the western approach to
the English Channel;
2) For routes M-G, M-E, and M-C, similar recommendations are offered for changing the following a route, as was
completed for route N-E.
For March, the route changes are:
1) for route N-E, it is recommended to follow the eastern course to point J, after which turn to the northeast and
follow the western approach to the English Channel;
2) for route M-G at point H, it is recommended to continue to the southeast, instead of the northeast, and only at
point I to turn east to point J. After point J, change course again to the southeast and follow the western approach to
Gibraltar;
3) For M-E and M-C routes, similar recommendations are offered for changing the following a route, as was
completed for N-E and M-G routes.

3. Conclusions
The issue of economical cost-effectiveness was considered when comparing the main and one of the
recommended ones for the vessel "CSCLLongBeach," a deadweight of 107372.5 tons, which followed from the port of
Felixtow (Great Britain) to the port of New York (USA) in November. Calculations showed that the distance traveled
by the vessel along the recommended route increased by 210 miles, and the difference in voyage profitability was less
than 3%. At the same time, it should be considered that even with saving costs on the main route, the risk of observing
wind of increased strength increases several times. This version of the voyage may be considered appropriate when
navigation in spring and summer, when the repeatability of storm winds is insignificant or absent at all. From the safety
parameters of navigation, the use of recommended routes reduces the risk of loss or damage of cargo, vessel, its
structures and generally improves the safety crew and/or passengers life. The difference in costs and running time is
insignificant, but the safety of the vessel, its crew and cargo is increased.

References
1. Луковский, В. 2009. Определение ветро-волновых потерь скорости судов смешанного плавания с
Вып. 27. — с. 159-168.
Mobile Road Condition Measurement as Support of RWIS in Urban Areas

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Abstract

The paper presents the problem of Urban Road Weather Information System quality support. The study was performed on the road traffic network of Bielsko-Biala city. The authors proposed mobile surface condition measurement inclusion into a standard urban road maintenance system. The research range included main arterial roads connecting residential areas to the centre of a city. Test runs were carried out in various ambient conditions over the course of one month. The study provides analysis regarding the variability of meteorological road conditions based on surface temperature fluctuations. In the course of the study, the authors noticed a significant impact of road infrastructure. Also, traffic control and local ambient microclimate seem to be relevant. Moreover, mobile weather sensor provides complex data concerning road meteorological characteristic in an urban area that might support the precise determination of road weather stations location.

KEYWORDS: RWIS, Road Weather Information System, mobile measurement, road conditions

1. Introduction

Road Weather Information Systems (RWIS) are an essential element of Intelligent Transport Systems, especially in the context of traffic safety. RWIS is mainly based on stationary automatic weather stations called Environmental Sensor Stations (ESS), which measure, among others, real-time atmospheric parameters, pavement conditions, water level conditions, and visibility. These data, along with weather forecasting models, are used to predict the condition and temperature of the pavement. In the winter time, the data from the ESS can be the input to decision support systems, which results in effective and timely road snow removal, which also translates into the durability of the pavement [1, 2]. The use of variable message signs continuously inform drivers about bad weather conditions and improve traffic management (particularly speed control). RWIS are gaining the popularity in many countries and develop rapidly covering the entire network of motorways and national roads [3, 4].

Due to the different specificity of the urban road network, RWIS systems face different challenges. Compared to the national network, the urban road system is characterized by a much higher density, an accumulation of engineering structures such as viaducts, bridges, tunnels, the presence of numerous intersections and a very large diversity of traffic intensity. Due to those factors the road conditions on nearby street sections may be diametrically different. Therefore, the network of stationary ESS may not be sufficient. In [5] a concept for a road surface conditions information system in the area of a selected city was proposed. The basis of the proposed system are mobile surface condition sensors, which could be mounted e.g. on public transport vehicles and continuously collect data regarding road surface condition. This paper presents the results of a road study to confirm the suitability of mobile sensors for the construction of a meteorological shielding system for an urban road network.

2. MARWIS Sensor – Characteristics (Measurement Apparatus and Test Runs)

Currently, mobile road surface condition sensors are offered by several companies [6-8]. They are typically mounted on the vehicle and assess the condition of the road surface in real-time. They generally classify the roadway surface into one of the following classes: dry, damp, wet, ice, snow/ice covered, chemically wet, slush, snow covered. In addition, they allow the reading of surface temperature, dew point temperature, relative humidity above the road surface and water film height. The research discussed in this paper was carried out using the MARWIS sensor manufactured by Lufft. It is worth emphasising that the papers [9,10] present a description of the parameters measured by the sensor, mounting on the test vehicle and test results indicating good repeatability of temperature measurements both in static conditions (stationary vehicle) and while driving.

The test drives that are the basis of this article were carried out in the city of Bielsko-Biała in March 2021. Bielsko-Biała has approximately 170,000 inhabitants. It is located in the south of Poland at the foot of the Beskid Mountains. Passing through the city are, among others, express roads S1 and S2 (being a fragment of E75 and E462), national roads No. 1 and 52 and provincial roads No. 940 and 942. Bielsko-Biała has a Western Bypass, while the North-Eastern Bypass is a part of the S1 road.

The test runs were carried out over 5 days. To avoid the influence of fluctuations in meteorological parameters caused by sunlight and the shading of individual carriageway sections, the measurements were performed in the evening. In all cases the air temperature fluctuated around 0°C. Detailed weather data for specific measurement days are presented in Table 1.
Table 1

Weather conditions observed during test days

<table>
<thead>
<tr>
<th>Test day</th>
<th>Air temperature</th>
<th>General conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>05.03</td>
<td>-1°C</td>
<td>sleety rain</td>
</tr>
<tr>
<td>06.03</td>
<td>-3°C</td>
<td>clear sky</td>
</tr>
<tr>
<td>08.03</td>
<td>-2°C</td>
<td>light snowfall</td>
</tr>
<tr>
<td>19.03</td>
<td>0°C</td>
<td>cloudy</td>
</tr>
<tr>
<td>21.03</td>
<td>-3°C</td>
<td>snow</td>
</tr>
</tbody>
</table>

The test route is presented in Fig. 1. It covers both a significant part of the Western Bypass, the main roads located in the strict city center and less traveled road sections. Test route was divided by sections (A - I). Sections A - D surrounds the center of the city. Section E is the main road leading through the city center in the direction of North-South. Sections F - I handle the traffic in the city center towards East-West direction. Table 2 presents the basic characteristics of each part of the route.

![Survey route with marked sections](image)

Table 2

Characteristics of individual measuring sections

<table>
<thead>
<tr>
<th>Section</th>
<th>Section length [km]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.86</td>
<td>part of the Western Bypass; a dual carriageway with two lanes in each direction separated by a green belt</td>
</tr>
<tr>
<td>B</td>
<td>3.06</td>
<td>part of the Western Bypass; a dual carriageway with two lanes in each direction separated by a green belt</td>
</tr>
<tr>
<td>C</td>
<td>5.33</td>
<td>single carriageway road with one lane in each direction, leading through residential and commercial areas</td>
</tr>
<tr>
<td>D</td>
<td>4.06</td>
<td>provincial road 940, single carriageway with two lanes in each direction</td>
</tr>
<tr>
<td>E</td>
<td>4.39</td>
<td>a single carriageway with two lanes in each direction, leading through the historical center of the city, which is an extension of the DK1 national road</td>
</tr>
<tr>
<td>F</td>
<td>2.25</td>
<td>carriageway with one traffic lane in each direction</td>
</tr>
<tr>
<td>G</td>
<td>2.86</td>
<td>in the initial run, a carriageway with alternating two lanes in one direction and one in the other direction, in the middle section one-way single carriageway running through the old town, and then a single carriageway with one lane in each direction</td>
</tr>
<tr>
<td>H</td>
<td>2.24</td>
<td>single carriageway with one lane in each direction</td>
</tr>
<tr>
<td>I</td>
<td>1.29</td>
<td>single carriageway with one lane in each direction</td>
</tr>
</tbody>
</table>
3. Measurement Results

The device app software dedicated to the MARWIS sensor allows to view the measured parameters in real-time, display them on the map showing the course of the journey and save the data to a database. An exemplary map indicating the condition of the carriageway for the test run performed on 19.03.2021 is presented in Fig. 2.

In the database, measurements from the MARWIS sensor are supplemented with GPS coordinates taken from the device on which the software is installed. This makes it possible to analyse the acquired data as a function of the road distance.

![Fig. 2 Map presenting roadway condition on test sections](image)

Due to the limitation related to the volume of the article further research focused on the analysis of surface temperatures for the measurement sections defined in Table 2. In the first step of the analyses, the authors ranked the test sections in terms of the global variability of the studied parameter. For this purpose, the standard deviation $sd$ averaged over all days from the mean temperature of the entire measurement route was determined for the considered sections. The results are presented in Table 3.

<table>
<thead>
<tr>
<th>Section</th>
<th>B</th>
<th>G</th>
<th>A</th>
<th>C</th>
<th>I</th>
<th>H</th>
<th>F</th>
<th>E</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$sd$</td>
<td>1.17</td>
<td>0.80</td>
<td>0.61</td>
<td>0.59</td>
<td>0.58</td>
<td>0.58</td>
<td>0.56</td>
<td>0.52</td>
<td>0.49</td>
</tr>
</tbody>
</table>

In a further step, comparative analyses of temperature plots as a function of road distance were carried out. In this paper, the authors present only the most relevant observation results.

### 3.1 Sections B and G – the Impact of Infrastructure

As shown in Table 3, sections B and G were characterized by the highest global variability of pavement temperature. Analyzing section B (Fig. 3), a large local temperature increase can be noticed at a road distance of about 1.8 km - 2.4 km and a peak at a distance of 2.8 km. The location corresponding to the temperature increase in the vicinity of 2 km was identified as a series of two tunnels running under the largest road intersection in Bielsko-Biała. Another local peak (about 2.8 km) corresponds to the location of the railway viaduct leading over the analysed section.

On the other hand, peaks at 0.8 km, 1 km, 1.3 km and 2.3 km of the road distance are noticeable in section G (Fig. 4). After careful analysis, it was determined that the increases in surface temperature are closely related to local building conditions. High-rise buildings close to the road provide shelter from the wind, while the narrow lane with its characteristic old town wrenching course prevents the formation of well-ventilated street canyons.
In the following analyses, authors decided to analyse the readings from the mobile sensor for sections A and C, being the two consecutive sections characterised by the highest standard deviation (Table 3). Graphs showing the deviation of the measurements from the mean value as a function of the road distance were created to highlight the local variability of the surface temperature and the repeatability of the readings. The repeating peaks in surface temperature (Fig. 5) around 0.4 km, 0.7 km and 1.2 km of the route correspond to the locations of traffic lights, more precisely, to the places where vehicles wait for the green signal. It is worth noting that the change in temperature at these locations was recorded irrespective of whether the test vehicle stopped in front of the signal or smoothly traversed the intersection. The last peak (around 1.5 km of the road) is located in a place sheltered by trees where the roadway is exposed to the south.
Section C (Fig. 6), which is also the longest test section in the entire study, has a varied character. Its initial route leads through the city's periphery – a residential zone with relatively little traffic and an industrial zone. Further on, it is a popular link between two main roads North-South – the provincial road 940 and the extension of the national road DK 1. Analysing the fluctuation of the surface temperature, a sharp variation in its initial course can be observed. This is caused by cyclical surface changes corresponding to the location of the paved island speed bump calming the traffic. The significant increase in the 3 km road distance coincides with the location of a shopping centre which is a significant traffic generator, followed by a major intersection with traffic lights. Rises in the vicinity of 4 km route corresponds to the locations of two consecutive roundabout and the peak at the end of the test section is a crossroad with traffic lights connecting the described route with provincial road 940.

![Fig. 6 Surface temperature as a deviation from mean value – section C](image)

4. Conclusions

The analysis of surface temperature as a function of road distance on the urban road network reveals a significant influence of infrastructure in the form of engineering structures and local buildings. The proximity of dense forest formations shielding the road from the influence of adverse weather conditions is also not without significance. In the analysis, an attempt was made to eliminate the influence of insolation by choosing night hours for the measurements. Cyclical fluctuations in readings caused by local surface changes in the form of paved island speed bumps were noted. A significant relationship between temperature peaks and the location of intersections on the road network was also visible. It was observed both in the vicinity of roundabouts and intersections with traffic lights, where the relationship was particularly strong. It is worth noting that this trend appeared regardless of whether the test vehicle was waiting for a green signal or passing smoothly through the road intersection. This indicates local surface heating before intersections but is not caused by the reading interfering with heat generated by the vehicle.

Performed measurements of meteorological road conditions in the area of Bielsko-Biala’s road network confirm the usefulness of the MARWIS mobile road conditions sensor to support urban RWIS. The results of the study allow the following statements to be made:

- infrastructure elements such as tunnels or viaducts, as well as high buildings, cause local surface temperature fluctuations with significant amplitudes;
- the influence of local surface changes was observed in the form of moderate pavement temperature fluctuations;
- the significant impact on the surface temperature caused by vehicles waiting for the green signal at intersections can be seen;
- sections with varied surroundings, e.g. running partly along forest formations located close to the roadway, are characterised by major pavement temperature variations.

The measurement results presented in this paper indicate a good resolution of the obtained data. This testifies to the fact that the increase in road temperature in the area of intersections is registered regardless of test vehicle speed. It can be seen that mobile measurements using the MARWIS sensor allow to define local changes of the pavement temperature caused by particular elements of the infrastructure and the roadway environment. Such data are very helpful for municipal road maintenance services. It is worth noting that on roads with two or more lanes in one direction road conditions can vary greatly [11]. Measurements with a mobile sensor give the opportunity to drive in a lane where, according to the person carrying out the tests, conditions are worse at a given moment.

Knowledge of the specific impact of the local environment on road conditions obtained through mobile measurement methods can be a key factor in supporting the decision-making process regarding the location of urban meteorological protection shield and winter road maintenance.
References


Effect of Improving Railway Crossings Technology on the Occurrence of Traffic Accidents in the Slovak Republic

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Abstract

This paper aimed at the railway crossings safety in the Slovak Republic and the impact of improving interlocking technology used on the prevention or mitigation of the consequences in road and rail vehicle accidents. The first part focuses on the need for cooperation between all relevant stakeholders in the field of transport safety to successfully face a constant increase in the traffic performance volume and therefore possible vehicle clashes on the railway crossings. Furthermore, technical and legislative point of view is analyzed as well as the correlation between traffic accidents and the technology used on railway crossings in the Slovak Republic. The last part is the practical example provided to justify the positive impact of technological improvement of the interlocking safety equipment of the railway crossing in terms of socio-economic benefits and number of accidents occurred.

KEY WORDS: rail transport, transport safety, railway crossing interlocking, traffic collisions

1. Introduction

The link and correlation between economics and transport are generally known. These two sets of processes are mutually determining each other and influence their basic characteristics. In terms of economics and transport, there is a relevant need for capacity-adequate and safe infrastructure that provides good conditions for growing investment, sustainable global economic growth and also stimulates the mobility of the inhabitants within the European Union (EU). High-quality transport infrastructure is also essential for the emergence of induced transport. It is also important to point out that both freight and passenger transport are an inherent part of economic processes, i.e. production, distribution of materials, goods, and also citizens. To max out the potential of economic growth is important to create a sustainable, safe, and capacitive transport system. Business nowadays is made worldwide with the differently localized origin and demand places which naturally leads to an effort to optimize the costs of goods and materials distribution, and moving people. Therefore there is a legit requirement for high-quality, high-capacity, and safe transport systems. As economic crisis came to the end the world transport is experiencing a constantly growing trend within the European Union, which brings rising living standards for citizens and good economic conditions of inhabitants and companies. This phenomenon also has a negative aspect, namely the production of higher emissions from vehicles. In light of the above, there is a significant rise in demand for transportation services and their qualitative and quantitative characteristics. To confirm an increase in traffic volume we use statistics from Eurostat from 2010 to 2019, which show 1,67% [1] rise in the number of passenger cars per 1 000 inhabitants within the EU. This leads to an increasing intensity of vehicles on the roads and therefore a higher volume of transport performance in road transport. The volume of train kilometers in rail transport has also increased (by almost 27,5% [2] over the same period. The need for cooperation of all relevant stakeholders (legislators, safety and licensing organizations, authorities, transport vehicle manufacturers, builders and infrastructure managers, transport operators, training and education organizations) is rooted in the phenomenon of rising performance in both passenger and freight transport, which will bring the issues about how to secure smooth, safe and environmentally friendly transport. The security issue is among all problems associated with a modern, high-capacity and high-quality infrastructure, one of the most important. It is the number one priority for all relevant partners to provide sufficient and safe conditions to meet the needs of population and goods mobility. Every mode of transport represents a separate closed system, which does not influence the operational and safety characteristics of other transport systems unless the possible collision point occurs. It can be defined, for this paper, as the level crossing of road and rail communication or the overpass crossing of water and rail or road communication. The overpass crossing of water and rail or road communication can be collision dependent on the particular technical solution and the characteristics of local conditions of the intersection. Usually, these objects are designed to avoid a possible collision. The overpass crossing of road and rail traffic is collision-free (depend on the design) unless an incident occurs on any of the communications (traffic accident, cargo release, leakage, etc.). In general, there is the highest rate of traffic accidents occur on the level crossings at road and rail communication crossing. To prevent or mitigate the consequences of these adverse events, the level crossings are secured with interlocking devices. The type of technology used depends on several factors, as follows: local traffic, urban, and other specific conditions at the intersection.
point and the level of importance of crossed communications. The area of transport safety is the main object not only for designers, operators, builders, and managers of the infrastructure, but also for governments, police forces, state institutions, and transport authorities. Another factor for safety is the consideration of the potential charging point for electric vehicles. A presumption of danger is created here due to a misunderstanding of the charging point. Transport safety is one of the top topics within the EU. Evidence to that statement lays not only in the statistics of decreasing amounts of fatal accidents but also in the fact that it is given due consideration to the field of transport safety in all relevant EU strategy papers focused on the theme of transport. One of good example is the strategic document called White Paper - A Roadmap to a Single European Transport Area [3]. This document states: “To meet the measurable indicators, individual member states should take effective measures that the effectiveness and positive impact of which is subsequently assessed”.

2. Analysis of the Accidents and their Consequences on Railway Crossings in Slovak Republic

Competencies and responsibilities for securing railway crossings belong to the administrators of rail and road infrastructure of intersected roads. In the Slovak Republic, the railway infrastructure is managed by Slovak Railways (Železnice Slovenskej republiky, further as ŽSR); in road transport, depending on the category of road, the Slovak Road Administration (Slovenská správa ciest), the Regional Road Administration, or towns and municipalities. Railway crossings fall under the management of ŽSR, which operates 3,629 km of tracks and 2,082 railway crossings [4] (as of 2019), i.e., approximately 1 crossing to 1.7 km of the railway line. The method and the type of security device used at the intersection of road and rail depend on: the type of railway line, the type of road, vision conditions and local conditions. Requirements for minimum level crossing safety are stipulated in the ŽSR regulation: “ŽSR Z.12 Crossings and Crossovers” [6]. Based on the number of crossed rails, the road communication group and the line speed, there exists the recommended safeguarding of existing or reconstructed crossings. Basic categorization of railway crossing facilities in the Slovak Republic divided into active, i.e., equipped with a crossover device, and passively, i.e. marked with traffic signs only, is shown in Table 1. Numbers of individual types of interlocking security plants are determined by historical, legislative and technical factors specific to the Slovak Republic. According to the type of traffic accident on the railway crossing (from the view of road traffic), it is possible to define 10 categories, namely: collision with a running non-train vehicle, collision with a parked/stopped vehicle, collision with a fixed obstacle, collision with a pedestrian, collision with a domestic animal, collision with a wildlife animal, collision with a domestic animal, collision with the train, collision with a tram, accident, another type of accident. The Table 2 compares the number of crossings accidents by category of the level of rail crossing security category, resulting in fatal and severe accidents in 2017 and 2018 (train collision accidents with road vehicle, pedestrian or cyclist).

It is clear from the Slovak Police Force's statistics on accidents at rail crossings that in 2017, the proportion of accidents resulting in fatal and severe accidents in 2017 and 2018 (train collision accidents with road vehicle, pedestrian or cyclist). It is clear from the Slovak Police Force's statistics on accidents at rail crossings that in 2017, the proportion of accidents (in categories: train collision with a road vehicle, train collision with a pedestrian or train collision with a cyclist) was approximately 12% at the active and 49% at the passive interlocked crossings from all registered accidents.

It is clear from the presented data that there was only a small year-on-year change in the total number of accidents on railway crossings, the most significant number of accidents occurring on light crossing facilities without ramps, but this phenomenon is also influenced by the total number of light signaling devices on ŽSR lines, of which these are absolute majority (see Table 1). An important factor is also the intensity of road transport on the intersected roads and the extent of transport performance in rail transport on individual lines equipped with this kind of road safety equipment. Modernization of a crossing interlocking system can have a positive impact on the occurrence of traffic accidents related to a train (tram) collision with a road vehicle, pedestrian or cyclist; other categories of traffic accidents are not affected by the replacement of the interlocking equipment - a higher level of crossing safety does not create a presumption of a lower incidence of traffic accidents in these categories. In this context, it is not possible to generalize the number of accidents on active and passive crossings, as based on the normative and real operating ratios that make a significant difference in the extent of traffic performed on highway intersections with higher category railways (with higher line speed and more tracks).

<table>
<thead>
<tr>
<th>Interlocking type</th>
<th>Year 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2082</td>
</tr>
<tr>
<td>Passive crossing (not secured)</td>
<td>1007</td>
</tr>
<tr>
<td>Active crossing (secured)</td>
<td>1075</td>
</tr>
<tr>
<td>Out of:</td>
<td></td>
</tr>
<tr>
<td>Mechanical ramps</td>
<td>48</td>
</tr>
<tr>
<td>Permanently locked rail crossings</td>
<td>38</td>
</tr>
<tr>
<td>Mechanical crossing device</td>
<td>1</td>
</tr>
<tr>
<td>Light crossing interlocking plants</td>
<td>988</td>
</tr>
</tbody>
</table>
Table 2
Number of accidents and deaths on railway crossings in Slovak Republic [6]

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of accidents at crossings</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Out of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PZS - Z</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>PZS</td>
<td>28</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>PZM</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Accidents resulting in injuries</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Death injuries</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Out of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>PZS</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>PZS - S</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>PZM</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Severe injuries</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Out of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>PZS</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>PZS - Z</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>PZM</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Legend: PZS – Z – crossing with traffic lights and ramps; PZS – crossing with traffic lights without ramps; PZM – mechanically equipped crossing; K – passive (unsecured) crossing

Statistical data show that there was a significant increase in fatal injuries in 2018, especially on crossings with traffic lights with no ramps, which, according to legislation, should be applied at road crossing points or lower-class railway lines, where there is no assumption of a large volume of realized transport performance. The influencing factor may be the absence of barriers, the failure to observe the warning signal but also the psychological factor of drivers who know the extent of rail transport and therefore do not pay increased attention when crossing the railway tracks. The year-on-year comparison of accident rate data from the database of Police Force of the Slovak Republic shows rearrangements within individual categories of traffic accidents, but the long-term trend of accidents on crossings and its severe consequences in Slovakia is decreasing. This phenomenon is caused by the society-wide emphasis on increasing road traffic safety, modernization of railway crossings interlocking equipment or off-road solutions at modernized and exposed infrastructure sites.

3. Solution for Interlocking Security Plants of Railway Crossings in the Slovak Republic

Tools for increasing safety at rail crossings can be either direct, with effect at the point where they are applied, or indirect, having legal, educational but also a technical or operational character with local or areal coverage.

Direct tools: building and upgrading railway crossings using a higher level of security, extending / upgrading road signs, road surface improvement in front of and behind rail crossings, etc.

Indirect tools: legislation on the construction and modernization of railways (rail crossings), rules on road marking, sanctions for non-respect of signaling and traffic signs, training of road users, compulsory training of professional drivers and train drivers, setting of maximum speed when the train passes the crossing, modernizing railway vehicles, etc.

As an EU Member State, the Slovak Republic has declared its participation in the construction (upgrading) of the significant communications defined in the Transeuropean Network - Transport (TEN - T), which outlines the main transport network within the common internal market through 9 corridors across Europe. TEN - T is divided into a Comprehensive Network and a Core Network, which is a subset of the comprehensive network and is made up of the most important transport routes. EU members are obliged to modernize their core network by 2030 and a comprehensive network by 2050. 3 TEN-T corridors are passing through the SR, namely: Baltic - Adriatic, Orient / East - Med, and Rhine – Danube [12]. To modernize and construct road communications, the EU has identified funding in the Structural Funds and other instruments (e.g., CEF - Connecting Europe Facility), which can be used by individual states through operational programs and transport infrastructure modernization projects included therein. The aim of the TEN - T network is not only to define the most critical communications across the EU but also to ensure the interoperability of individual transport systems (especially in rail transport), which are different for individual nations because of different historical background. For this reason, the European Railway Agency has developed so-called Technical specifications for interoperability (TSIs) issued by the European Commission and published in the Official Journal of the European Union. The individual TSIs apply to specific subsystems or sub-subsystems with the primary objective of meeting the essential requirements.
and technical parameters for transport infrastructure and thus ensuring the coherence and interoperability of the internal transport network. The TSIs also specify the technical parameters and minimum safety requirements that the upgraded infrastructure must meet. In the Slovak Republic, in the area of modernization of railway infrastructure, legislation at the national level is stricter than the TSIs and is defined by Act no. 513/2009 Coll. on Railroads, that: "The crossing of new main railway lines with roads is being established as a fly-over one. When upgrading or significantly restoring existing main railway lines or intersecting roadways, the builder will rebuild the existing level crossing or cancel it. "All modernized main lines are, therefore, by national legislation, equipped with an fly-over crossings of road and rail infrastructure, which results in the complete elimination of traffic accidents that could arise in connection with the crossing of roads. The safety-related problem at rail crossings is thus automatically eliminated for a set of upgraded TEN-T lines. As national and European funds are limited, their allocation must be subject to some priority. This means in practice that the infrastructure modernization plan and its actual implementation take place in specific logical steps, taking into account the significant defined modernization projects and the building of integrated sections, where the synergetic effects of modernization occur, possibly on the most exposed parts of the transport infrastructure. The process of modernization of railway lines therefore takes into account the volume of available funds, the importance of railway lines and intersected roads, EU requirements for interoperability and building of TEN-T network, strategic documents in the development of the transport system of the SR and also the technical readiness of individual projects. For some lines (regional, with minor traffic importance, outside the TEN-T network), the conversion of intersections to fly-over ones is questionable. Besides, the allocation of funds for the modernization of railway lines of minor or local importance is about the state budget and EU funds problematic. Exploiting significant funds required by interlocking security plants is in some cases not even aligned with the value-for-money principle. If upgrading to such lines occurs, there is a high probability that the crossing will either be canceled or left as one at a level crossing. Thus, the safety-related problem will continue.

The number of road accidents on active crossings is higher than on passive crossings, with a relatively equal number of secured and unsecured rail crossings in SR (Table 1). However, in this context, it is also necessary to take into account the extent of rail and road traffic passing through the collision points, their localization and local circumstances, as well as the psychological factor of warning traffic light device, respectively traffic signs. For the reasons mentioned above, it is necessary to consider the assessment of the need for and the expediency of the solution of the railway crossing equipment individually. Traffic performance has a generally increasing trend, and the question of safety at rail and road intersections will become more timely as time goes by. The solution for implementing a strategic approach to infrastructure upgrading could be to develop a document at the national level that would define the need for modernization and propose its technical parameters (including level/interchange crossing). The list of projects created should take into account the priorities of the state transport policy, the infrastructure manager, the carriers, the available funds from the state budget and the EU, the development of transport and demography and the economic situation in the regions.

4. A Practical Example of the Potential Effect of Improving Railway Crossings Technology on the Occurrence of Traffic Accidents

To illustrate the impact of increasing the level of rail crossing security, the following model example of changing the interlocking security plants of level crossing for road and rail communications is presented. On the unsecured railway crossing (equipped only with traffic signs) near the village of Polomka in the Slovak Republic, a passenger train and a bus collided in 2009. This tragic accident was an impulse for the Ministry of Transport, Post and Telecommunications of the Slovak Republic (currently the Ministry of Transport and Construction of the Slovak Republic) and the railway infrastructure manager of ŽSR to increase safety in this section of the line and led to the modernization (rebuilding) of passive railway crossing to active - equipped with light signaling. According to the Slovak Police Force's Traffic Accident Statistics, 12 people were killed in this rail crossing for the years 2006-2009 (up to the time of modernization of the interlocking safety equipment) due to road and rail collision, 6 people were seriously injured and 19 easily injured. After the application of the warning traffic light device, the number of injuries for the period 2009 - 2017 was 0. Of course, it is not possible to state only by comparing traffic accident statistics on a particular rail crossing at selected time series, that changing a security device in the past would prevent any traffic accident from occurring on that crossing or eliminate its occurrence in the future. Transport is to some extent a stochastic phenomenon, and whether a road accident occurs and the extent of its consequences cannot be predicted only by changing the level of road safety. However, it is clear from the data presented that since the 2009 event there have been no road accidents involving loss of life or injury to accident participants. There are also other factors, that can influence the emergence, course, and extent of the consequences of road accidents on rail crossings, such as road quality and road condition, weather, visibility, vision conditions, and other site-specific conditions of the rail crossing. From investment in transport infrastructure, the socio-economic benefits of applying such a measure would be reduced social costs of accidents, time savings for passengers and road users in the case of no traffic accident and costs of property damage and environmental damage to be put back to the current state. A detailed economic analysis of the model case in Polomka would require the availability of an extensive database and detailed non-available accident information so that only cost comparisons and social cost savings from accidents are taken into account in the calculation. The source for a unit cost of savings for fatal, severe and light injuries is the Methodological Guide to Cost-Benefit Analysis Creation, presented in Table 3. The values given in Table 4 are related to the 2010 price level, i.e., approximately the time when a roadside interlocking device was deployed at the site of the traffic accident, so the data are comparable without the need for further correction. The calculation of the societal benefits of the measure is shown in Table 4.
The main factor is the limited amount of funds available for the modernization of transport infrastructure, which in turn affects localization and local communication crossings come with. Therefore, all aspects of the application of such measures generally applicable to any rail crossing, due to the impact of the stochastic phenomenon in transport and the specificities and conditions in the critical site, which is the subject of research and prospective status in terms of the extent of road and rail users. However, this statement is not able to accurately predict the number of significant injuries or fatalities that would result from the application of interlocking equipment on rail crossings.

The price for reconstruction (modernization) of the railway crossing can be different due to local conditions, technical specifics and scope of the project. The following examples of public procurement for the modernization of railway crossings in the Slovak Republic are presented to get an idea of what costs such activity can be realized. Construction of interlocking crossing plant (PZZ) on the Šahy - Čata line section in the range: low voltage connection for PZZ, road reconstructions, traffic signs and technological security of the crossing. The total value of the procurement was EUR 268 641.29 excluding VAT [9]. Construction of an interlocking crossing plant (PZZ) on the Šahy - Čata line section in the range: low voltage connection, traffic signs, PZZ technological adjustment and PZZ itself. The total value of the procurement was EUR 396 060 excluding VAT [10]. Reconstruction of the crossing on the Komárno - Dunajská Streda railway section in the range: low voltage connection, modification of the railway substructure, superstructure, traffic signs, interlocking security plant equipment. The total value of the procurement was EUR 514 824.52 excluding VAT [11]. In general, however, if the average cost of raising the level of the signaling equipment is in the amount of hundreds of thousands of euros (building only the interlocking safety plant equipment), such a measure is profitable in the case of the modernization of the railway crossing prevention of a traffic accident resulting in 1-2 serious injuries or approximately 15 minor injuries. Fatal injuries would be cost wise several times higher than investment costs in terms of the unit social cost of accidents.

5. Conclusions

Currently, there is an increase in traffic performance and passenger and goods mobility globally throughout the EU. The Community supports the development and modernization of transport infrastructure to build a quality and sufficient capacity network through various financial instruments. With increased mobility, there is also a security issue that is inadequately addressed by the authorities and institutions involved, as evidenced by the practical application of various road safety tools, as well as by accident statistics, which stagnate or even slowly decrease when road intensities increase. A model example based on information and circumstances about a real traffic accident and statistics on accidents confirms that the application of suitable interlocking equipment on rail crossings can prevent traffic accidents or to positively influence the health and property impacts of passengers and road and rail users in the future. However, this statement is not generally applicable to any rail crossing, due to the impact of the stochastic phenomenon in transport and the specificities that localization and local communications crossings come with. Therefore, all aspects of the application of such measures need to be considered comprehensively when deciding on the appropriateness of a change in the level crossing security. The main factor is the limited amount of funds available for the modernization of transport infrastructure, which in turn has to assess the allocation for individual projects in the context of the societal value and costs incurred. The basis of the state's investment activity in the field of transport policy should be the plan for the construction and modernization of transport infrastructure and the resulting prioritization of individual projects. An important determinant is also the specific conditions in the critical site, which is the subject of research and prospective status in terms of the extent of road and rail transport, the economic development of the region and the expected demography in the particular location.
Acknowledgment

This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

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An Analysis of Head-on Frontal Collisions by Modelling Crash Tests

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Abstract

This paper presents mathematical modelling of head-on frontal collisions in which lumped-mass models of cars are validated against full-width rigid barrier (FWRB) and head-on frontal crash tests. The crash tests are selected from the database of the National Highway Traffic Safety Administration (NHTSA). A case study is performed in which a 1999 model year car impacts head-on a 2004 model year car. Using the FWRB frontal crash tests, the loading/unloading stiffnesses and the force-drop ratios of the cars are estimated. The force-drop ratio is introduced to model the transition between the loading and unloading phases of the impact. A mathematical model of head-on frontal collisions is developed which requires as inputs the masses, impact velocities, loading/unloading stiffnesses and the force-drop ratios of the cars. The mathematical model is shown to estimate successfully the key responses in vehicle crashes which are the mean accelerations, deformations and change of velocity of the cars in the head-on collision. The presented approach is analytical and provides hand computation of key responses.

KEYWORDS: frontal impact, head-on collision, NCAP tests, stiffness, lumped-mass model

1. Introduction

In the United States New Car Assessment Program (US NCAP), cars impact a rigid barrier at 56 km/h with 100% overlap (i.e. full-width). Researchers can download US NCAP and compliance crash test data from the website of National Highway Traffic Safety Administration (NHTSA) [1]. Crash tests are expensive and they are performed at certain impact velocities. Therefore, modelling crash tests is a very useful tool to estimate key responses in vehicle crashes with different test conditions [2, 3].

Crash test data can be utilised to derive the stiffness of a vehicle which is one of the key parameters in a vehicle impact model [2-4]. Stiffness affects directly the acceleration of the vehicle, thus it is an important parameter in restraint system (e.g. seatbelt, airbag, seat) design. The mean acceleration of the occupant compartment, crash pulse shape, restraint system properties and the amount of intrusion into the occupant compartment determine the injury risk for an occupant involved in a vehicle crash [4-7].

Cars can receive good ratings in consumer crash tests but they may not achieve the same performance when they collide with other cars in real-world as a result of incompatibility between cars. The differences between the masses and stiffnesses of vehicles produce load incompatibility. A lighter and a less stiff vehicle is at a disadvantage when it collides with a heavier and stiffer vehicle. Besides, there is also a problem called shape incompatibility between vehicles due to the misalignment of energy-absorbing structures of the interacting vehicles together with the differences in the strengths of these structures. Override/underride crashes, oblique impacts, side impacts and offset crashes are typical examples of shape incompatibility [2].

Considering the issues related to vehicle crashes as mentioned above, it is essential to make crash simulations to evaluate the safety of occupants. In this paper, lumped-mass car models are presented to simulate both full-width rigid barrier (FWRB) and head-on frontal crash tests. Lumped-mass modelling can provide cheaply the key responses in the preliminary design of vehicle safety systems, accident reconstruction and load compatibility analyses of cars [2, 4, 8].

In this study, a head-on frontal collision test between a 1999 model year car and a 2004 model year car is selected from the NHTSA crash test database. In order to model this head-on collision, the lumped-mass models of the cars are built with the aid of the full-width rigid barrier (FWRB) crash tests of the two cars. A mathematical model of frontal head-on collisions (with 100% overlap) is then constructed and then validated against the collision test. The presented modelling approach predicts the key responses which are the mean accelerations, deformations and change of velocity of the cars with a high degree of accuracy.

2. Lumped Mass Modelling of FWRB Crash Tests

A lumped mass model of the cars in full-width rigid barrier (FWRB) crash tests is given in Fig. 1, in which the spring-like element represents the crush force versus deformation behaviour of the car. The impact speed \( V_0 \) in the FWRB crash tests is 56 km/h. The car whose mass is \( m \), moves along the \( x \)-direction only since this is usually the predominant motion of cars at impact speeds at or below 56 km/h in the FWRB crash tests [1]. The crush force versus deformation behaviour of the cars are derived from the FWRB crash test data in the NHTSA database [1]. In these tests, the rigid barrier (i.e. rigid wall) is equipped with load cells which measure the crush forces and moments at the interface between the car and the barrier. Accelerometers are also attached to the occupant compartment which are used to obtain the
displacement of the car and its deformation. Once the crush force and the deformation are obtained after processing these data, the total barrier force is plotted against the displacement of the occupant compartment to get the crush force versus deformation behaviour of the frontal structural elements of the car as shown in Fig. 2. Detailed information about FWRB crash test data analysis can be found in reference [3].

Fig. 1 Lumped-mass model of the car to simulate FWRB impacts

Fig. 2 shows a typical crush-force versus deformation curve of a passenger car together with its piecewise linear approximation for the FWRB crash test at an impact speed of 56 km/h. The deformation (or loading) phase of the impact starts when the car first contacts the barrier and ends when the car reaches its maximum deformation $x_T$. This phase is approximated by the straight line with the slope $k_L$. The slope $k_L$ is called the loading stiffness and it is determined by equating the area under the crush force versus deformation curve in the loading phase to the area under the straight line with the slope $k_L$. The unloading phase which starts at the end of the loading phase, involves the rebound of the car from the barrier during which the elastic energy stored in the frontal structures are returned to the car. At the end of the unloading phase, the car loses contact with the barrier and the car reaches its permanent deformation $x_P$. This unloading phase is approximated by the straight line with the slope $k_U$. The slope $k_U$ is called the unloading stiffness and it is determined by equating the area under the crush force versus deformation curve in the unloading phase to the area under the straight line with the slope $k_U$; in doing this the separation force $F^*$ is determined. The ratio $F_{\text{max}}/F^*$ is defined as the force drop ratio $c$. The equations to calculate these slopes and the separation force are given in reference [5]. During this research, it was found that Emori [9] had also suggested this piecewise linear approximation in the past but the author did not provide the analytical solution and identification of the unloading phase as given here.

Fig. 2 Linear approximation at 56 km/h
Fig. 3 Approximation for different impact speeds

As mentioned in the previous paragraph, the parameters $k_L$, $k_U$, and $c$ are determined from the FWRB crash test data at an impact speed of 56 km/h and these parameters are regarded to be the constant characteristics of the frontal structure of the car. For FWRB crash tests at around 56 km/h or below, the piecewise linear approximation of crush force versus deformation curves can be obtained by applying the method given in Fig. 3. In this proposed method [3], the maximum crush forces developed at impact speeds 1 and 2 are $F_{\text{max}1}$ and $F_{\text{max}2}$ respectively; the separation forces at impact speeds 1 and 2 are $F^*_1$ and $F^*_2$ respectively; the maximum deformations at impact speeds 1 and 2 are $x_{T1}$ and $x_{T2}$ respectively; the permanent deformations at impact speeds 1 and 2 are $x_{P1}$ and $x_{P2}$ respectively; $k_L$, $k_U$, and $c$ are defined to be the same for both impact speeds 1 and 2. The method given in Fig. 3 was validated successfully in a previous research [3] which are in line with the results of another study [10] in which the crush force versus deformation curves of 42 different cars subjected to 158 FWRB crash tests were presented at impact speeds up to 64 km/h. It should be noted that for impact speeds higher than 56 km/h, deformation rate effects and occupant compartment deformation become significant which requires a modification of the method presented in Fig. 3 [3].

3. Modelling Head-on Frontal Collisions

Head-on (100% overlap) frontal collisions as shown in Fig. 4 are modelled by using the lumped mass model of the cars given in Fig. 1, Fig. 2 and Fig. 3. In the formulations given below, tractional and/or braking forces are neglected which is a reasonable approximation since the crush forces are much more dominant unless the impact speeds are too low [2, 3, 5]. The equation of motion in the longitudinal direction ($x$) for the loading phase is given by Eq. (1) whose derivation can be found in reference [4]. In Eq. (1), $x_1$ and $x_2$ are the displacements of cars 1 and 2 respectively. In Eq. (2), $m_1$ and $m_2$ are the masses of cars 1 and 2 respectively; $k_{L1}$ and $k_{L2}$ are the loading stiffnesses of cars 1 and 2 respectively; $m_{eq}$ and
are the equivalent mass and loading stiffness of the system respectively. The impact starts when time equals zero. As given in Eq. (3), \(\omega_n\) is the natural frequency of the system in the loading phase; \(t_P\) is the time at which the loading phase of the impact ends and at this instant both cars have their maximum deformations. The solution of the equation of motion is given in Eq. (4) where \(V_{CL}\) is the closing velocity of the cars; \(V_1\) and \(V_2\) are the velocities of cars 1 and 2 respectively at the start of the impact. A work-energy equation can be written for the motion in the longitudinal direction as shown in Eq.(5) where \(W_T\) is the total energy absorbed by the structures of both cars and \(V_c\) is the common velocity of both cars at the end of the loading phase. The common velocity \(V_c\) occurs at time \(t_{zv}\). The detailed derivation of the work-energy equation can be found in reference [2]. When the loading phase ends, the unloading phase starts immediately during which the cars push each other until they separate.

\[
\begin{align*}
    m_{eq}\ddot{x} + k_{eq}x &= 0; \quad x_r = x_2 - x_1; \\
    m_{eq} &= m_1m_2 / (m_1 + m_2); \quad k_{eq} = k_{L1}k_{L2} / (k_{L1} + k_{L2}); \\
    \omega_n &= \sqrt{k_{eq} / m_{eq}}; \quad t_{zv} = \pi / (2\omega_n); \\
    x_r(t) &= (V_{CL} / \omega_n)\sin(\omega_n t); \quad V_{CL} = V_2 - V_1; \\
    W_T &= (1/2)m_1V_1^2 + (1/2)m_2V_2^2 - (1/2)(m_1 + m_2)V_c^2.
\end{align*}
\]

4. Validation of the Car Models in FWRB Crash Tests

A case study is selected from the NHTSA database [1] to validate the lumped mass models in FWRB crash tests and head-on frontal collisions. In this case study, Car1 is a 1999 model year car which impacts head-on a 2004 model year car which is Car2. Lumped mass models of Cars 1 and 2 are first validated against their respective FWRB crash test data. The loading stiffness \((k_L)\), the unloading stiffness \((k_U)\) and the force drop ratio \(c\) of each car are determined by applying the linear approximation as defined in section 2 which are depicted in Fig. 5 and Fig. 7 for Car1 and Car2 respectively. Considering \(k_L\), \(k_U\) and \(c\) as constant parameters, the lumped mass models are then subjected to FWRB impact at 56 km/h and the resulting crush force versus deformation responses of the models are shown in Fig. 6 and Fig. 8 for Car1 and Car2 respectively. The numerical results are given in Tables 1 and 2 including the key responses which are \(x_T\) (maximum deformation of the car i.e. dynamic crush), \(x_P\) (permanent deformation of the car), \(F_{max}\) (maximum crush-force), \(F_{mean}\) (mean crush-force in the loading phase), \(a_{max}\) (peak x-acceleration of the occupant compartment), \(a_{mean}\) (mean x-acceleration of the occupant compartment in the loading phase), \(V'\) (rebound velocity of the car), \(e\) (coefficient of restitution of the impact). The masses of the cars are denoted by \(m\).

| Car1: Model vs actual car responses (FWRB impact at 56 km/h) |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | \(m\)  | \(x_T\)  | \(x_P\)  | \(F_{max}\)  | \(F_{mean}\)  | \(a_{max}\)  | \(a_{mean}\)  | \(V'\)  | \(e\) |
| Model | 1976 kg | 0.730 m | 0.602 m | 662 kN | 331 kN | -34.16 g | -21.75 g | -7.0 kph | 0.124 |
| Actual car | 1976 kg | 0.789 m | 0.648 m | 763 kN | 358 kN | -44.35 g | -18.46 g | -7.6 kph | 0.135 |

| Car2: Model vs actual car responses (FWRB impact at 56 km/h) |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | \(m\)  | \(x_T\)  | \(x_P\)  | \(F_{max}\)  | \(F_{mean}\)  | \(a_{max}\)  | \(a_{mean}\)  | \(V'\)  | \(e\) |
| Model | 1624 kg | 0.679 m | 0.556 m | 591 kN | 295 kN | -37.12 g | -23.63 g | -6.7 kph | 0.119 |
| Actual car | 1624 kg | 0.721 m | 0.591 m | 655 kN | 314 kN | -36.54 g | -21.01 g | -7.1 kph | 0.126 |

Tables 1 and 2 indicate that the lumped-mass models for the cars predict the real-world responses with a good level of accuracy, therefore these models can also be used in simulating head-on frontal collisions.
5. Simulation and Validation of a Head-on Frontal Collision Test

The selected case study involves the head-on frontal collision test between Car1 (1999 model year) and Car2 (2004 model year) as indicated in the previous section. The experimental data indicates that Car1 has an impact velocity of 101.2 km/h while Car2 is stationary. The test masses for cars 1 and 2 are 2004.4 kg and 1636.8 kg, respectively. The permanent deformations $x_{P1}$ and $x_{P2}$ of cars 1 and 2 are recorded as 0.430 m and 0.511 m, respectively. The only other useful data are the occupant compartment accelerations. The aim here is to extract the loading and unloading stiffnesses of the cars in the head-on collision test which will be different than those of the FWRB crash tests.

First, the occupant compartment accelerations are filtered according to SAE J211-1 [12] and then integrated to find the velocities of the cars as shown in Fig. 9. Then, the time $t_{v1}$ at which the common velocity occurs, is found by determining numerically the intersection of the velocity-time curves of the cars in Fig. 9. Using Eq. (3) and Eq. (2), the natural frequency and the equivalent stiffness of the system in the loading phase are calculated. The ratio of the loading stiffnesses $k_{L1}$ and $k_{L2}$ are inversely proportional to the ratio of the maximum deformations $x_{T1}$ and $x_{T2}$ of cars 1 and 2 respectively as shown in Eq. (6). However, since $x_{T1}$ and $x_{T2}$ cannot be extracted from the crash test data, the ratio of the maximum deformations are taken to be approximately equal to the ratio of the permanent deformations $x_{P1}$ and $x_{P2}$ of the cars. This is a reasonable approximation since FWRB crash test data indicated that permanent deformation over maximum deformation ratios were very similar for the same cars at different impact speeds [11]. Using Eq. (6) and the computed equivalent stiffness $k_{eqL}$, the individual loading stiffnesses $k_{L1}$ and $k_{L2}$ of the cars in the head-on frontal collision test can be calculated. It can be shown that [2] the maximum crush force $F_{max}$ experienced by both cars is given by Eq. (7). $W_T$ is calculated by using Eq. (5). In the unloading phase, the elastic rebound displacements $x_{e1}$ and $x_{e2}$ of the frontal structures of cars 1 and 2 respectively are found by using Eq. (7) and Eq. (8). The lumped mass model of the cars given in Fig. 1, Fig. 2 and Fig. 3 indicate that the unloading stiffnesses $k_{U1}$ and $k_{U2}$ of the cars can be estimated by using Eq. (9) where $F_1^*$, $F_2^*$ are the separation forces and $c_1$, $c_2$ are the force drop ratios of cars 1 and 2, respectively. For the sake of estimating the unloading stiffnesses $k_{U1}$ and $k_{U2}$ in the head-on collision test, the force drop ratios obtained from the individual FWRB crash tests are used. The masses, estimated stiffnesses ($k_{L1}$, $k_{L2}$) and the force-drop ratios ($c_1$, $c_2$) of cars 1 and 2 in both FWRB crash test and the head-on frontal collision test are given in Table 3.

$$k_{L1} / k_{L2} = x_{T2} / x_{T1}; \quad x_{T2} / x_{T1} = x_{P2} / x_{P1};$$  \hspace{1cm} (6)

$$F_{max} = \sqrt{2W_T k_{eqL}}; \quad x_{T1} = F_{max} / k_{L1}; \quad x_{T2} = F_{max} / k_{L2};$$  \hspace{1cm} (7)

$$x_{e1} = x_{T1} - x_{P1}; \quad x_{e2} = x_{T2} - x_{P2};$$  \hspace{1cm} (8)

$$F_1^* = F_{max} / c_1; \quad F_2^* = F_{max} / c_2; \quad k_{U1} = F_1^* / x_{e1}; \quad k_{U2} = F_2^* / x_{e2}. \hspace{1cm} (9)$$
Fig. 9 Velocities of the cars in the head-on frontal collision test

Table 3

<table>
<thead>
<tr>
<th>Masses, stiffnesses and force-drop ratios of cars 1 and 2</th>
<th>m [kg]</th>
<th>k_L [N/m]</th>
<th>k_U [N/m]</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car1 - FWRB crash test</td>
<td>1976</td>
<td>907349.26</td>
<td>459785.44</td>
<td>11.29</td>
</tr>
<tr>
<td>Car1 - Head-on collision</td>
<td>2004.4</td>
<td>739698.42</td>
<td>190015.51</td>
<td>11.29</td>
</tr>
<tr>
<td>Car2 - FWRB crash test</td>
<td>1624</td>
<td>871054.46</td>
<td>378642.56</td>
<td>12.76</td>
</tr>
<tr>
<td>Car2 - Head-on collision</td>
<td>1636.8</td>
<td>622446.81</td>
<td>141475.06</td>
<td>12.76</td>
</tr>
</tbody>
</table>

As expected, the loading/unloading stiffnesses in the head-on frontal collision test are lower than those of the FWRB crash tests since the longitudinal structural members of cars 1 and 2 are not perfectly aligned in the head-on collision leading to a different structural engagement of cars. It is observed that for Car1, the loading stiffness ratio (head-on/barrier) is 0.82 whereas the unloading stiffness ratio (head-on/barrier) is 0.41. For Car2, the loading stiffness ratio (head-on/barrier) is 0.71 whereas the unloading stiffness ratio (head-on/barrier) is 0.37.

The mathematical lumped-mass model expressed by the equations given in this paper is validated against the experimental data for the given case-study corresponding to the head-on collision test between Car1 (1999 model year) and Car2 (2004 model year). The model requires as inputs the masses, impact velocities, loading/unloading stiffnesses and the force-drop ratios of the cars. In the simulation, the loading and unloading stiffnesses of the cars obtained from their FWRB crash tests are multiplied with their respective stiffness ratios (head-on/barrier) as calculated from Table 3. In the mathematical model, the responses of the cars in the unloading phase (i.e. rebound phase) are found by using Eq. (10) and Eq. (11). Eq. (10) describes the crush energy returned ($W_R$) to the cars in the unloading phase in the longitudinal direction which is equal to the total area under the unloading lines of both cars as shown in Fig. 2 and Fig. 3. In Eq. (10), $W_I$ is the energy lost in the collision and $W_T$ is the total energy absorbed by the structures of both cars for the longitudinal motion. In order to calculate the longitudinal velocities of the cars at the end of impact (i.e. $V'_1$ and $V'_2$) and the resulting velocity changes, Eq. (11) is used which involves the conservation of momentum and the coefficient of restitution ($e$) equations.

Table 4 presents the key responses of cars 1 and 2 in the head-on frontal collision test and compares them against the model responses. In Table 4, for each car, $m$ is the mass, $V$ is the initial impact velocity, $V_c$ is the common velocity during impact, $t_v$ is the duration of the loading phase, $a_m$ is the mean $x$-acceleration of the occupant compartment in the loading phase, $x_T$ and $x_P$ are the maximum and permanent deformations, $\Delta V$ is the velocity change experienced as a result of the impact and $e$ is the coefficient of restitution of the impact.

Table 4

<table>
<thead>
<tr>
<th>Model vs actual car responses (head-on frontal collision test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$ [kg]</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Car1: Model</td>
</tr>
<tr>
<td>Car1: Actual</td>
</tr>
<tr>
<td>Car2: Model</td>
</tr>
<tr>
<td>Car2: Actual</td>
</tr>
</tbody>
</table>
6. Discussion and Conclusions

This paper presents the modelling and validation of FWRB crash tests and head-on (100% overlap) frontal collisions. A case study is analysed in which Car1 (1999 model year) impacts Car2 (2004 model year) in a head-on collision test. The lumped-mass models of the cars are represented by a single degree-of-freedom spring-mass system in which the spring-like element represents the frontal structure behaviour of the car. The fixed parameters of the lumped-mass models are the mass, loading/unloading stiffnesses and the force-drop ratios.

First, the lumped-mass models of the cars are validated successfully against their respective FWRB crash test data. The results indicate that there is around 5 cm error in the deformations, up to 10% error in the mean accelerations and up to 8% error in the coefficient of restitution. It is observed that estimating the peak acceleration value is not easy since there can be sharp peaks in the occupant compartment accelerations as seen in Car1 FWRB crash test data.

In the second stage of this study, the loading and unloading stiffnesses of the cars are re-estimated by using the head-on collision test data. It is observed that the loading/unloading stiffnesses in the head-on collision test are 0.77/0.39 times lower on average than those of the FWRB crash test. This is an expected result because the principal energy absorbing structures (PEAS) of the two cars do not meet well and the energy absorbing potential of the PEAS are reduced as typically seen in override/underride impacts.

The selected head-on frontal collision test is simulated by using the lumped-mass models of the cars with their updated stiffness values extracted from the experimental data. The results indicate that the mathematical model is able to estimate the mean accelerations, deformations, change of velocities and the duration of the loading phase with a high level of accuracy with the exception of the coefficient of restitution.

The piecewise linear approximation of the force versus deformation curves presented in this study, is valid for impact speeds at around or below 56 km/h regarding the FWRB crash tests. The FWRB crash test is equivalent to a head-on frontal collision between two identical cars which both have 56 km/h impact speeds (this is equivalent to a closing speed of 112 km/h). In the case study presented, the closing speed of the cars is 101.2 km/h, hence the cars in the head-on frontal collision test experience similar levels of crash severity compared to their FWRB crash test.

The present study can be further improved by analysing more head-on frontal collision tests which are limited in number whereas FWRB crash tests are performed almost for all cars. The stiffness values estimated from FWRB crash tests can be scaled by different factors to simulate head-on frontal collisions to perform vehicle safety performance analyses in the car fleet.

Considering the high cost of crash tests, the presented modelling technique is an efficient and analytical tool which can be used in the preliminary design of vehicle safety systems, accident reconstruction and compatibility analyses of cars.

References

Leadership in Air Transport

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Abstract

The article deals with the issue of leadership. There are not always people in management positions who have the necessary predispositions for leading people resulting from the typology of their personality. Therefore, a questionnaire investigation was conducted in an attempt to find predispositions for managerial work in people working in the aviation environment. The questionnaire survey evaluated 8 areas in which the successful manager should have the required skills. Respondents performed best in the areas of communication and interpersonal skills. Through a questionnaire survey, we found that 26% of respondents do not have sufficient predispositions to work effectively in a management role. It was also found that women performed better than men in terms of the assessed predispositions to managerial work.

KEY WORDS: leadership; personality typology; aviation professions; management

1. Introduction

In the aviation industry, there is a high emphasis on the selection of staff within the various aviation professions, be it flying staff, ground aviation staff or air traffic control staff. Highly skilled aviation personnel create the prerequisites for employees to be able to work in teams, communicate effectively with each other, analyse and resolve emerging problem situations promptly, adhere to established procedures and time schedules, and manage their work under constant pressure and stress. The career development of an employee working in air transport depends on the internal organisational structure of the airline in which he works and is also dependent on his professional knowledge, experience and predisposition to manage and lead people. Professional knowledge is determined by the licences and certificates obtained, experience by the length of experience. Determining what preconditions an employee has in order to effectively manage a team of people is not objectively evaluated in terms of his career growth. Therefore, it is appropriate to ask the question, what group of people are predisposed to leadership, and what skills or abilities should employees in leadership positions in aviation possess?

A person's personality characteristics play an important role in assessing managerial ability. In order to determine the suitability of a candidate for a managerial, leadership or executive position, it is necessary to take into account his or her personality traits, which are a typical set of characteristics only for a particular individual. They define the way in which a person approaches external influences acting and influencing the way of his behavior, expression, intentions or goals that he wants to achieve. Personality traits can affect job performance and manifest themselves towards other people.

A person's personality is shaped by four groups of factors, i.e. biological, cultural, social, and self-development and self-creation factors [1]. One of the most important abilities required for the role of a manager is the rational abilities such as intelligence, which determines the ability to think rationally and act purposefully. The personality of such a worker should have a steady way of behavior, manifesting itself in a standard and normal way in certain situations. Emotional stability, assertiveness, empathy, communicativeness and others are also appropriate personality traits of a manager [1]. Even though a manager would meet all the personality prerequisites, it does not mean that these positive qualities will be the guarantee for successfully coping with the difficult tasks in managing and leading people.

It is clear from research in this area [2, 3] that we cannot define a precise schema of the characteristics of a leader. We can only identify approximate requirements for the manager's personality. As an example, the characteristics of manifestations of healthy self-esteem, self-confidence, intelligence and interpersonal skills are given. Rational abilities such as strategic thinking play an important role. Suitable traits are flexibility of responding to situations, stable behavior, assertiveness and communicativeness. Inherent in the behavior of managers are enthusiasm, perseverance, and stress resistance, but personality traits alone are not the only parameters that should be evaluated in selection for a managerial position or a prerequisite for leadership skills.

Several studies have attempted to classify and evaluate personality typology also in the context of the performance of work activities. Probably the most intuitive way of classifying personality typology seems to be the Hippocratic one, i.e. sanguine, choleric, phlegmatic and melancholic. However, there are other ways of estimating a person's typology, e.g. on the basis of color scales [4], communication types [5, 6], or in more exact ways declared, for example, in the study [7]. The last mentioned study profiled four basic biological behavioural styles that are influenced
by hormones, i.e. the dopamine type (Explorer), the serotonin type (Builder), the testosterone type (Director) and the estrogen type (Negotiator). This research provides a detailed overview based on neuroscience, offers guidance on recognizing people's temperament, personality styles, describes body language, strengths and weaknesses, ways to deal with crisis situations with a given personality style, and describes the mindset of the personality style group.

Although the concept of leadership can be interpreted differently in the literature, its basic elements are, goal achievement, group activities and influence on the behaviour of other people. Thus, the assumption is that a person's type of behavioural can have an impact on leadership per se. It should be noted that there are significant differences between leadership and management. Leadership is about providing vision, inspiration and strategy, whereas management is about implementation, support and direction. In practice, the differences between management and leadership overlap, with the concept of leadership referring not only to the top ranks of the hierarchy in an organisation but also to all the other lower ranks down to the employees who interact with each other in a collaborative way. Leaders and managers work and manage those people. For the most effective team building, it is important to consider the strengths of individuals but also the strengths of the team as a whole. Team members who know each other's strengths can more effectively avoid potential conflicts and are more cohesive. Don Clifton's research [8] in this area has confirmed that employees who use their strengths in their jobs are more motivated to perform, are up to 8% more productive, and are 15% less likely to fluctuate.

In relation to leadership, it is also possible to identify undesirable behaviours that can lead to demotivation of the environment. In this context, for example, the 21st century phenomenon called procrastination can be mentioned. From a psychological point of view, this is a habit of a dysfunctional nature that causes a person to experience feelings of guilt, which has a negative effect on his or her performance. In behavioral psychology, it is also referred to as time inconsistency. Failure of self-regulation from the perspective of neuropsychology is related to the activity of the frontal system in the brain, which is involved in many processes related to self-regulation. One of the first studies to look at the impact of procrastination on humans was published in 1997. The conclusion of the study confirmed that people with procrastination tendencies experienced impaired performance and increased perceived stress levels [9]. Professor J.R. Ferrari of DePaul University says that procrastination is a self-defeating behavior by which so-called procrastinators seek to undermine their own efforts. His research has confirmed that up to 20% of people may be so-called chronic procrastinators [10]. In relation to leadership, such behaviour is undesirable. Understanding procrastination and early identification of procrastinating behavior or identifying predispositions to such behavior can help the manager in dealing with this problem.

Based on the above, the aim was to develop a methodology based on a questionnaire survey that takes into account human behavioural typology and leadership predispositions, with simultaneous validation of this methodology on a representative sample of respondents. All respondents were in the aviation industry as ground aviation personnel but also students in the field. The questionnaire was evaluated according to predetermined criteria. The primary factor evaluated was what percentage of respondents fell into the category: - has a high aptitude to be a capable manager, - has the aptitude to become a manager, - can temporarily hold a managerial position, - does not have the aptitude to become a manager.

2. Methods

2.1. Questionary Survay Setup-up

A questionnaire was developed for the survey which contained 40 questions based on theoretical knowledge about leadership and personality typology. In terms of assessing the predispositions for holding managerial positions, we established 8 domains within which we assessed predispositions for managerial work. The areas assessed were - coping with situations, task and goal accomplishment, decision making and feedback, problem solving, relationships, communication, planning, self-reflection - self-confidence, self-assessment and attitudes. For each area, we selected 5 questions from the question database. The individual questions were presented to the respondents in the form of statements such as:

- I show myself as a dominant personality.
- I easily make contacts with other people.
- I often postpone assignments for later.
- I plan things systematically and in detail.
- I can usually solve difficult problems without strong emotions.
- I retreat into the background when conflicts arise, etc.

For each question, the respondent expressed his or her level of agreement with the statement on a five-point scale. We chose this form because the statement clearly defined the condition about which the respondent was taking a position. The form of the questionnaire survey was used to determine whether it was possible to identify predispositions to holding managerial positions that could contribute to the effective management of an employee's career in personnel work.
2.2. Demography of Respondents

We used a short questionnaire survey to determine a person's predisposition to leadership. The questionnaire contained 40 questions from 8 areas based on theoretical knowledge about leadership and personality typology. The questionnaire was processed electronically using Google questionnaire tool, which stored the collected data and created a structure for its evaluation. 115 respondents participated in the survey, which were mainly airport security control officers and employees, aviation maintenance technicians and students of the Faculty of Air Transport in Košice. Demographic data show that 59 males and 56 females (2.6% more males than females) aged 18–65 years participated in the survey. The largest group (64%) was made up of respondents aged 18–26 and 11% of respondents were over 40 years of age. Up to 80% of respondents reported that they were single. Secondary education was reported by 63% of the respondents, 37% had completed either a first or second degree.

The most numerous sample examined was security staff, who accounted for 34% of the sample. Students of the Faculty of Aviation 32%, aircraft maintenance technicians 16% and other professions in aviation 18%.

3. Results

As many as 55 respondents (48 %) said they had leadership experience. Of these, 40% were women and 60% were men. 42% of the respondents having leadership experience are employed in the security control department.

In order to find out the respondents' aptitude for leadership, we scored each area based on a point-scoring system, with a maximum score of 25 for each area. The average score for each area ranged from 5.67 to 12.94. The highest mean scores were achieved in the areas of 'communication and attitudes' - 12.94 points, 'interpersonal skills' - 12.14 points and 'goal setting and achievement' - 11.22 points. The lowest mean scores were achieved in the areas of 'Analysis and problem solving' - 5.94 points and 'Planning and organising' - 6.31 points. Except for the areas of "Analyzing and solving problems" and "Decision making", women performed better than men.

We formulated the questions to find out how the respondents perceived themselves, their dominance behaviors, flexibility and resilience, ability to learn new things, emotional stability, and extroversion.

In the self-assessment area, we looked at how respondents perceived themselves. Only 8% of respondents fully perceived themselves as dominant personalities compared to 37% who did not perceive themselves as dominant personalities. Willingness to learn new things was confirmed by 86 % of respondents. Only 7% of respondents do not perceive themselves as flexible and resilient personalities, which is 11 times less than respondents who rate themselves as flexible (80%). Frequent mood swings are experienced by 13% of respondents, while 32% of respondents do not experience mood states. 60% of the respondents consider themselves to be social types.

In the area of communication, we focused on communication skills and attitudes towards other people. Sixty-eight percent of respondents report that they are able to make contacts with other people easily, and only 17% report difficulty in making contacts. A clear, consistent and comprehensive method of communication, during which all necessary information is provided, is reported by 29% of respondents. Twenty-five percent of the survey participants believe themselves to be goal-oriented and persistent. Half of the respondents are able to listen to other people's opinions and attitudes and explain what is expected of them.

In the area of interpersonal skills, respondents had the highest average scores across all areas assessed. We focused on relationship issues. Over 50% of survey participants considered working in teams to be important. Approximately 80% of respondents report having good relationships in their environment, but in exchanges and conflicts, up to 31% of participants report being forceful, stubborn, and having noisy behavior. Conflict situations are avoided by 18% of respondents.

In the area focused on time management and procrastination inclinations, we focused on whether the respondents were able to organize their time, whether they were subject to procrastination behavior, which is a dysfunctional habit and which should not be present in the personality traits of a leader. Assigned tasks are often postponed for later by 30% of respondents and on the other hand 55% of respondents complete assigned tasks without delay. As many as 83% of the respondents are able to manage their time effectively while performing a task. 11% of the respondents have a problem with completing the tasks. 31% of the respondents solve the assigned tasks at the last minute because they feel more efficient and effective in time pressure.

In the area focused on setting and meeting goals, 39% of respondents report that they always do everything they can to achieve what they set out to do, but only 21% of respondents achieve the resolutions they set. 66% of respondents are turning their visions into reality. If complications arise in realizing their own visions, this demotivates 19 % of respondents. Motivation is not lost at all for 24 % of respondents. In case of failure in achieving their set goals, new solutions are always sought by 31% of respondents.

In the area of planning and organizing schedules and timetables, 73% of respondents prefer planning and 68% of respondents prefer systematic and detailed planning. As the responses show, scheduling is not practiced at all by 20% of the respondents. The same number of respondents said they like to let things flow naturally and 16% of respondents try to have constant control over what is happening. Punctuality is not a problem for 60% of respondents.

On the issue of respondents' ability to analyse and solve problems, the survey showed that over 70% of respondents spend enough time to solve the causes of their problems, also up to 62% of respondents reported that they can solve their problems without strong emotions. 30% of respondents also report that sometimes they do not solve problems and wait for them to solve themselves. On the other hand, 54% of the respondents consider a problem that
arises as a challenge. 22% of the respondents prefer their own suggestions in solving problems, on the other hand, 44% of the respondents take into account the opinions of others when looking for solutions to problems.

In the area of decision-making, the survey showed that 70% of participants are able to make decisions quickly even under pressure and in unclear situations, while standing by their decisions. Even in stressful situations, about 60% of respondents agreed that they can concentrate and think clearly.

Individual responses to the questionnaire questions were assigned point values ranging from -5 to +5 points. For the overall evaluation of the respondents in the questionnaire survey, 5 categories were selected into which the respondents were placed based on the scores they achieved (Table 1).

### Table 1

<table>
<thead>
<tr>
<th>Range of points</th>
<th>Category</th>
<th>Dispositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>to 100</td>
<td>1.</td>
<td>High aptitude to be a capable manager</td>
</tr>
<tr>
<td>99 to 50</td>
<td>2.</td>
<td>Prerequisites for the management position</td>
</tr>
<tr>
<td>49 to -49</td>
<td>3.</td>
<td>Not recommended to hold a managerial position</td>
</tr>
<tr>
<td>-50 to -99</td>
<td>4.</td>
<td>Does not have the predispositions for a managerial position</td>
</tr>
<tr>
<td>-100 to -200</td>
<td>5.</td>
<td>Absolutely unsuitable type for a managerial position</td>
</tr>
</tbody>
</table>

Of the total respondents participating in the survey, 27% of the respondents with scores ranging from 100–200 were categorized as Category 1 "High aptitude to be a capable manager", with 55% of these respondents being female. As many as 74% of respondents placed in this category indicated that they had experience in managing and leading people. Airport security screening employees represent the highest percentage of respondents in this category (48%). Of the total respondents participating in the survey, 7% of the students at the Faculty of Air Transport fell into this rating category (Table 2).

### Table 2

<table>
<thead>
<tr>
<th>Gender</th>
<th>Management experience</th>
<th>Security Control</th>
<th>Aircraft maintenance</th>
<th>Another profession</th>
<th>Students Faculty of Air Trans.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Σ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category 1</td>
<td>Man</td>
<td>10</td>
<td>4</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Woman</td>
<td>13</td>
<td>4</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Σ / %</td>
<td>23/74%</td>
<td>8/26%</td>
<td>31/100%</td>
<td>15/48%</td>
</tr>
<tr>
<td>Category 2</td>
<td>Man</td>
<td>14</td>
<td>13</td>
<td>27</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Woman</td>
<td>6</td>
<td>21</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Σ / %</td>
<td>20/37%</td>
<td>34/63%</td>
<td>54/100%</td>
<td>16/30%</td>
</tr>
<tr>
<td>Category 3</td>
<td>Man</td>
<td>9</td>
<td>9</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Woman</td>
<td>3</td>
<td>9</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Σ / %</td>
<td>12/40%</td>
<td>18/60%</td>
<td>30/100%</td>
<td>9/30%</td>
</tr>
</tbody>
</table>

Respondents who were assessed as having the aptitude for a managerial role accounted for up to 48% of all respondents, with only 37% of respondents placed in this category 2 stating that they already had experience of managing and leading people. The highest number of respondents who have the prerequisites to act in a managerial function is found among students of the Faculty of Air Transport in Košice and airport security control staff.

Category 3 "Not recommended to hold a managerial position" was assigned to 26% of all participants based on the results of the questionnaire survey. 60% of the respondents assigned to this category had no experience of managerial skills. In this category, students of the Faculty of Air Transport in Košice are the most represented (43%).

No respondents were included in categories 4 and 5.

In categories 1 and 2, 43 respondents have experience in managing and leading people. This represents 37% of all survey respondents. Respondents who indicate they have no experience in leading and managing people but are ranked in either category 1 or 2 based on the assessment represent 36% of all respondents. The questionnaire survey shows that only 27% of respondents classified in category 1 have a high aptitude to be a capable manager and 26% of respondents classified in category 3 are not recommended to hold any managerial position.

### 4. Discussion

The results of the management skills assessment survey showed that 27% of the respondents have high aptitude to be a capable manager. A further 48% of respondents have the disposition to be in managerial positions. 26% of the respondents from all the participants of the survey appear to be problematic to hold a managerial position. The questionnaire investigation did not reveal a group of respondents who were assessed to have no aptitude or to be
absolutely unsuitable types for a managerial position.

We conclude on the basis that the analysis of the individual questions revealed inconsistencies in the responses. For example, in the area of fulfilling and setting goals, 21% of respondents state that they always fulfill their resolutions, and in the question of whether they try to accomplish what they set out to accomplish, the statement was already confirmed by 39% of respondents. Another example might be in the area of planning and organizing, where 73% of respondents say they like to plan things ahead and prefer schedules and timetables. On the other hand, in another question, 59% of respondents state that they like to let things flow naturally.

The reason why we did not identify a category of participants in the survey who have no aptitude or are absolutely unsuitable types for a managerial role may be that the survey was taken by people who are in, or are interested in being in, the airline industry. There are high demands for professionalism in many of its professions. Employees undergo various types of training as part of their career development. In terms of personality typology, both aircraft maintenance technicians and airport security control staff must exhibit traits such as emotional stability, communication, problem-solving skills, and stress resistance, which are also essential prerequisites for successful management and leadership of people.

The results may also be influenced by the fact that up to 48% of respondents who participated in the survey had leadership experience. The survey showed that only 37% of the 48% of respondents who indicated that they had experience of managing and leading people had the personal qualities to hold a management position and were categorised as category 1 and 2. The remaining 11% of respondents, despite having experience in managing and leading people, were placed in category 3, where it is not recommended that these types of people be placed in a managerial position. By the fact that these people have already worked in a managerial position, it is evident that their predispositions to leadership, in terms of their typology, are not fully taken into account when selecting employees for these positions.

The survey showed no gender differences in terms of skills suitable for leading and managing people. However, where a difference between the genders is evident is that there are 10% more women than men who have experience of managing or leading people and are categorised as Category 1. On the other hand, there are 20% fewer women than men classified in category 3, where it is not recommended to hold a managerial position. Overall, 4.5% fewer women than men participating in the questionnaire survey are unsuitable for managerial positions. It should be noted that there are 10% fewer women than men who participated in the questionnaire survey and have experience in managing and leading people. This may be due to the widespread perception that women are not good enough leaders compared to men. This view is held by up to 50% of society, which is confirmed by the research „Sociological Institute of the Slovak Academy of Sciences: Men and Women in Management Positions,” where they focused specifically on the different views of men and women in management positions and confirmed that 59% of men are inclined to say that they are better managers than women [11].

Airport security control staff account for the largest number of respondents with experience in leading and managing people, accounting for 42% of respondents with experience. In comparison, aircraft maintenance technicians represent only 16%. One reason for this may be that 21% fewer aircraft maintenance technicians participated than airport security screening employees. Another factor that may have influenced this is the fact that security and screening employees are practical-technical or administrative types in terms of personality typology. This implies that they have very good organisational skills and tend to be broad-minded due to their technical-administrative skills and tend to be successful in work teams.

Respondents excelled in terms of assessed predispositions in the areas of communication and interpersonal skills, scoring an average of 12–13 out of a maximum score of 25. Contributing to these results was the fact that both airport security screeners and aircraft maintenance technicians work in teams, and their communication, interpersonal skills should be at a higher level, as a result of the soft skill requirements for these professions. Respondents scored the lowest mean scores in the areas of planning, organizing, analyzing and problem solving, where their mean score was 5 points out of a maximum of 25 points. This indicates the reserves that the respondents have in these areas and which they should develop through self-development activities.

The questionnaire survey assessment of managerial skills and predispositions of a person to lead and manage people in the aviation professions also revealed that there are people working in managerial positions who are typologically not the right types to fill managerial positions.

5. Conclusions

The style and method of leading and managing people depends on the personality typology, the method and form of communication, the chosen leadership methodology, and therefore the predisposition to become an effective manager depends on the ability to use one's strengths in the activities associated with the managerial position. The dispositions to become an effective leader cannot be defined through one particular characteristic, as the function of a manager requires a complex set of qualities, skills and expertise. We can only identify an approximate set of qualities, personality traits and manifestations of a manager, which are mainly communicativeness, extroversion, flexibility in decision-making, stress resistance, etc. Not every person possesses this set of qualities to such an extent that he or she is able to effectively fulfil the tasks of a managerial position. Therefore, we used a questionnaire survey to find out the managerial skills of the respondents in the aviation environment. The questionnaire included 8 areas assessed in terms of the requirements that a successful manager should meet. The survey revealed that 75% of the respondents have good
aptitude for managing other people. We identified two problem areas where respondents scored lowest on average. These were analysis and problem solving, planning and organizing skills. Respondents scored the highest average scores in the areas of communication and interpersonal skills, which are important for building strong workplace relationships, preventing conflicts, as well as motivating and supporting subordinates. These are skills that, when used appropriately, can inspire other people to create a motivating work environment that contributes to better work results, reduced errors at work or in the analysis and resolution of problems, thus reducing the level of perceived stress.

Such a questionnaire survey could help in the process of selecting suitable employees for managerial positions not only for airport security and screening staff, aircraft maintenance technicians, but also for other aviation personnel. The developed questionnaire may reveal deficiencies or confirm the established requirements in terms of personality characteristics for the performance of the occupied management function. It is important that the selection for the management function also takes into account the expertise and knowledge of the subject and it is also appropriate to conduct a practical test of the candidate’s skills in a model situation in the context of the management position, the so-called ‘trial manager’. This would create a three-stage model involving an assessment of predispositions for managing people, professional knowledge and the ability to apply it in practice.

References

The Proposal of Functions Describing the Opening and Closing Process of the Low-pressure Gas-phase Injector

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Abstract

In the article, functions describing the process of opening and closing of the low-pressure gas-phase injector necessary for creating mathematical models of the operation of a gas supply system for an internal combustion engine were proposed. To determine the real displacement of the injectors plunger, a special test stand was used, which allows a variety of adjustments associated with the injection process. The injection time and the working medium pressure were defined experimentally. The course of plunger lift was registered using an inductive displacement sensor, a carrier wave amplifier and an oscilloscope. Regression and the least squares method were used to identify the coefficients of the proposed functions. On the basis of the conducted analyses, it was found that the mapping of the process of opening and closing of the gas injector is correct. Moreover, the possibility of identifying the injector response times during the opening and closing processes was considered, i.e. the times when the plunger position does not change despite the input signal change.

KEY WORDS: mechanical engineering; combustion engines; alternative fuel supply; injector; research

1. Introduction

Despite the growing interest in hybrid [1] and electric [2, 3] vehicle powertrains, work continues on alternative fuelling systems for internal combustion engines. The use of low-carbon fuels, particularly liquefied petroleum gas (LPG) and compressed natural gas (CNG), favours the reduction of CO₂ emissions [4]. A significant effort is still being made to powertrain non-road machinery and vehicles [5], where there is also an attempt to use gaseous fuels [6, 7]. Studies are also related to the cost of converting the engine to alternative fuels [8], the possibility of expanding diagnostic systems [9], the use of new ways to power working elements [10, 11], or friction nodes [12, 13].

One of the main executive parts in gas power systems for internal combustion engines is the low-pressure gas-phase injector. A number of experimental studies of varying degrees of complexity are being conducted on this component. They are not only aimed at determining flow properties but also functional parameters such as injector opening and closing times [14, 15]. However, in process calculations of the gas injector, the complexity of the mathematical models varies greatly. Custom models are built and solutions are sought using specialized software environments such as Matlab/Simulink or Amesim [16, 17] or using finite element based software (FEM and CFD) SolidWorks, ANSYS [18, 19].

The operation of the low-pressure gas-phase injector is complicated. It combines electrical, mechanical and hydraulic (flow) parts. Each of these parts requires a separate functional description. The most problematic part is the electrical one, where the electromagnetic field effect is described [20], additionally taking into account the moving core inside [3, 4]. The electromagnetic field involves taking into account a number of nonlinearities [21], magnetic hysteresis and magnetostriction of ferromagnetic materials [22].

Model descriptions combined with process analysis formed the basis in proposals for diagnostic methods used in fuel injector performance diagnostics [17]. The opening and closing processes can be evaluated in several ways. Analysis is carried out on electrical signals such as voltage and current in the supply line [23], vibrations of the injector body [15], flow rate through the injector [24], or pressure at the outlet of the injector nozzle [25].

The development of mathematical models describing the operation of the supply system of an internal combustion engine, and consequently the whole engine, entails the adoption of certain simplifications. Building very complicated models taking into account as many details as possible is labour consuming and requires the use of large computational power. That is why it is advisable to use characteristic functions describing operation of particular components in the course of calculations.

The aim of the study was to propose functions that describe the process of opening and closing of the low-pressure gas-phase injector. The essential parameters of the proposed functions were determined by numerical identification in dedicated software. The knowledge of the model runs of the process of opening and closing the gas injector allows to significantly simplify the process of modelling the operation of the combustion engine power supply system.
2. Object of the Research

The test object was the low-pressure gas-phase injector Valtek Type 30 (Fig. 1). This injector represents a group of plunger injectors, which are normally closed in the unpowered state using a pressure spring. An electrical pulse of a certain shape and duration forces the injector to open. An essential feature of all fuel injectors, regardless of their type, is the opening and closing process. This process determines the relationship between the command from the injector operation control module and the response in the form of opening and closing. The basic technical data of the tested injector are shown in Table.

![Fig. 1 Valtek Type 30 injector](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>- nozzle size</td>
<td>4 mm</td>
</tr>
<tr>
<td>- piston stroke</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>- coil resistance</td>
<td>3 Ω</td>
</tr>
<tr>
<td>- opening time</td>
<td>3.4 ms</td>
</tr>
<tr>
<td>- closing time</td>
<td>2.2 ms</td>
</tr>
<tr>
<td>- max. working pressure</td>
<td>450 kPa</td>
</tr>
<tr>
<td>- operating temperature</td>
<td>(-20...+120) °C</td>
</tr>
</tbody>
</table>

3. Tests Stand and Result of the Measurement

The test stand used in this research course is used to determine the flow and functional characteristics, dosing irregularities of multi-injector sections and cycle-by-cycle dosing uniqueness of gas injectors. In this case, it was used to determine the plunger lift of the injector. For safety reasons, the tests were performed using air instead of gas as the working medium. The station was supplied with air from the air supply (1 in Fig. 2). Next, air was passed through air preparation system 2 to buffer tank 3. Buffer tank was designed to reduce air pulsations in supply system during cyclic opening of injector. The tested injector 4 was controlled with pulse generator 5 based STAG LLC. The measuring needle of inductive displacement sensor 6 was mounted to the plunger of injector 4. The measured signal from the displacement sensor was processed in carrier wave amplifier 7. The basic working parameters of the plunger displacement measuring setup (CL 80 and CL 104F ZPEWN Marki) were: response time < 0.1 ms, range ±1 mm, accuracy 1%. The amplifier waveforms were recorded with a Rigol MSO 4014 oscilloscope (bandwidth – 100 MHz, real time sample rate – up to 4 GSa/s, vertical resolution – 8 bit, frequency – 1 kHz).

![Fig. 2 Scheme of the test stand](image)

A control pulse time of 5 ms, no PWM (pulse width modulation), was used in the pulse generator 5 in this study. The operating pressure in the air supply system was 0.1 MPa. Fig. 3 shows the plunger displacement at the given input parameters. Significant distortions in the recorded waveform of the signal can be observed, due to the presence of the injector coil in the close range of the inductive displacement sensor, as well as disturbances in the power supply network affecting the operation of the carrier wave amplifier.

By reading the opening and closing times from the waveform (Fig. 3), differences were observed in relation to the injector manufacturer's declaration. From the measurements, the opening time was about 3.8 ms (manufacturer 3.4 ms), while the closing time was about 2.6 ms (manufacturer 2.2 ms). The difference is a result of mounting the measuring needle to the plunger, which increases its mass by 12%.

From Fig. 3, the time until full opened and time until full closed could be easily read. The problem is to read the response time for both the opening and the closing process. In the opening process the response time results from overcoming the preload of the pressure spring and possible friction resistances. In the closing process, the response time results from the rate of disappearance of the coil's electromagnetic field and possible frictional resistances. Furthermore, the response times are also a challenge in identifying the parameters of important functions describing the injector opening and closing processes.
4. The Proposal of Functions Describing the Opening and Closing Process

Based on the analysis of the opening and closing processes of the low-pressure gas-phase injector, the simplest function that can be proposed for description is the exponential function. For the opening process of the injector the function Eq. (1) was proposed.

$$h_{\text{open}} = h_{\text{max}} \left( \frac{t}{t_{fo}} \right)^{n_{o}},$$

where $h_{\text{max}}$ – maximum displacement of plunger; $t_{fo}$ – time until full opened; $n_{o}$ – exponent.

Whereas for the injector closing waveform Eq. (2):

$$h_{\text{close}} = h_{\text{max}} - h_{\text{max}} \left( \frac{t}{t_{fc}} \right)^{n_{c}},$$

where $h_{\text{max}}$ – maximum displacement of plunger; $t_{fo}$ – time until full opened; $n_{o}$ – exponent.

The significant parameters of the functions to be sought were considered to be $t_{fo}$ and $t_{fc}$ and exponents of powers $n_{o}$ and $n_{c}$.

5. Results and Discussion

Significant parameters of the function Eq. (1) and Eq. (2) ($t_{fo}$, $t_{fc}$, $n_{o}$ and $n_{c}$) were determined in the course of the identification based on the recorded and calculated displacement curves. To this end, a regression was used, minimizing the FPE estimator (Eq. (3)) through the Nelder-Mead simplex [27, 28] until the required calculation accuracy was obtained ($10^{-6}$).

$$\text{FPE} = \frac{j+l}{j(j-1)} \sum_{i=1}^{l} \left( h_{\text{exp}} - h_{\text{mod}} \right)^{2},$$

The mean and maximum prediction error (Eq. (4)):

$$\text{PE}_{\text{mean}} = \text{MEAN} \left| h_{\text{exp}} - h_{\text{mod}} \right|, \quad \text{PE}_{\text{max}} = \text{MAX} \left| h_{\text{exp}} - h_{\text{mod}} \right|.$$

The coefficient of determination adjusted to the degrees of freedom (Eq. (5)):

$$R^2 = 1 - \frac{j-l}{j-1} \frac{\sum_{i=1}^{j} \left( h_{\text{exp}} - h_{\text{mod}} \right)^{2}}{\sum_{i=1}^{j} \left( h_{\text{exp}} - \text{MEAN} \left( h_{\text{mod}} \right) \right)^{2}}.$$

Two parts were cut from the waveform shown in Fig. 4 at the initial identification phase. The first part representing opening begins at the moment of the impulse appearance (1 ms) and ends 0.01 mm before the maximum
The performed calculations resulted in the value of time until full opened $t_{fo} = 3.72$ ms, with exponent $n_o = 9.49$ and time until full closed $t_{fc} = 2.54$ ms, with exponent $n_c = 2.99$. The mean prediction error for opening was 0.0128 mm, for closing 0.0367 mm. The values of the maximum prediction error are largely due to disturbances during recording and are respectively 0.0567 mm for opening and 0.1617 mm for closing. The values of coefficient of determination representing the quality of fitting the model run to the experimental run are 0.9815 for opening and 0.8772 for closing. On this basis, it should be concluded that the proposed functions correctly describe the process of opening and closing of the low-pressure gas-phase injector analysed in this study. It should be highlighted that the calculations presented are for one type of injector and need to be extended to other models and types for determining general guidelines.

6. Conclusions

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Acknowledgment

This research was financed through subsidy of the Ministry of Science and Higher Education of Poland for the discipline of mechanical engineering at the Faculty of Mechanical Engineering Białystok University of Technology WZ/WM-IIM/4/2020.

References


The Simulation Model of a Multi-scrubber for Cleaning Gases Emitted by Marine Engines

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Abstract

The article presents the results of study hydrodynamics MULTI-scrubber with three inputs. The purpose of the study is to determine the distribution of velocity in the device with three inputs located at different angles. To conduct the study, 3D models of MULTI-scrubber with three inlets that clean the gas coming from marine engines were developed. Computational fluid dynamics (CFD) methods were used to study the gas flow in the MULTI scrubber. At the first stage of the work, two solid-state models of the MULTI scrubber were developed. The diameter of the MULTI-scrubber is 2.5 m, the height is 6.15 m, the diameter of the inlets is 1.1 m, the maximum gas volume is 17.2 kg / s. The research plan included seven computational experiments for different modes of operation of the MULTI-scrubber. Visualization of the results of gas flows made it possible to identify areas of increased gas velocities in the MULTI scrubber. Analysis of gas trajectories showed that for almost all modes of operation of the MULTI-scrubber there is a zone of high speeds in the near-wall zone of the device. Gas leakage and absorption efficiency may be reduced in this area. To improve the aerodynamics of the MULTI-scrubber in the part of the device where leakage can occur, it is necessary to provide increased irrigation of the gas flow to ensure a sufficient level of absorption. At the next stage of work on the models, the trajectories of the mud lines were studied. Experiments have shown the presence of circulating gas flows in the lower part of the MULTI-scrubber, which interact with the liquid irrigating the device from above and the liquid retained in the lower part of the device. In general, these flows can be considered a positive phenomenon due to the fact that the circulation improves the interaction in the gas-liquid system. Based on the simulation, measures were taken to improve the design, modes and efficiency of the MULTI-scrubber.

KEY WORDS: ship’s MULTI-scrubber for cleaning gas, computational fluid dynamics (CFD) for scrubbers, distribution of air flows in scrubber, simulation model flow in ship’s MULTI-scrubber

1. Introduction

To ensure high environmental performance of marine engines not only main engine should be connected with exhaust gas cleaning system but also diesel generators. In this case scrubbers with two, three or four inlets are used (MULTI-scrubbers). Such systems are developed as standard systems by leading manufacturers [1].

The principle of operation of the MULTI-scrubber is as follows: contaminated gas produced by marine engines enters the first stage of purification - Venturi scrubber where it reacts with the scrubbing liquid (modeling of this device is not considered). Then the gas passes through the second stage of purification - hollow scrubber. The use of several inlets allows to clean the gas from several marine engines.

The cycle of the scrubber is as follows: the gas flows from the inlet through the device to the outlet to the atmosphere [2]. The device produces spray of liquid (special NaOH solution). During process of interaction of the liquid and the gas it is being cleaned, harmful compounds are absorbed by the NaOH solution.

When using these devices there is a need to ensure even distribution of gas in the scrubber at partial loads. The use of several inlets allows to clean the gas from several marine engines.

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When performing numerical simulation, it was proposed to compare two designs of the device. The first design with the placement of inlet pipes as shown on Fig. 1 (MULTI-scrubber has pipes for gas supply at an angle of 90°) [2], and the second with the placement of inlet pipes in a circle at an angle of 120° (Fig. 2), this design is proposed as an alternative. Both scrubber designs are designed to connect three engines with a total capacity of 8 MW.

Technical characteristics of MULTI-scrubber:
- total power of connected engines - 8 MW;
- weight consumption of exhaust gas - 17.20 kg/sec;
- diameter of the device - 2500 mm;
- overall length - 4915 mm;
- overall width - 3860 mm;
– effective height - 6150 mm;
– supply height - 7285 mm;
– drainage outlet at the bottom of the base - 250 mm;
– height of gas cleaner supply - 2735 mm;
– nominal supply diameter - 750 mm;
– nominal outlet diameter - 1100 mm;
– nominal diameter of the drainage outlet - 400 mm

At the first stage of research, solid-body models of scrubbers were developed. The development of solid models allows to provide more informative visual representation of the design of the MULTI-scrubber and helps in the next stages of research. For example, from the model you can automatically obtain images of all components in dismantled condition and use them as illustrations for development of operating instructions for the device.

Solid state models also allow you to specify different materials from which the device and its individual elements can be made [3]. On the basis of selected materials in model it is possible to carry out the analysis of stresses and deformations by a finite element method. Thus, design errors can be detected at the early stages of designing [4].

Simulating the operation of a multi-scrubber is based on the studies carried out earlier in [5] and is their continuation.

2. Research of MULTI-Scrubber

Mass gas flow pressure and gas temperature was set at the inlet to the MULTI-scrubber. Atmospheric pressure was set at the outlet. To simplify the mathematical model, the following assumptions are made:
– gas is considered as an ideal incompressible gas;
– the influence of the scrubber walls on the gas movement is not taken into account;
– aerodynamic calculations are performed without taking into account the irrigation of the scrubber with scrubbing liquid.

As a result of the research it is necessary to find the distribution of gas velocities in the device. The numerical experiment was performed according to the developed plan (Table 1). A total of 7 experiments were performed for different modes of operation of the MULTI-scrubber, for two options of the MULTI-scrubber.

<table>
<thead>
<tr>
<th>Device type</th>
<th>Maximum gas consumption, kg/s (3 inputs work)</th>
<th>Average gas consumption, kg/s (2 inputs work)</th>
<th>Minimum gas consumption, kg/s (1 input works)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>17,2</td>
<td>11,5</td>
<td>5,73</td>
</tr>
<tr>
<td>Option 1</td>
<td>180°</td>
<td>11,5</td>
<td>–</td>
</tr>
<tr>
<td>Option 2</td>
<td>17,2</td>
<td>11,5</td>
<td>5,73</td>
</tr>
</tbody>
</table>

Studies were conducted for three modes of operation of the MULTI-scrubber:
– 1st mode - at maximum load, 3 inlets in use (three engines in use);
– 2nd mode - at moderate load, 2 inlets in use (two engines in use);
– 3rd mode - at the minimum load, one inlet in use (one engine in use).

Simulation of current lines for all modes of operation of the device is shown in Fig. 3 (operation of the device according to option 1).

From the results of visualization of flow processes it can be seen that when gas is supplied from three inlets circulating flows are formed below the inlet pipes, (Fig. 3, a), which interact with the liquid irrigating the device from
above and the liquid held at the bottom of the device. In general, these flows can be considered a positive effect due to the fact that the circulation improves the interaction in the gas-liquid system.

A similar effect of circulation is observed when supplying gas from two inlets (Fig. 3, b, c).

However, the intensity of circulation decreases slightly, which can be explained by a decrease in the flow of gas entering the device. Visualization of current lines during gas supply through one inlet (Fig. 3, d) also showed the presence of circulation in the lower part of the device.

For a more detailed analysis of currents in the device, 3 cross sections were selected: in the lower part of the device (directly at the outlet of the pipes), in the middle of the device and in the upper part. Analyzing the distribution of velocities in the sections, the most rational layout of the device can be chosen and measures to improve the hydrodynamics of flows in the device can be developed. Also, on the basis of the analysis of gas flow it is possible to define the most sustainable operating mode of irrigation nozzles which provides uniform irrigation and interaction of gas and liquid.

The simulation of gas flow in the MULTI-scrubber shows that the maximum velocities are observed in the area of the inlets to the device, and the main flow is formed in the center of the device. In the middle section of the device there is an area of significant reduction in gas velocity above the inlet pipes. At the same time in the center of the device the maximum velocity of a flow is observed. Therefore, in the middle section of the device there is a significant uneven distribution of velocities, which can affect the efficiency of gas interaction with the scrubbing liquid and reduce the efficiency of absorption.

When operating two engines, there can be 2 cases: first case when the inputs work at an angle of 90° or second cases - the inputs located opposite to each other, the angle 180°. The results of speed distribution studies show that the operation of the two inlets at an angle of 90° forms a zone of increased velocity on the opposite side, while a zone of reduced velocity is formed above the inlet pipes. In the upper part of the device there is a significant equalization of flow velocities almost throughout the whole cross section of the device. With this mode of operation, the leakage of polluted air through the device is possible only in the wall area of the device.

Considering the simulation results of the operation of the two inlets at an angle of 180°, we can see that in the center of the device, in the lower section, there is a zone of increased gas velocities. Then the gas velocity significantly reduces above the inlets, maintaining a center of increased velocities in the center and near the walls. In the upper part of the device a significant field of uniform velocities is formed, which improves the interaction of liquid and gas. Gas leakage is possible on the walls of the device.

During the operation of one engine in the cross sections of the device, the flow pattern changes slightly. In the lower section, a zone of maximum velocities is formed in the center of the device. In the middle section, a even velocity zone is formed along the entire cross section of the device with a zone of increased velocities in the walls opposite to the entrance. Such kind of flow remains the same in the upper part of the device. With this mode of operation, the phenomenon of leakage of the gas-air mixture may occur only in the wall area through the opposite entrance.

Simulation of a MULTI scrubber made according to option 2 was performed according to the experimental plan (Table 1). The task of the first numerical experiment was to determine the distribution of gas velocities in the MULTI-
scrubber with the simultaneous operation of three inputs (simulates the operation of three engines). The inlets of the MULTI scrubber are located at an angle of 120° to each other.

Simulation of current lines for all modes of operation of the MULTI-scrubber option 2 is shown on Fig. 4. From the given results of visualization of processes of a stream it is possible to see similar effect occurring at work of the MULTI-scrubber option 1 (Fig. 3, a). When gas is supplied from three inlets circulating currents are formed below the inlet pipes (Fig. 4, a).

Such a bottom gas circulation in the device is also observed when supplying gas from two inlets (Fig. 4, b), but the intensity of circulation slightly decreases.

Visualization of current lines during gas supply through one inlet (Fig. 4, c) also showed the presence of circulation in the lower part of the device.

A detailed analysis of the velocity distribution in the device shows that when the gas enters the device (in the lower section) (Fig. 4, a) a fairly uniform velocity field is formed in the center, which extends to almost the entire cross section of the device. Moving closer to the middle cross section of the device uniform velocity field remains the same with some deceleration of the flow in the areas above the inlet pipes. This deceleration occurs due to the peculiarities of the flow. In the upper section of the device a distribution of gas velocities remains relatively uniform.

![Fig. 4 Gas line trajectories in the MULTI-scrubber model, option 1: a – three inputs in use; b – two inputs in use (angle 120°); c – one input in use](image)

The formation of gas flows in the sections of the MULTI-scrubber during the operation of two engines (two inputs) is shown in Fig. 4, c. Visualization of the velocity distribution in the lower section of the MULTI scrubber shows a fairly uniform distribution of gas velocities. Moreover, it should be noted that this picture will probably be the same when operating any two inputs (due to the design of the location of the inlets at an angle of 120°).

Then moving to the middle section of the device there is a slight difference in speed across the section of the device. The distribution of currents in this section is close enough to the distribution in the same section for MULTI-scrubber option 1 (Fig. 1, b), this is due to a slight difference in the conditions of gas entry into the device.

Further movement of gas in the device to the upper section shows not a significant difference in velocity, but also formed zone of increased speeds in the wall area (opposite the inlets). This zone is similar to the zone of increased velocities shown in Fig. 1, c. Gas leakage is possible in this zone, thus the reduction in efficiency of absorption.

The flow pattern in the cross sections of the device is completely similar to the flow for the MULTI-scrubber option 1 (Fig. 1) when only one engine is used. In this flow mode, the phenomenon of leakage of the gas-air mixture can occur only in the wall area in front of the entrance.
3. Conclusions

The developed computer model allows to analyze the mode of operation of the MULTI-scrubber (for two variants of the MULTI-scrubber) by constructing the distribution of velocity fields and gas trajectories. Studies of the aerodynamics of the MULTI scrubber were performed for different aerodynamic loads. During the simulation, the gas flow rate varied from 5.73 to 17.2 kg/s, which corresponds to the modes of operation of the device in working conditions.

Analysis of gas trajectories shows that for almost all modes of operation of the MULTI-scrubber there is a zone of increased speeds near the walls of the device. Gas leakage and reduction of absorption efficiency is possible in this zone.

To improve the aerodynamics of the MULTI scrubber in the part of the device where leakage can occur, it is necessary to provide increased irrigation of the gas flow to ensure a sufficient level of absorption.

Experiments have shown the presence of circulating gas flows in the lower part of the MULTI-scrubber, which interact with the scrubbing liquid irrigating the device from above and the liquid retained at the bottom of the device. In general, these flows can be considered a positive effect due to the fact that the circulation improves the interaction in the gas-liquid system.

On the basis of simulation, it is possible to develop measures to improve the design, modes and efficiency of the MULTI-scrubber.

References

3. Discover the power of SOLIDWORKS with a free trial. Available from: https://plm-group.ru/solidworks-trial
Autonomous Emergency Braking (AEB) Experiments for Traffic Accident Reconstruction

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Abstract

Experiments on the behavior of the Autonomous Emergency Braking (AEB) feature of an Audi A4 and a Tesla Model X were performed at the indoor and outdoor facilities of the Center of Automotive Research on Integrated Safety Systems and Measurement Area (CARISSMA) research center of the University of Ingolstadt. The aim of these tests was to investigate the AEB system behavior of modern vehicles in the case of a crossing pedestrian, such as braking deceleration, delay times, and possibly stored digital traces, in order to be able to derive deductions for traffic accident reconstruction.

The first results of the tests show that the behavior of the AEB diverges significantly. This underlines the necessity to store the influences of an AEB system in case of a traffic accident in an Event Data Recorder (EDR).

KEY WORDS: Autonomous Emergency Braking (AEB), Instrument Cluster, Event Data Recorder (EDR)

1. Introduction

At the indoor and outdoor facilities of the Center of Automotive Research on Integrated Safety Systems and Measurement Area (CARISSMA) research center of the University of Ingolstadt experiments on the behavior of the Autonomous Emergency Braking (AEB) feature of an Audi A4 and a Tesla Model X were performed. AEB is a braking feature that is applied automatically by the vehicle in response to the detection of a likely collision to reduce the vehicle speed and potentially avoid the collision [1]. Resulting from this fact, the AEB feature performs accident-related system interventions, but is not included in the Event Data Recorder (EDR) according to the U.S. standard [2].

Fig. 1 EURO-NCAP CPNC-50 scenario, running child from nearside from obstruction vehicles [1]
The aim of these tests was to investigate the AEB system behavior of modern vehicles, such as braking deceleration and delay times, as well as possibly stored digital traces. The results will be used to substantiate the need, as described in several publications [3-5] to store the AEB behavior in the EDR in the event of a collision. For this purpose, the EURO-NCAP scenario known as Car-to-Pedestrian Nearside Child 50% (CPNC-50) was used for the test. In the process, a child target obscured by parked vehicles moves into the driving corridor of the Vehicle Under Test (VUT). The vehicle and pedestrian target are synchronized in such a way that a possible contact would occur in the middle of the vehicle front (position L) as shown in Fig. 1.

2. Test Preparation and Set-Up

In the first step, preliminary tests were carried out on the outdoor test facility with a self-constructed foam dummy pulled by a UFO platform from the company Humanetics. An Audi A4 Avant equipped with Audi pre-sense city was used as the VTU and an Audi Q7 was used as an obstruction to vision. This can be seen in Fig. 2.

An Automotive Dynamic Motion Analyzer (ADMA) with Differential Global Navigation Satellite System (DGNSS) from Genesis was used to collect the vehicle dynamics data. GoPro cameras were used inside the vehicle and digital SLR cameras were used outside to record the videos. The tests showed that the AEB system of the Audi did not react reliably to the self-constructed foam dummy which was partially irreversibly damaged by the collisions. However, the preliminary tests provided valuable results with regard to the handling and evaluation of the measurement and video technology used and with regard to efficient test execution.

Based on the knowledge gained from the preliminary tests, indoor tests were carried out in the CARISSMA test hall under laboratory conditions, including tests in the dark and rain. Here, a Tesla Model X, with first registration in 2018 and Autopilot version 2.5, was used as the VUT. The AEB tests were performed with a crossing adult dummy of the company 4a, which was mounted on a UFO platform. A total of 6 synchronized video streams, as shown in Fig. 3, were recorded. In addition, the motion data of the UFO platform and the driving data of the Tesla were recorded via an ADMA in conjunction with a correvit sensor from the company Kistler.
In addition to the driving data and the AEB intervention data also the displayed pictograms and system messages in the Tesla’s instrument cluster were evaluated. Via the position determination, which is refined not only by the measurement systems used but also by the use of the camera optimization module in PC-Crash, a correlation between the indication in the instrument cluster and the actual position of the accident participants can be determined.

3. Comparison of the Indication in the Instrument Cluster to the Reality

For a more in-depth investigation of the behavior of the AEB, the display generated by the vehicle in the instrument cluster, which represents the surrounding area, was examined. The pictorial representation is based on data from the installed sensors, which record and process the external area of the VUT. As the internal processing of the recordings in the vehicle is protected by the manufacturer, it is not possible to interpret them without having the corresponding documents. To circumvent this and still be able to perform an approximate interpretation, the synchronized external video files were analyzed, which already contain a temporal comparability between the real recorded event and the display shown in the instrument cluster. For this purpose, individual time points in the sequence were recorded pictorially so that the display in the instrument cluster could be compared with the real event. In order to achieve this, the camera that has a clear view through the windshield was used for the comparison with the recordings of the instrument cluster. In order to be able to determine the corresponding positions from the recorded points in time, an image alignment was carried out using the software PC-Crash (program module Camera Optimization). To compare the positions, the tests were simulated with PC-Crash. This procedure is shown in Fig. 4.

![Fig. 4 Position determination by image superimposition in PC crash](image)

For further interpretation of the behavior, the determined positions with the recordings were summarized in an overview. For this, a template, which can be taken from Table 1, was used. The videos were processed with a recording rate of 60fps and thus have the time format [s:fps].

<table>
<thead>
<tr>
<th>Description of the recorded position, time of recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recording of the camera that records the view through the windshield of the VUT.</td>
</tr>
<tr>
<td>2. Recording of the camera that records the display of the instrument cluster.</td>
</tr>
<tr>
<td>3. Recording of the camera, which records the overall VUT environment.</td>
</tr>
<tr>
<td>4. Evaluating the positions in PC Crash.</td>
</tr>
</tbody>
</table>

Table 1

For the following interpretations, the recordings of third and fourth have been removed from Table 1 to improve comparability. Fully evaluated tests will follow in a further publication.

In the example of experiment A that is shown in Table 2, a clear misinterpretation of the system can be seen, since at the beginning of the detection a motorcycle is detected on the roadway, whereas the 4a adult target was centered on the vehicle axis at this point. Before the collision, the target was recognized as a human being and was also shown as such on the display.

Another misinterpretation of the system can be seen in experiment B from Table 3. In this case, the target was detected, but it is not recorded as a hazard despite the imminent collision. In the further course of the test, no target is shown in the display, although it is located directly in the hazardous area. After the collision, the dummy is again displayed as a hazard and, in the further course of the crash, a human is also detected as a hazard at the vehicle side.
Table 2

Extract from the evaluation of experiment A

<table>
<thead>
<tr>
<th>Experiment A</th>
<th>Position 1: First appearance of the target (in the form of a motorcycle) as a warning, video timing: 10:19 [s:fps]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="Image1" alt="Position 1" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Position 2: Detection as human target just before collision, video timing: 10:25 [s:fps]</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Image2" alt="Position 2" /></td>
</tr>
</tbody>
</table>

Table 3

Extract from the evaluation of experiment B

<table>
<thead>
<tr>
<th>Experiment B</th>
<th>Position 1: First appearance of the target without warning despite hazardous area, video timing: 09:21 [s:fps]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="Image3" alt="Position 1" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Position 2: Collision point without detection of the target, video timing: 09:34 [s:fps]</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Image4" alt="Position 2" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Position 3: Recognition of the target as a warning, video timing: 09:41 [s:fps]</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Image5" alt="Position 3" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Position 4: Detection of a second target on the side of the VUT, video timing: 09:56 [s:fps]</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Image6" alt="Position 4" /></td>
</tr>
</tbody>
</table>
4. Conclusions

The performance of the AEB used in the Tesla Model X, which detects objects in the vehicle's surroundings and displays the information in the instrument cluster, is not reliable. Weaknesses in the correct processing can be seen, since there is sometimes no recognition of the target in the hazardous area in front of the VUT. If the target is detected and correctly interpreted or classified, there are significant deviations between the target positions displayed in the instrument cluster and those in reality. Whether this is based on the latency between detecting the target by the AEB system and displaying the information in the instrument cluster in the case of correct interpretation or classification, or essentially on the latency between sensor recording and processing or interpretation by the system, must be clarified by further research. For traffic accident reconstruction, it can be stated that in the future the EDR not only has to store in the event of a collision whether an AEB system was active or not active, but also on which basis it made its decision to intervene or not to intervene in the vehicle's driving dynamics or to warn or not to warn the driver about the dangerous driving situation.

Acknowledgements

This work was supported by the German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung) [grant number 13FH71041A], through the funding program “Forschung an Fachhochschulen”. The third-party funding source of the project is the DEKRA Automobil GmbH.

References

Evaluating the Degradation Process of Electronic Elements on Combat Vehicles in Accelerated Reliability Test on Multifactor Stress

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Abstract

Combat vehicles often work under harsh conditions, greatly affecting the lifetime and reliability of the equipment used on them, especially electronic equipment. Electronic equipment is made up of electronic elements, so the used electronic elements must be highly reliable to meet the survival requirements of combat vehicles. The reliability study of electronic elements in simulated conditions close to the actual working conditions of the combat vehicle is necessary before using them on combat vehicles under real working conditions. The tests of this type usually must be conducted over a long time to obtain the desired results. Therefore, Accelerated Reliability Test (ART) is an effective resolution and is often used thanks to shortening the time and cost for testing. However, even in the ARTs, hard failures of highly reliable products rarely occur, and it leads to many limitations in evaluating product reliability over lifetime data. Then the degradation data containing information about the product degradation process is analyzed using statistical mathematical models (typically Wiener process-based model, Gamma process-based model, or statistical regression model ...). The result is the information about the state of the product, as well as its lifetime or residual lifetime (via soft failures), can be determined. In this paper, the methodology and procedure of an accelerated reliability test for a typical electronic element on combat vehicles - LEDs - is presented. In this test, three accelerating factors (high temperature, ON/OFF cycling, and current load) have been applied to accelerate the degradation process of LEDs. To evaluate the degradation data of the experiment, the Wiener Process-Based Model with measurement errors and Statistical Regression Model are used, and a comparison between evaluation results of the two models will be done.

KEY WORDS: accelerated reliability test; LED; combat vehicle; electronic part; Wiener process; regression model

1. Introduction

Currently, electronic devices are present on all high-tech devices, in the civil field as well as in the military. The use of the above devices helps to solve the main problems of the equipment, thanks to the diverse features, high reliability, and compactness of the electronic devices used. The above factors are especially important for vehicles, which always require the reduction of equipment in both size and mass. It further increases the role of electronic devices for the whole device.

On combat vehicles, including modern combat vehicles and tanks, electronic elements are used in most systems and devices, for example, fire control systems, reconnaissance systems, navigation systems, communication systems, and warning system, signalling system, engine control system, hybrid systems (electric – mechanical, electric – hydraulic, electric – pneumatic), sensing systems, active and passive defence systems.... The stable and effective operation of the above systems and equipment plays a decisive role in the operational efficiency as well as the survival of combat vehicles. Obviously, the working reliability of the above systems is determined by the electronic elements used inside. Therefore, the study of reliability, determining the lifetime as well as determining the technical status of electronic components on combat vehicles is a really necessary issue. To perform the above tasks, the accelerated reliability tests are often implemented, thereby reducing the time and costs of testing. In the above experiments, experimental conditions are simulated close to actual working conditions on combat vehicles, helping to accurately evaluate their operation when used on real vehicles.

LEDs are a type of electronic elements widely used in both civilian and military fields, as well as on combat vehicles due to their technical advantages, including high reliability and lifetime (lifetime can reach 50,000 ÷ 70,000 hours), wide working temperature range (–20 ÷ 80°C), more resistant to mechanical impact than other traditional light sources. LEDs are used as a light source for many different types of electronic devices, including LCD backlights (Mobile phones, Cameras, Portable media players (PMPs), Notebooks, Monitors, TVs), displays (Electric scoreboards, Outdoor billboards, Signage lighting), transportation equipment lighting (Vehicle/train lighting, Ship/airplane lighting), and general lighting (Indoor lighting, Outdoor lighting, Special lighting). On combat vehicles, LEDs also perform the same functions as mentioned above, but the working conditions will change. The working load (voltage, current) is higher and changes more frequently in different high temperatures, humidity, vibration, and mechanical shock.

The accelerated reliability tests of LEDs in the civilian field have been carried out quite a lot, for example, the experiments in published works 2, 3, 4. In these works, the accelerated reliability tests of LEDs were performed at different temperatures and the parameter of interest measured is emitted light output. However, direct measurement of the emitted light output on combat vehicles is not easy, so, for LEDs on combat vehicles, the parameter of interest...
measured can be voltage or current, due to these parameters can be more easily measured in the case of continuous monitoring of the technical condition of LEDs. Currently, there are not many works on implementing accelerated reliability test for LEDs on combat vehicles. This article presents an accelerated reliability test designed for LEDs on combat vehicles with three accelerating factors (high temperature, ON/OFF cycling, and current load).

In addition, a very important issue in assessing the technical condition and life of electronic elements is processing and evaluating data obtained from experiments. Nowadays, electronic elements are high-reliability products. So even in the accelerated reliability tests, the hard failure rarely occurs. As a result, the product life, as assessed through failure data, will be limited. Therefore, it is common to use product degradation process data during use to determine the technical condition of the product as well as to predict the product RUL through the soft failure. The degradation data are usually processed by mathematical-statistical models, in which a reasonable selection of the mathematical model will help reduce the deviation of the model from the data, reduce the amount of information lost in the data processing. The mathematical-statistical models commonly used to describe the degradation process are Wiener process-based model, Gamma process-based model, Statistical Regression model, etc. The above types of mathematical-statistical models are detailed in the following published works 5, 6, 7. In the above mathematical-statistical models, the Wiener process-based model and the Statistical Regression model are two types of models that are widely used to describe the degradation process of many different objects, thanks to its flexibility, i.e., applicable with many different degradation data structures (with both monotonic or variable increments), and mathematically straightforward. In this article, the Wiener Process-Based Model with measurement errors and Statistical Regression Model will be used to process the degradation data of LEDs from the accelerated reliability test. These two models also include the differences between subjects in a sample into the model, called unit-to-unit variates.

2. Experiment Based on ART

International Standard IEC 62506 gives the definition of Accelerated Reliability Test: “Accelerated Reliability Test is the test shortened by application of increased stress levels or increasing the application rate of repetitive stresses, thereby speeding up product reliability assessment through failure mode discovery and mitigation” 8. According this standard, the Accelerated Reliability Test can be divided into three groups: In this standard, the Accelerated Reliability Test is divided into three groups: Type A (Highly accelerated limit tests (HALT), Highly accelerated stress tests (HAST), and Highly accelerated stress screening/audit (HASS/HASA)), Type B, and Type C. Especially with type C, we can combine some acceleration factors to perform ART to further shorten the experiment time. In this section, the ART is described through the following aspects: the testing conditions of the experiment, the experiment objects, and the experiment procedure.

2.1. The Testing Conditions of the Experiment

The testing conditions of the experiment are determined based on several parameters: actual working conditions of LEDs on combat vehicles, type of acceleration factors used, and required values of acceleration factors.

When working on combat vehicles, LEDs are usually assembled in sealed cases with protective, moisture-proof elements and shock absorbers to help minimize all impacts during work. So even though combat vehicles often must work in harsh and varied conditions, the main factors that affect the working reliability of LEDs are temperature, load, and working conditions. The main causes of the degradation process and failure of LEDs also analysed in detail in the work 1. So, three accelerating factors of the experiment are selected, respectively high temperature, ON/OFF cycling, and current load. The average working conditions of LEDs on selected combat vehicles are as follows: average working time of a combat vehicle is 8 hours per day, where the average time in ON mode of electronic equipment is 1 hour; the number of ON/OFF cycles per day is two cycles.

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2.2. The Experiment Objects

The selected experimental object is warm white LED 10W 700LM / 90° with basic parameters: the luminous flux 700 ÷ 800 lm; forward current 1.05 A; forward voltage 9 ÷ 11 V; the power dissipation 9.45 W. The experiment temperature is 90 °C. Use the approximate formula (1), suggested by BMW in 9, one can determine approximately the acceleration factor of temperature:

\[ A_F = 2^{\frac{\Delta T}{T}} , \]  

(1)

where \( \Delta T = T_s - T_0 \) is the temperature difference between the testing and normal operating conditions, \( T_s \) and \( T_0 \) are the normal operating temperature and the accelerated test temperature, respectively. In this case, \( T_s = 90 \, ^°\text{C} \) and \( T_0 = 30 \, ^°\text{C} \). Then \( A_F = 2^{\frac{90-30}{10}} = 64 \). Thus, one working hour of LEDs in the experiment is equivalent to one working hour of LEDs in real conditions or eight working hours of combat vehicles. One ON/OFF cycle per minute in the testing condition. Thus, for one minute, LEDs are on for 30s and off for 30s. Thus, two ON/OFF cycle in testing condition ensures one
minute of LEDs working under experimental conditions, equivalent to 1 hour working of LEDs in actual conditions or 8 hours working of combat vehicles. The selected loading current is the forward current 1.05A of the LEDs. This reduces the risk of electrical overloading the LEDs. However, the forward currents 0.95A and 0.85A are also used to test the effect of load current on the reliability of LEDs.

2.3. The Experiment Procedure

The experiment was performed simultaneously on 38 LEDs of the same type. LEDs are fixed on aluminium panels in groups with 4 ÷ 5 LEDs in one group. The aluminium plate used here is both a mounting bracket, as well as making the heat exchange process between the LED and the outside environment easier. In a group, LEDs are connected in series with the same loading current (see Fig. 1). The voltage of each LED is measured continuously by KEYSIGHT 34980A Multifunction Switch / Measure Unit. Measured data are transmitted and stored in the PC with BenchLink Data Logger Pro software.

![Fig. 1 Diagram of series LEDs in a group](image)

![Fig. 2 The current change chart provided for each LED in ON/OFF mode](image)

Each LEDs group is powered by high-precision digital DC power units (KEYSIGHT E3634A). The loading currents of the LEDs groups fluctuate with different amplitudes. Specifically, the four first groups (18 LEDs) are supplied with an oscillating current with amplitude \( I_f = 1.05 \) A, the second group (5 LEDs) with an oscillating current with amplitude \( I_f = 0.95 \) A, the third group (5 LEDs) - with an oscillating current with amplitude \( I_f = 0.85 \) A. All the above LEDs groups were placed collectively at the temperature of 90°C in the climate chamber Votsch VC3 7034. The chart of current load changes with different \( I_f \) values (1.05A; 0.95A; 0.85A) is shown in Fig. 2.

The remaining ten LEDs (the last two groups) are tested by a constant loading current of 1.05A and placed in the climate chamber Votsch VT 4004 collectively at the temperature of 90°C.

In this experiment, the parameter of interest is the voltage between the two ends of the LEDs, measured continuously every 5 minutes. These voltage values carry information about the degradation of LEDs. Because the first 28 LEDs work in ON/OFF mode, when the last 10 LEDs work under constant loading current, so the degradation quantities comparison of LEDs in different working modes becomes inaccurate due to the different measurement conditions. To avoid the above problem, degradation measurement of all LEDs is performed between 11:00 am and 11:30 AM. During this time, all LEDs are working with a different constant loading current.

3. Evaluating Experiment Degradation Measurements

Evaluating experiment degradation measurements is an important step of the experiment. Although the experiment is going on and there has not been any failure yet. However, analysing the degradation data has yielded some useful information about the degradation process of LEDs, as well as being able to help predict the RUL if a critical level for the soft failure is predefined. Evaluating experiment data usually consists of two phases: processing the raw data and using mathematical-statistical models to describe the degradation process to obtain useful information. In this paper, only the degradation data of the first four group of LEDs (18 LEDs) with oscillating current load with amplitude 1.05A in ON/OFF mode and the last two group of LEDs (10 LEDs) with constant loading current 1, 05A in ON/ON mode are being processed.

In this case, from the raw data obtained from the experiment, the unique voltage value between 11:20 am and 11:25 AM every two days is taken and combined into the degradation data for each LED after the test time. The degradation parameter, a function in respect of time, is calculated by subtracting the other voltage values measured at the remaining times from the voltage values of the first measurement. Fig. 3 shows the mean degradation parameter values \( \Delta U \), of LEDs over 65 days, where each data set is the mean degradation of all LEDs in one working mode (ON/OFF and ON/ON modes). The graphic shows an increasing trend of the degradation parameter over time, and it can be seen that the mean degradation values of LED in ON/OFF mode are equivalent to the mean degradation values of LED in ON/ON mode, although the working time of LEDs in ON/OFF mode is only half of the working time of LEDs in ON/ON mode. This can be explained as the effect of ON/OFF cycling on the degradation process of LEDs.

Because measurement errors are an unavoidable factor in experiments, therefore, the paper uses the Wiener Process-Based Model with Measurement Errors and SRM to process the degradation data of LEDs. In addition, to investigate the effect of differences between LEDs of the same type in the degradation process, the unit-to-unit variate is included in the model.
3.1. Wiener Process-Based Model with Measurement Errors and Unit-to-Unit Covariates

Wiener Process-Based Model (WPBM) with measurement errors and unit-to-unit covariates is proposed and used in works 10, 11, 12. Assume that, we have degradation data set, with $n$ unit and $m$ observations for each unit. Let $y_{ij} = y(t_{ij})$ be observed degradation value at the time $t_{ij}$ with $i = 1 \ldots n$ and $j = 1 \ldots m$. Then this degradation process can be described by the model, as shown in the following Eq. (2):

$$y_{ij} = x(t_{ij}) + \epsilon_{ij} = \mu(t_{ij}) + \sigma B(t_{ij}) + \epsilon_{ij},$$

where $y_{ij}$ is the observed degradation values of $i$-th object at the time $t_{ij}$; $x(t_{ij})$ is the true degradation values of $i$-th object at the time $t_{ij}$. The true degradation increments $x_{i1}, x_{i2} - x_{i1}, \ldots, x_{im} - x_{i(m-1)}$ are independent of each other and follow a normal distribution with mean $\mu(t_{ij}) - \Lambda(t_{j-1})$ and variance $\sigma^2 \left( \tau(t_{ij}) - \tau(t_{j-1}) \right)$; $B(t_{ij})$ is a Brownian motion; $\epsilon$ is measurement errors, and has normal distribution, $\epsilon \sim N(0, \sigma^2)$ and are independent of each other and of the true degradation value $x(t_{ij})$; $\mu_i$ is drift parameter; $\sigma$ is variance parameter; $\Lambda(t_{ij})$, $\tau(t_{ij})$ is time-scale transformation functions and can follow the different laws, including linear law $\left( \Lambda(t) = at \right)$, the Power law $\left( \Lambda(t) = e^{at} \right)$ or exponential law $\left( \Lambda(t) = t^a \right)$, $a$ is unknown fixed coefficient.

Assuming that the degradation values are measured at the same times for all units, then subscript $i$ can be removed from the time notation. At the same time, the vector and matrix are denoted by a bold symbol. Denote $y_i = (y_{i1}, y_{i2}, \ldots, y_{im})'$ is a vector of the degradation values of $i$-th object at the time $t_{ij}$; $x_i = (x_{i1}, x_{i2}, \ldots, x_{im})'$ is a vector of observation time; $\epsilon_i$ is a vector of measurement errors; $\Lambda = (\Lambda(t_1), \Lambda(t_2), \ldots, \Lambda(t_m))'$ and $\tau = (\tau(t_1), \tau(t_2), \ldots, \tau(t_m))'$ are the vectors of the time-scale transformation functions. Then the Eq. (2) can be rewritten as follows:

$$y_i = \mu_i \Lambda + \sigma B(\tau) + \epsilon_i.$$

Then $y_i = (y_{i1}, y_{i2}, \ldots, y_{im})'$ follows a multivariate normal distribution with mean $\mu_i \Lambda'$ and covariance matrix $\Sigma$ with its $ij$-th elements defined in Eq. (4):

$$\Sigma_{ij} = \text{cov}(Y_i, Y_j) = \begin{cases} 
\sigma^2 \tau(t_{ij}) & j = k \\
\sigma^2 \min(\tau(t_i), \tau(t_j)) & j \neq k
\end{cases}$$

To include the unit-to-unit variate in the mathematical model, $\mu$ is assumed to be different between different units, and is normally distributed, $\mu \sim N(\mu_0, \sigma_\mu^2)$. Then $y_i = (y_{i1}, y_{i2}, \ldots, y_{im})'$ follows a multivariate normal distribution with mean $\mu_i \Lambda'$ and covariance matrix $\Sigma = \Omega + \sigma_\mu^2 \Lambda \Lambda'$, where:
\[ \Omega = \sigma^2 Q + \sigma^2 I_m, \text{where } Q = \begin{bmatrix} \tau(t_1) & \tau(t_2) & \cdots & \tau(t_k) \\ \tau(t_1) & \tau(t_2) & \cdots & \tau(t_k) \\ \vdots & \vdots & \ddots & \vdots \\ \tau(t_1) & \tau(t_2) & \cdots & \tau(t_k) \end{bmatrix} \] (5)

and \( I_m \) is an identity matrix. In 12, the MTTF can be computed by Eq. (6):

\[ t_{MTTF} = \Lambda^{-1} \left( \frac{h}{\mu_0} \right), \] (6)

where \( h \) - predefined critical level, which is assumed, that product will fail (soft failure) when the observation degradation exceeds this level.

### 3.2. Statistical Regression Model

Statistical Regression Model (SRM) can be applied to a degradation data structure, which has linearity or can be linearized. Derived from the model used in 13, using the symbols specified in 3.1, the Statistical Regression model can be written as in Eq. (7):

\[ y_i = X\beta + \varepsilon, \] (7)

where \( y_i \) is \( m \times 1 \) vector of degradation quantiles of \( i \)-th unit; \( \varepsilon \) is \( m \times 1 \) vector of measurement errors in experiment, 

\[ \varepsilon \sim N(0, \sigma^2 I_m); \ I_m \text{ is } m \times m \text{ identity matrix; and } X = \begin{bmatrix} 1 & \Lambda(t_1) \\ \vdots & \vdots \\ 1 & \Lambda(t_m) \end{bmatrix}. \]

To include the unit-to-unit variate in the equation of mathematical model, in this case, \( \beta \) is assumed to be different between different units, and follows a normal distribution, shown in (8):

\[ \beta = \begin{bmatrix} \beta_0 \\ \beta_1 \end{bmatrix} \sim N \left( \begin{bmatrix} \alpha_0 \\ \alpha_1 \end{bmatrix}, \begin{bmatrix} \sigma_0^2 & \sigma_{01} \\ \sigma_{10} & \sigma_1^2 \end{bmatrix} \right); \ \alpha = \begin{bmatrix} \alpha_0 \\ \alpha_1 \end{bmatrix}; \ V = \begin{bmatrix} \sigma_0^2 & \sigma_{01} \\ \sigma_{10} & \sigma_1^2 \end{bmatrix}. \] (8)

Then \( y_i \) also follows a normal distribution with mean \( \mu_i = E(y_i) = Xa \) and covariance matrix \( \Sigma_i = \text{cov}(y_i) = XVX^T + \sigma^2 I_m \). The unknown parameters of this model also are estimated by Maximum Likelihood method (MLE). The expression to define the \( p \)-quantile of the failure time is given in 13.

### 3.3. Statistical Inference

The first step is determining the form of time-scale transformation function. The time-scale transformation function \( \Lambda(t), \tau(t) \) can be one in three forms: linear law, the Power law, or exponential law. The form of time-scale transformation function can be defined from the prior knowledge of physical mechanisms or the degradation data based on correlation coefficient. In this article, based on the suggestion of works 12, 14, the form of time-scale transformation function is selected that \( \tau(t) = \tau(pt) = a t^r \), where \( a \) is unknown fixed coefficient.

The mathematical model of the degradation process is deterministic when all its unknown parameters have been found. The unknown parameters of the two above models can be estimated by Maximum Likelihood Method (MLE), where the total Log-likelihood function (Log-LF) of \( n \) unit is computed by Eq. (9):

\[ l(\theta) = \sum_{i=1}^{n} l(\theta) = -\frac{nm}{2} \log 2\pi - \frac{1}{2} \log \det(\Sigma) - \frac{1}{2} \sum_{i=1}^{n} \left( y_i - E(y_i) \right)^T \Sigma^{-1} \left( y_i - E(y_i) \right), \] (9)

where \( \theta \) is parameters vector, \( \theta = (\mu_0, \sigma_0^2, \sigma^2, \alpha_0, a) \) and \( E(y_i) = \mu_i \Lambda \) for WPM; or \( \theta = (\alpha_0, \alpha_1, \sigma_0^2, \sigma_1^2, \sigma_{01}, \sigma^2, a) \) and \( E(y_i) = Xa \) for SRM. Getting the first partial derivatives of \( l(\theta) \) and set equal to 0, the equations system (10) is obtained. Solving this equation system, the estimators \( \hat{\theta} \) are defined for the above mathematical models.
However, in practice, solving a system of equations with many unknowns is relatively difficult, especially when the degradation data is large enough, the expression of Log-LF is very complicated. So, a three-step computing method has been introduced and used for WPBM in the works 10, 11, 12. The detailed procedure of this method is as follows:

The first step: using least square method, the rough estimates of $\mu_1, \mu_2, \ldots, \mu_n$ and $a$ can be obtained by minimizing the mean squared error (MSE): \[ MSE = \sum_{i=1}^{n} (y_i - \mu A)^2 (y_i - \mu A); \] The second step: the rough estimates of $\mu_0, \sigma^2_0$ and $a$ can be found by fitting the estimations $\mu_1, \mu_2, \ldots, \mu_n$ to normally distributed $N(\mu_0, \sigma^2_0)$; The final step: based on the found estimates $\mu_0, \sigma^2_0$ and $a$, the remaining estimates of $\sigma^2$ and $\sigma^2_v$ can be computed from MLE.

Based on the idea of the above three-step computing method, this article proposes a similar three-step computing method for SRM. Because $\beta=(\beta_0, \beta_1)^T$ is assumed to follow a bivariate normal distribution, as shown in (8), the $\beta_0$ and $\beta_1$ also follow a univariate normal distribution, respectively $N(\alpha_0, \sigma^2_0)$ and $N(\alpha_1, \sigma^2_1)$. The first step: using least square method, the rough estimates of $\beta_0, \beta_1, \ldots, \beta_n$, $\alpha_0, \alpha_1, \ldots, \alpha_n$ and $a$ can be obtained by minimizing the MSE: \[ MSE = \sum_{i=1}^{n} (y_i - X \beta_i)^2 (y_i - X \beta_i); \] The second step: the rough estimates of $\alpha_0, \sigma^2_0$, and $\alpha_1, \sigma^2_1$ can be found by fitting the estimations $\beta_0, \beta_1, \ldots, \beta_n$ and $\alpha_0, \alpha_1, \ldots, \alpha_n$ to univariate normally distributed $N(\alpha_0, \sigma^2_0)$ and $N(\alpha_1, \sigma^2_1)$ respectively; The final step: based on the found estimates $\alpha_0, \sigma^2_0, \alpha_1, \sigma^2_1$ and $a$, the remaining estimates of $\sigma^2_v$ and $\sigma^2_{hv}$ can be computed from MLE.

### 3.4. Applying two Models into the Degradation Data of LEDs in ART

In this part of the article, the degradation data of the first group of LEDs (18 LEDs) with oscillating current load with amplitude 1.05A in ON/OFF mode and the degradation data of the last group of LEDs (10 LEDs) with constant loading current 1.05A in ON/ON mode have been used with two models above. The comparison of the fitness of the two above models with the degradation data is performed by the Log-LF values $l(\theta)$ and the corresponding Akaike information criterion (AIC) values calculated for the two models. The results are given in Table 1 and Table 2 and are shown in Figs. 4-7. From the obtained results, it can be seen that the WPBM and the SRM give a similar result. However, with the bigger LED quantity, the WPBM has a higher $l(\theta)$ value and lower AIC values than the SRM. It means that this model better fits with the degradation data from ART.

### Table 1

<table>
<thead>
<tr>
<th>The testing condition</th>
<th>LED quantity</th>
<th>$\mu_0$</th>
<th>$\sigma^2_0$</th>
<th>$\sigma^2$</th>
<th>$\sigma^2_v$</th>
<th>$\sigma^2_{hv}$</th>
<th>$a$</th>
<th>$l(\theta)$</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5A ON/OFF</td>
<td>18</td>
<td>4,273.10^{-4}</td>
<td>6,211.10^{-9}</td>
<td>3,839.10^{-7}</td>
<td>3,939.10^{-7}</td>
<td>0,7213</td>
<td>3564</td>
<td>-7118</td>
<td></td>
</tr>
<tr>
<td>1.5A ON/ON</td>
<td>10</td>
<td>1,3.10^{-3}</td>
<td>1,32.10^{-8}</td>
<td>5.83.10^{-7}</td>
<td>2,72.10^{-8}</td>
<td>0,4598</td>
<td>2122</td>
<td>-4234</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>The testing condition</th>
<th>LED quantity</th>
<th>$\alpha_0$</th>
<th>$\alpha_1$</th>
<th>$\sigma^2_v$</th>
<th>$\sigma^2_{hv}$</th>
<th>$\sigma^2_v$</th>
<th>$\sigma^2_{hv}$</th>
<th>$a$</th>
<th>$l(\theta)$</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5A ON/OFF</td>
<td>18</td>
<td>4,491.10^{-4}</td>
<td>2,45.10^{-4}</td>
<td>1.04.10^{-6}</td>
<td>9,421.10^{-10}</td>
<td>-2,32.10^{-8}</td>
<td>1,71.10^{-7}</td>
<td>0,8498</td>
<td>2053</td>
<td>-4092</td>
</tr>
<tr>
<td>1.5A ON/ON</td>
<td>10</td>
<td>7,91.10^{-4}</td>
<td>7,858.10^{-4}</td>
<td>7,906.10^{-7}</td>
<td>1,544.10^{-8}</td>
<td>-1,57.10^{-7}</td>
<td>1,12.10^{-7}</td>
<td>0,5528</td>
<td>2130</td>
<td>-4246</td>
</tr>
</tbody>
</table>
4. Conclusions

This article introduces an ART, used to test the reliability of LEDs, a typical electronic element used on combat vehicles, under experimental conditions, close to their real working conditions on this type of vehicle. The three acceleration factors selected are high temperature, ON/OFF cycling, and current load, which all are the main causes affecting to reliability and lifetime of LEDs. The article also gives two mathematical-statistical models - the Wiener Process-Based Model with measurement errors and unit-to-unit covariates and Statistical Regression Model, a method to find the estimates of unknown parameters of models, and used them with the degradation data obtained from the ART. The obtained results show that the degradation process of LEDs in ON/OFF mode is almost equivalent to the degradation process of LEDs in ON/ON mode. It is the influence of the acceleration factor - ON/OFF cycling – on the degradation process of LEDs and shows the need to include the acceleration factor of ON/OFF cycling in the mathematical-statistical model.

Acknowledgement

This paper has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development, VAROPS, University of Defence, Brno.

References


Covid 19 as a New Risk Factor in the Work Safety Management of Professional Drivers

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Abstract

The year 2020 and the Covid -19 pandemic significantly affected all spheres of our lives and this fact also affected the sphere of passenger transport. The Covid 19 pandemic has brought number of challenges to the management of urban public transport companies. At the time the virus came to Slovakia, there were no crisis pandemic plans, there was a lack of supplies of crisis material; crisis management practices have developed over the course of the process. It is difficult to keep a business in operation, the task of which is to ensure that the population of the city is relocated for work during a pandemic, when movement is restricted. It is not possible for public transport drivers not to feel the effects of the corona crisis, but it is necessary to minimize them. Coronavirus poses a new risk in the work conditions of professional drivers and, although it is a biological factor, it carries risks not only for physical but also for mental health. The article focuses on the analysis of the principles of managing the safe work of professional drivers of urban public transport and the impact of the current situation during the pandemic Covid 19 on changes in driver management from the aspect of their safety and health protection.

KEY WORDS: driver, human resources, management, risk, safety, work

1. Introduction

One of the most demanding professions is the job of a professional driver. A truck or van driver, a courier, a hauler, a public transport driver or a taxi driver are quite common occupations in our country, which feed thousands of people. According to the Unified Road Transport Information System, we currently have more than 80,000 truck drivers and more than 20,000 bus drivers in Slovakia. At work, they spend hours behind the wheel every day and drive an average of 300 to 700 kilometres. The transport sector is dominated by men. Employees in this sector are exposed to long sittings, tiring and painful positions, long working hours (on average more than 48 hours per week) and non-standard working hours (working at night and in the evening, working on weekends and working more than 10 hours a day). Not surprisingly, this sector has a relatively negative impact on work-life balance. In addition, drivers have limited options when it comes to healthy eating and exercise during breaks on the road. Bus drivers face many occupational risks. The most common health problems reported by drivers include lower back pain, overweight, cardiovascular and respiratory diseases, and work-related stress. These problems have been found to be related to work environment factors (e.g. poor work organization) and working conditions (static work) and individual risk factors (e.g. lack of exercise, unhealthy diet, and alcohol abuse, smoking, age and pre-existing conditions). When preparing programs to promote workplace health, it is extremely important to assess and address the role and impact of both factors, organizational and individual, on the health and well-being of drivers. By quality of working life we mean a complex of conditions that affect a person in the work process and result in his effective course [1, 2]. We consider working conditions to be a very important part of the lives of all workers, and even more so in the case of professional drivers. The Covid 19 pandemic has affected every sector of the economy, including transport. Covid 19 also poses a new risk for urban public transport bus drivers. The article deals with the impact of the Covid 19 pandemic on the working conditions of bus drivers and the emergence of new health and psycho-social threats.

2. Working Conditions in Company Management

We define working conditions as a set of factors directly or indirectly affecting the health and work performance of a person in the work process, which directly or indirectly condition the course and results of the work process, are influenced by work regime, rest and state of work environment [3]. This set consists of factors of the working environment: physical, chemical biological, which are the product of material and technical equipment of the workplace.

Working conditions can be divided into immediately tangible and tangible conditions, such as work and operating facilities, premises, workplace equipment, work equipment, work aids, etc. and intangible conditions such as working time arrangements, rest periods, work organization, degree of workload, responsibility, degree of independence, the level of care of the employer for the safety and health of its employees and the like [4]. We can also distinguish between social conditions where interpersonal relations in the team in which the employee is included, interpersonal relations in the organization and relations with persons outside the organization with whom the employee...
comes into contact within the work [5].

**Legal aspects of working conditions and protection of employees**

The basic source for the regulation of working conditions and protection of employees in the Slovak Republic is normative legal acts, especially the Constitution of the Slovak Republic, laws and legal regulations issued for their implementation. In the field of working conditions, the provision of Article 36, which states that employees have the right to fair and satisfactory working conditions, is particularly important. Act no. 311/2001 Coll., The Labour Code regulates individual employment relationships in connection with the performance of dependent work of natural persons by legal entities or natural persons, as well as collective employment relationships [6]. Act no. 124/2006 Coll., The Act on Safety and Health at Work defines the application of requirements for safe work. This Act establishes the general principles of prevention and basic conditions for ensuring occupational safety and health and for the exclusion of risks and factors conditioning the occurrence of accidents, occupational diseases and other occupational health damage [7]. Pursuant to § 147 paragraph 1 of the Labour Code, the employer is obliged to continuously ensure the safety and health of employees at work and to take the necessary measures for this purpose, including prevention, the necessary means and appropriate system for managing occupational safety and improve all activities and to adapt the level of labour protection to changing realities. He is also obliged to identify hazards and threats, assess the risk and prepare a written document on the risk assessment of all activities performed by employees. It is also important to issue internal regulations, rules on safety and health at work and to give instructions to ensure safety and health at work. The employer classifies employees for the performance of work with regard to their state of health, in particular the result of the assessment of their medical fitness for work, abilities, their age, qualifications and professional competence. In order to fulfil the obligation in the area and to ensure safety and health protection at work of the employer's employees, the employer must eliminate all hazards at their source through the thoughtful creation of the work environment and work procedures.

**Specifics of the work of a bus driver**

The bus driver independently drives and operates a motor vehicle - a bus for the purpose of transporting persons in road transport. The performance of this employment is regulated by the following legal regulation: Act no. 280/2006 Coll. on compulsory basic qualifications and regular training of certain drivers, as amended by the Road Traffic Act. The performance of this job requires a statutory certificate or other written certificate: Driving license to drive motor vehicles of group D according to Act no. 8/2009 Coll. on Road Traffic and on Amendments to Certain Acts as Amended by Later Regulations Driver Qualification Card, Certificate of Basic Qualification and Certificate of Regular Training pursuant to Act no. 280/2006 Coll. on compulsory initial qualification and periodic training of certain drivers [8]. The issue of medical and mental fitness of motor vehicle drivers is regulated by the legal rules. Medical fitness is assessed by a medical examination; mental fitness is assessed by psychological examination. In traffic psychology, it is mainly about perception, attention, memory and decision-making. Emotions and moods and various personality variables such as temperament, motivation, attitudes, values and interests are also important. In addition to cognitive and personality variables, the driver's psychomotor skills, his flexibility, coordination of movements and the speed and accuracy of driving responsibilities also play an important role.

**General competences of the bus driver**

The bus driver must have a high level of decision-making, physical fitness, good communication skills, and cultivated speech. He must be independent, technically literate, and able to analyse and solve problems. Elementary information literacy and communication in a foreign language at a basic level and mathematical literacy are also required. The driver should be able to plan and organize work, be adaptable, flexible, flexible in thinking and capable of improvisation.

**Professional knowledge and skills**

Knowledge of transport regulations, pricing and tariffs in public passenger transport is required; legal regulations in the field of driver's working time according to the Act No. 462/2007 Coll. on work time organisation, law on labour inspection [9]. Knowledge of the means of control of passengers in the means of transport, internal organizational guidelines - normative instructions, internal regulations, internal standards, principles of providing first aid knowledge of risks endangering one's own health or the health of others and principles of safety at work is also required; legislation and basic concepts in the field of road transport. It is important to orientate in the regulations for driving buses, resp. trolleybuses or trams, driving buses, checking the operability of buses before the start of the journey (Checking the functionality of the brakes, signalling and signalling equipment, air systems passengers follows from the driver of § 12 of Act No. 56/2012 Coll. on Road Transport, as amended.), the provision of information to passengers on connections in urban public transport. The driver is obliged to observe the principles of safety at work and occupational hygiene, provide assistance to disabled passengers in getting on and off the bus, assist passengers in storing luggage in the luggage compartment of the bus, keeping the prescribed documentation on the operation of buses, providing first aid [10].

Driving a motor vehicle is a demanding and complex activity requiring constant readiness and response of the organism to incoming stimuli, which can take place on a conscious and unconscious level and is dependent on several variables. From driver skills, abilities, experience. From various cognitive determinants ensuring the reception and processing of information from the outside and inside world. The safe driving of a motor vehicle does not depend only on the skills, abilities, knowledge of the driver or the technical condition of the vehicle. The key in a given situation is the driver himself, his perception, experience and subsequent behaviour affects the overall outcome of the situation. And it is the driver's personality structure, his temperament, emotionality, motives, attitudes, ability to manage the load
that have a decisive influence on traffic behaviour. The author Kleinmann express the driver's driving behaviour by the equation $R = f(S - O)$, where $R$ is the driver's behaviour (response to stimuli), which is a function of perceived and acting stimuli on the driver $S$ and his personality characteristics $A$. According to these authors, driver behaviour can take place on two levels. On an unconscious level, i.e. automated activities of the driver, and at a level of consciousness, where the driver engages in automated activities consciously, according to changing driving conditions and stimuli, and decides on the most appropriate correct choice of response [11]. According to Štikar et al. driving is a complex activity composed of several elements such as sensorimotor coordination, reaction time, judgment, attention, emotions, motivation and the ability to create the ability to drive a motor vehicle through learning [12]. Havlík is of the opinion that driving a motor vehicle means constantly responding to a changing traffic environment and meeting its requirements [13]. Working conditions and fulfilled requirements for the work of bus drivers significantly contribute to the elimination of their occupational risks.

3. Risk Factors in Drivers' Working Conditions

The work of professional drivers is one of the most risky occupations.

**Risk factors of work in the transport sector**

These risks can generally be divided into three groups: factors related to work, work environment and individual factors. Work-related factors - whole-body vibration, noise, long sitting, tiring and painful postures, strict schedules, work for shifts and night rides, insufficient breaks and sleep, repetitive tasks and monotonous routine work, irregular eating, traffic accidents, transport flammable, explosive and toxic substances, air conditioning, non-ergonomic movement when entering or leaving the cabin, etc. Factors related to the working environment - carbon monoxide (CO), sulphur dioxide (SO2), nitric oxide (NO) x, asbestos, polycyclic aromatic hydrocarbons (PAH), benzene, particulate matter, climatic conditions, pollen, physical violence, etc. Factors related to the individual - gender, age, ethnic origin, education, personality, attitudes, risk perception, experience with accidents and previous motor vehicle accidents, private life events, fatigue, pre-existing diseases (allergies, asthma, diabetes, myocardial infarction, etc.), drug use (antihistamines, sedatives), lifestyle (lack of physical activity and unhealthy eating habits) and risky behaviour (smoking, excessive alcohol consumption, use of hard and soft drugs), etc. [14].

**Specific health risks**

Drug addiction - this is a reported and/or confirmed addiction to various psychoactive substances (so-called soft and hard drugs), which can lead to various mental disorders to complete degradation of personality. This includes chronic alcoholism. Depending on the degree of personality disintegration and the ability to abstain, it leads to a complete or partial reduction in working capacity, up to complete disability. The issue of a driving license is, in the case of chronic alcoholism, subject to a safe withdrawal period, consistent and persistent abstinence lasting at least 2 years. An individual approach to the assessment of an employee's medical fitness requires, in some cases, close cooperation with a psychiatrist and the employer in order to prevent the aggravation of the disease or the risk of the victim, resp. its surroundings.

Behavioural disorders - They include e.g. aggressive, antisocial and defiant behaviour of a lasting nature, often associated with an unfavourable psychosocial environment and unsatisfactory family relationships. They manifest themselves, for example: in isolation; manifestations of hostility towards the environment or, conversely, the search for authorities and groups with dissocial and delinquent activities. They can restrict the choice of profession, especially professions requiring psych tests.

Psychosocial risks - arise as a result of poor work planning, organization and management, as well as poor social work context, and can have negative psychological, physical and social consequences such as work-related stress, burnout or depression. Working conditions that lead to psychosocial risks include, for example, excessive workload; conflicting tasks and insufficiently clear definition of tasks; insufficient involvement of the worker in decision-making on matters concerning him and insufficient influence on the way the work is performed; poorly managed organizational change, job insecurity; ineffective communication, lack of support from management or colleagues; psychological and sexual harassment, third party violence. When assessing the complexity of work tasks, it is important not to confuse psychosocial risks, such as excessive workload, with conditions that may be stimulating and sometimes demanding, but in which the work environment provides support and workers are properly trained and motivated to perform according to their the best skills. A good psychosocial environment supports quality performance and personal development, as well as the mental and physical well-being of the employee. An important factor of motivation is if the company emphasizes safety within the corporate culture and creates such conditions in which the safety of drivers, but also the safety of the logistics process comes first. Drivers are relatively easy to identify with this, as it directly affects them and often motivates them to stay in such a company for a long time [15].

**Changes in drivers’ working conditions due to the current Covid 19 pandemic**

COVID-19 has resulted in unprecedented challenges for workers’ safety, health and well-being. Managers must communicate clearly, consistently, transparently, and empathetically with all employees about policies, programs, and procedures that protect their health from COVID-19 to reduce their sense of insecurity and health concerns (J. T. Dennerlein, et al., 2020). Within the area of working conditions, the central element of worker health protection is effective infection control in the workplace with the aim of eliminating or at least reducing the possibility of COVID-19 exposure to workers. These include technical inspections, e.g. increased fresh air ventilation and highly efficient air filters to reduce airborne pathogens. This also includes ensuring the testing of workers and monitoring contacts to
ensure the safety of workers. (J. T. Dennerlein, et al., 2020). "The main risk of a pandemic is fear of the future," said economist Vladimír Baláž (2020) at the end of February. Individual attitudes to risk vary between individuals. If it is negative, we call it risk aversion [16]. When perceiving the risk of death, an individual's attitude may vary depending on the size of the probability that the condition will occur and the total volume of deaths recorded. The results of experiments suggest that people are risk averse when they are unlikely to make a loss and behave differently when they are unlikely to make a profit [17]. The collective fear of a new viral disease, called "corona phobia," has caused a number of psychiatric manifestations at various levels of society" (Dubey et al., 2020). On the other hand, fear is a person's natural protective response to an identified threat that is taking place at a given moment. "People who show an aversion to insecurity are more likely to interpret any ambiguous information as threatening, which contributes to significant somatic stress responses [18, 19].

Research results and discussion

The pandemic brought changes to drivers' working conditions. The obligation of increased hygiene, wearing a veil and respirator, mandatory testing was added. Drivers use respirators as well as passengers to prevent the spread of infection. Due to the emergency situation, increased emphasis is placed on hygiene and cleanliness even during the daily maintenance of vehicles. From 1 October 2020, all buses and trolleybuses returning from day and night lines undergo thorough disinfection in addition to standard cleaning. Interior elements such as handles, seats, markers and door demand buttons are treated with disinfectants with high effectiveness against bacteria and drift viruses. Comprehensive disinfection of the room and especially the upholstered parts of the seats is deeply treated by pressure spraying of a special disinfectant solution. The biggest risk for drivers has become the risk of infection. Coronavirus poses a new risk in the working conditions of professional drivers and, although it is a biological factor, it carries risks not only for physical but also for mental health. Employees experience stress when the demands of their work are disproportionate and greater than their ability to face them. In addition to mental health problems, workers who suffer from long-term stress can develop serious physical health problems such as cardiovascular disease or muscle and bone disease.

The questionnaire survey was realised in Slovakia, in the period from 10 March to 30 April 2021, 121 bus drivers took part in this research. The survey focused on the perception of risks in the driver's work in connection with a pandemic. They consider the threat of Covid 19 to be the most significant risk. In connection with the current situation, the driver's responsibilities of a hygienic nature, disinfection of the vehicle, and control of drapes for passengers have been extended. They perceive as a negative the obligation to wear respirators, which was later abolished for drivers in a separate cabin. Drivers come into conflict with undisciplined passengers. 24% of respondents came into conflict with passengers in the course of half a year, especially in the evening. Drivers report increased stress caused by a pandemic situation but also possible job loss. 74% of respondents are aware of stress as a significant factor at work. While driving, the driver is exposed to a certain psychological load, the management of which depends on the overall ability to handle the load and the degree of his stress tolerance. Resistance to psychological stress in traffic psychology means the ability to process and cope with the requirements and influences of the traffic environment. For drivers (27%), the perception of the risk of job loss due to reduced mobility of the population during a pandemic is not negligible, which also increases stress. The ability to handle load and stress is a prerequisite for safe driving. Research shows that drivers are affected by stressful situations. Their impact depends on the situation and the type of profession. Hill and Boyle (in Horáková, 2009) identified the 4 most important stressors: weather, visibility, interactions with others, and the tasks that are placed on the driver [20]. A coronavirus pandemic also has an indirect effect on mental health, making many people more likely to succumb to stress, anxiety and depression. Abroad, the term coronavirus anxiety, i.e. anxiety from coronavirus, is increasingly used. Drivers were satisfied with the availability of testing and the organization of work by employers, the use of new technologies to disseminate the necessary information. Drivers are also concerned about the possible transmission of the disease to their loved ones. Drivers are also aware of other risks in their work, such as the risk of an accident, the onset of illness in connection with a long sitting while driving. Sitting all day behind the wheel has a detrimental effect on health and significantly increases the risk of cardiovascular disease. 27% of drivers are also concerned about the worsening of existing health problems. 48% of respondents negatively perceive increased fatigue.

The majority of respondents (75%) are in favour of vaccination against Covid 19, but had reservations about the availability of vaccination due to the vaccination strategy in Slovakia. They argue that they should have been given priority for vaccination as part of critical infrastructure. According to several studies, every fifth traffic accident is caused by a driver's fatigue or micro sleep, with the most vulnerable group being professional drivers. Injuries resulting from an accident, which cause, for example, limited wrist mobility, do not have as negative an effect on other jobs as they do on professional drivers. Serious traffic accidents can not only leave permanent bodily injury, but also lead to disability. However, it is not only the damage to the wrist that causes the professional driver to withdraw his driving license, but also, for example, paralysis, reduced sensitivity in the legs or significantly impaired vision and blindness. The driver not only looks at the traffic in front of him, but also around himself, in the rear-view mirrors, etc.; it also monitors the on-board computer, but also the passengers, to see if everything is in order. If the passenger folds the veil, he will warn him of the obligation to put it on. The current situation regarding the spread of the new coronavirus exposes people to conditions to which many have not become accustomed. Social isolation is deepening, interpersonal relationships are being disrupted, and people are losing economic security and stability, which can evoke feelings of hopelessness and fear. Long-term mental strain can escalate into anxiety and depression. Anxiety is a complex emotion, a state of arousal, a reaction to danger. Adrenaline is flushed out, the heart beats, breathing speeds up, arms and legs are perfused, ready to escape or attack. At the same time, it is difficult to channel this excitation because there is no clear source of anxiety or any straightforward solutions and "rescue" options. We cannot guess at first glance who is and is
not infected, on which handle someone left a virus.

**Risks after Covid19**

Little is known about the long-term consequences of covid, and studies are ongoing. It is certain that in many patients serious cardiological, pneumological, but also neurological, internist and other difficulties were observed after overcoming the disease. The most common persistent symptoms include shortness of breath, fatigue and muscle aches. Many cured people claim that their normal activities are much more tiring than before the disease. Others claim to have been in a wheelchair as a result of the disease. Many of those cured also had heart problems, difficulty breathing or worsening liver values. Another alarming finding is that COVID-19 can cause diabetes. In a broader context, the driver's senses can also be negatively affected. During a pandemic, we not only fight the virus, but we also try to control and manage the fear and stress that affect our mental health. However, not all of us manage it well. This is one of the reasons why helplines for mental health problems are overloaded, and it is no coincidence that the topic of mental health has become a major topic during a raging pandemic, in addition to COVID-19. Regular monitoring of health risks and health education of drivers should be a key part of any initiative of an organization to promote occupational health. Health risk control is an evidence-based process that can be used to identify key health threats and lifestyle issues: such as sleep apnoea, diabetes, high blood pressure, and tobacco use problems. In addition, trained professionals should provide guidance to drivers on how to directly address these issues. Particular attention should be paid to diet, physical activity, maintaining adequate weight, sleeps habits and personal responsibility for health habits. Health education training should focus on specific topics. As a rule, health education training should place great emphasis on developing skills and strengthening drivers' self-confidence in order to maintain motivation and good health habits. It turned out that the active participation of employees during the whole control of health risks and in the process of health education contributed to the acquisition of good health habits by drivers. The management of human resources in transport, on the one hand, is under pressure from production and sales alone to reduce transport costs, which should be linked to improving the quality of all components of transport services and, on the other hand, creating new world structures in transport [21, 22].

4. Conclusions

The negative impact of the pandemic on the organization includes a low overall business performance, an increased number of absences, the so-called too strict attendance (the employee comes to work when he is ill and unable to perform the required performance) and an increased rate of accidents and injuries. Absences are usually longer than those for other reasons, and work-related stress can contribute to increased early retirement rates. The estimated costs for businesses and society are significant. Coronavirus has brought new risks to the work of professional drivers in urban public transport, many of which will only become apparent in the longer term. In order to eliminate the negative effects of the pandemic on transport companies and drivers' working conditions, a thorough and timely identification of risks in the area of not only physical but also mental health is needed. Vaccination against Coronavirus appears to be the most effective, but the pre-existing consequences and threats of a pandemic must also be taken into account. The management of these companies faces challenges that require the application of many managerial and organizational measures in crisis management and risk management. The situation calls for the development of scenarios for which further research should be focused. In order to effectively manage and prevent Covid risks, organisations should use a host of actions and strategies aimed at both the worker and the workplace.

Acknowledgement

This publication was created thanks to support under the Operational Program Integrated Infrastructure for the project: Identification and possibilities of implementation of new technological measures in transport to achieve safe mobility during a pandemic caused by COVID-19 (ITMS code: 313011AUX5), co-financed by the European Regional Development Fund.

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A Case Study of Digital Technologies in Intermodal Freight Forwarding

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Abstract

The object of this study is the application of digital technologies, namely KIPIS, used by the chosen forwarding company in intermodal freight forwarding. The main factors determining the long duration of the intermodal freight forwarding process operations are the need to physically present the documents to the customs, registration, and waiting in line. The analysis of the application of the chosen company’s digital technology KIPIS revealed its significant impact because the duration of the critical path was shortened by 3 hours 10 minutes, i.e. 2.28-fold. This saves time, paper, printer ink, and fuel. Labor productivity increased 2.28-fold.

KEY WORDS: digital technologies, intermodal forwarding, productivity

1. Introduction

Container shipping is an activity that is widespread around the world and is becoming increasingly important in the shaping of the global economy. About 60% of all goods are transported in containers. The value of the goods transported has increased almost 150-fold in the last forty years. It is necessary to improve data processing and transmission systems in order to ensure uninterrupted and smooth movement of cargo flow. Digital technologies used in intermodal freight forwarding are investigated worldwide. The studies [1–10] take a look at such important issues as e-logistics of cross-border transportation, container security, control optimization, digital sociotechnical system, etc. The object of the study is the application of digital technologies, namely KIPIS (Freight and Goods Information System of Klaipeda State Seaport), in intermodal freight forwarding. The methods, such as structural analysis of freight forwarding operations, chronometric observation, expert method, network graph, Gantt chart, and productivity assessment, are applied to the study.

2. Research Results

Before presenting the results of the study obtained by applying the above methods, it is appropriate to mention that the share of the container market held by the chosen port company is 1%, based on container handling indicators of Klaipeda State Seaport. However, in the last 5 years, the annual market share has increased by 0.19 percentage points on average.

2.1. Chronometric Observation

The chronometric observation was performed in order to assess the freight forwarding process over time (Table 1).

<table>
<thead>
<tr>
<th>Operations</th>
<th>Start and end of operation</th>
<th>Optimistic time (h)</th>
<th>Pessimistic time (h)</th>
<th>Average time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry of data into KIPIS before arrival of the vessel</td>
<td>0-1</td>
<td>0.5</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>Generation of a declaration</td>
<td>1-2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>Referral of the container to the forwarder</td>
<td>2-3</td>
<td>0.1</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Preparation of an invoice and CMR, copy of T2L, entry of data into KIPIS</td>
<td>3-4</td>
<td>0.2</td>
<td>0.3</td>
<td>0.24</td>
</tr>
<tr>
<td>Customs, phytosanitary, and X-ray inspections</td>
<td>3-5</td>
<td>0.5</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Selection of a truck, sending of instructions to the driver</td>
<td>5-6</td>
<td>0.1</td>
<td>0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>Report to the client on arrival, inspection of the container</td>
<td>6-7</td>
<td>0.1</td>
<td>0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>Invoicing</td>
<td>7-8</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The observation showed how much time the individual steps of the forwarding process required. The average time necessary to perform a particular operation in accordance with the early and late period of the stages was determined. A
time reserve was calculated but not included. The available results are sufficient to determine the impact of KIPIS.

2.2. Expert Method

This method helps to estimate the duration of several operations before the implementation of the KIPIS system. The evaluation criteria are as follows: submission of data on the incoming ship to the customs authorities, time during which a declaration is generated and the container is referred to the freight forwarder (Table 2).

<table>
<thead>
<tr>
<th>Operations</th>
<th>Minimum time (h)</th>
<th>Maximum time (h)</th>
<th>Average time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submission of data on the incoming ship to customs authorities</td>
<td>0.5</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Time during which a declaration is generated</td>
<td>1.5</td>
<td>5</td>
<td>2.9</td>
</tr>
<tr>
<td>Referral of the container to the forwarder</td>
<td>0.3</td>
<td>0.6</td>
<td>0.42</td>
</tr>
</tbody>
</table>

The physical delivery of documents to the customs authorities, registration, waiting in line determines the long duration of the operations. The time before the implementation of KIPIS is compared with the time when the KIPIS system is installed.

2.3. Network Graph in the First Case

The average time of the forwarding operations without the KIPIS system for the network graph is presented in Table 3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Operations</th>
<th>Start and end of operation</th>
<th>Optimistic time (h)</th>
<th>Pessimistic time (h)</th>
<th>Average time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Submission of data on the incoming ship to customs authorities</td>
<td>0-1</td>
<td>0.5</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>Arrival at port of destination</td>
<td>1-2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Generation of a declaration</td>
<td>2-3</td>
<td>1.5</td>
<td>5</td>
<td>2.9</td>
</tr>
<tr>
<td>4</td>
<td>Unloading of the container from the vessel</td>
<td>3-4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Referral of the container to the forwarder</td>
<td>4-5</td>
<td>0.3</td>
<td>0.6</td>
<td>0.42</td>
</tr>
<tr>
<td>6</td>
<td>Preparation of an invoice and CMR, copy of T2L</td>
<td>5-6</td>
<td>0.2</td>
<td>0.3</td>
<td>0.24</td>
</tr>
<tr>
<td>7</td>
<td>Customs, phytosanitary, and X-ray inspections</td>
<td>6-7</td>
<td>0.5</td>
<td>1.5</td>
<td>0.9</td>
</tr>
<tr>
<td>8</td>
<td>Selection of a truck, sending of instructions to the driver</td>
<td>5-8</td>
<td>0.1</td>
<td>0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>9</td>
<td>Transport process control</td>
<td>7-9</td>
<td>0.1</td>
<td>0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>10</td>
<td>Report to the client on arrival, inspection of the container</td>
<td>9-10</td>
<td>0.1</td>
<td>0.2</td>
<td>0.14</td>
</tr>
</tbody>
</table>

The time data are obtained by means of the expert method and observation. The next step is a critical path in the network graph (Fig. 1).

![Fig. 1 Network graph of the forwarding process without the KIPIS system](image)

The critical path lasted 5.64 hours. Operations 2 and 4 did not affect the time but, of course, these operations were part of the forwarding process.
2.4. Network Graph in the Second Case

The average time of the forwarding operations, using the KIPIS system, for the network graph is presented in Table 4.

<table>
<thead>
<tr>
<th>No.</th>
<th>Operations</th>
<th>Start and end of operation</th>
<th>Duration (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Submission of data on the incoming ship to customs authorities</td>
<td>0-1</td>
<td>0.7</td>
</tr>
<tr>
<td>2</td>
<td>Arrival at port of destination</td>
<td>1-2</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Generation of a declaration</td>
<td>2-3</td>
<td>0.25</td>
</tr>
<tr>
<td>4</td>
<td>Unloading of the container from the vessel</td>
<td>3-4</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Referral of the container to the forwarder</td>
<td>4-5</td>
<td>0.1</td>
</tr>
<tr>
<td>6</td>
<td>Preparation of an invoice and CMR, copy of T2L, entry of data into KIPIS</td>
<td>5-6</td>
<td>0.24</td>
</tr>
<tr>
<td>7</td>
<td>Customs, phytosanitary, and X-ray inspections</td>
<td>6-7</td>
<td>0.9</td>
</tr>
<tr>
<td>8</td>
<td>Selection of a truck, sending of instructions to the driver</td>
<td>5-8</td>
<td>0.14</td>
</tr>
<tr>
<td>9</td>
<td>Transport process control</td>
<td>7-9</td>
<td>0.14</td>
</tr>
<tr>
<td>10</td>
<td>Report to the client on arrival, inspection of the container</td>
<td>9-10</td>
<td>0.14</td>
</tr>
</tbody>
</table>

The time of submission of data to the customs authorities, generation of a declaration, and delivery of the container to the forwarder shortened (Fig. 2).

![Fig. 2 Network graph of the forwarding process using the KIPIS system](image)

The critical path lasted 2.47 hours (or 2 hours 29 minutes), i.e. it was 3 hours 10 minutes (2.28-fold) shorter. The difference between the longest and the shortest times was 1 hour. After the implementation of the KIPIS system, the physical filling in documents, printing of documents in 4 copies, their transportation, and waiting in line at the customs were eliminated.

2.5. Gantt Chart

The assessment of digitization of the freight forwarding operations using the KIPIS system is shown (Fig. 3).

![Fig. 3 Duration of forwarding operations in Gantt chart](image)

The Gantt chart shows the time of the freight forwarding process in hours and minutes. The critical path, as
mentioned, is 2 hours 29 minutes. Customs, phytosanitary, and X-ray inspections in the case where a diversion is received for cargo inspection, and data entry into the KIPIS system before the arrival of the vessel take the longest time. The declaration is confirmed automatically within 15 minutes if there are no comments.

It is important to mention that the KIPIS system operates on a one-stop-shop basis. The biggest advantage is that the data entered is visible to all relevant authorities.

2.6. Productivity Assessment

The last objective is to determine how many individual forwarding operations an employee can perform per working day. In the case of the chosen forwarding company, the forwarder’s productivity will be calculated twice – before and after the implementation of the KIPIS system. The condition is that the working day corresponds to 8 hours. The data in both cases is recorded in the productivity formula (1), (2).

\[
Productivity_1 = \frac{1,418 \text{ operations}}{8 \text{ hours}};
\]

\[
Productivity_2 = \frac{3,24 \text{ operations}}{8 \text{ hours}},
\]

where \(Productivity_1\) – before the implementation of the KIPIS system; \(Productivity_2\) – after the implementation of the KIPIS system.

In this case, productivity is relative because the condition relating to the duration of a working day has been introduced for comparison. However, the key aspect is the number of operations over the same period of time. The higher the number of operations, the more efficient the freight forwarding process is. The formulas show that with the introduction of the KIPIS system, labor productivity increased 2.28-fold.

3. Conclusions

The main factors determining the long duration of the intermodal freight forwarding process operations are the need to physically present the documents to the customs, registration, and waiting in line. The analysis of the application of the chosen company’s digital technology KIPIS revealed its significant impact because the duration of the critical path was shortened by 3 hours 10 minutes, i.e. 2.28-fold. This saves time, paper, printer ink, and fuel. The environment is less polluted. After the implementation of the KIPIS system, labor productivity increased 2.28-fold. This confirms the relationship between the critical paths in both network graphs.

References

Experimental Investigations of Radio Coverage Conditions in CNMC 2G-4G along the Railway

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Abstract

With the continuous development of modern railway transport, the demands and requirements of wireless communication networks for railway are continuously changing and increasing. Insufficient coverage is one of the key challenges in the deployment and maintenance of mobile cellular networks, therefore accessible and precise methods of investigating radio coverage conditions should be determined and described. The paper presents the results of testing the radio coverage of 2G, 3G and 4G service areas of cellular mobile network operators along the railway. The experimental studies were conducted on the Riga–Jelgava railway line of the Latvian Railway company (LDz) using mobile terminals with the installed cellular mobile communication network testing and parameter monitoring software. Results of experimental measurements were used to determine network coverage areas and the influence of the environment on the uniformity of radio coverage. Areas with the large attenuation of radio signals were marked on the provided coverage maps, measures for improving the quality of mobile communications for railway applications were observed as well.

KEY WORDS: mobile network, cellular network, railway, GSM, GSM-R, UMTS, LTE, measurements, monitoring, radio coverage, radio wave propagation

1. Introduction

To provide reliable high quality services in cellular networks of mobile communications (CNMC), it is essential to constantly monitor and measure the conditions of radio coverage of the service area by the operator [1-9]. Detecting and eliminating problematic areas in a timely manner can prevent problems with the deterioration of communication quality or their interruption [1,2]. This is especially important in areas of high demand for services and requirements of high reliability of CNMC, which are primarily: railway stations, airports, highways, densely populated areas. Due to the growing popularity of mobile devices running on the Android operating system (OS), there are now a series of software solutions available for CNMC monitoring [5, 6, 9]: 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, which can be used online to determine both the level of radio coverage of areas along the railroad line and a range of basic KPI.

2. Formulation of the Problem

In the modern CNMC on the railroad transport, there are several network options for the GSM-R standard, as well as for cellular architecture LTE (4G) and 5G generation [7]:
\begin{itemize}
  \item a) single layer variant with weak cell overlap,
  \item b) single layer option with high cell overlap,
  \item c) dual layers solution with co-located Base Tower Stations (BTS),
  \item d) dual layers with BTS interleaving.
\end{itemize}
The advantages of the single layer variant with a weak cell overlap (Fig. 1) are: inexpensive; high efficiency of spectrum use; small number of base stations; simple setup. Disadvantages: if one base station fails, network services will not be available in that base station's radio coverage area; in the case of ETCS 2/3, the train will stop.

Single layer solution with high cell overlap (Fig. 2) offers additional advantage in the form of partial redundancy of base stations due to coverage area, while maintaining average cost of the components. The disadvantages are: no base station redundancy, if one element of the base station is damaged; large number of base stations; medium complexity configuration; low spectrum efficiency; large number of transmissions.

Fig. 3 Dual layers, co-located BTS

Dual layer solution with co-located Base Tower Stations (BTS) (Fig. 3) provides full reservation of base stations; requiring only small number of base stations. The disadvantages: high cost; difficult to configure; if one BTS is damaged, network services will not be available in the coverage area of this base station; low efficiency of spectrum use.

Benefits of the dual layer solution, installing BTS with interleaving (Fig. 4) include: full backup of the base stations; if one BTS is damaged, network services will be available in the coverage area of this base station. To the disadvantages: highest costs; very complicated configuration; if one BTS is damaged, network services will not be available in the coverage area of this base station; low efficiency of spectrum use; large number of BTS.

In connection with the ongoing EU Rail Baltic project (Fig. 5), there is a task to conduct model measurements of the uniformity of radio coverage of possible 2G, 3G, 4G generation CNMC service areas along the Riga-Jelgava railroad track and the influence of the environment on the uniformity of radio coverage conditions.

As shown in [2, 3, 7-9] for measuring and monitoring of CNMC it is advisable to use the operating system (OS) Android, which is installed in mobile devices (for example, tablets), as well as software complexes (SC).

3. Use of Mathematical Models of RFW to Calculate the Radio Coverage Areas in CNMC

In the work [2] were considered various mathematical models of RFW in the SSMS for different radio bands and taking into account the influence of the environment (buildings, forests, etc.). Let consider as examples:

1. In the work [5], with the relief profile shown in Fig. 6, the distances between the railway stations in Table, were calculated CNMC along the route Riga - Jelgava (Fig. 7), the total length of which is 43 km.

2. In the work [7], as shown in Fig. 8, an example of the calculation of radio signal levels in the radio coverage area along the railway line Jelgava - Meitene using the Longley - Rice model in Mathcad (Math Software for Engineering Calculations). As follows from the left figure - in blue color the irregularities of the route are marked, and in green - the calculated levels of radio signals, at minimum level - of the order (-90 dBm). The right part of the figure shows the results of the calculation of the CNCM radio coverage along the trace, where, in accordance with the colored indicators, the changes in signal levels in Downlink mode are presented.
4. Results of Measurements and Monitoring of the Radio Coverage Areas of CNMC 2G-3G-4G Along the Railway Riga-Jelgava

The measurement and monitoring procedure was performed for the three existing standards EDGE [GSM (2G/2.5)], UMTS (3G) and LTE (4G), used by the operator TELE2 in Latvia along the railway route Riga - Jelgava, while from the SC nomenclature, the article presents the results of experiments when using SC: G-Net Track Lite, Network Cell Info Lite, Net Monitor. Fig. 9 shows the change of RSSI parameter along the route Riga - Jelgava. As follows from figure, for standard EDGE the levels of signals from BTS changed within the limits from (-60 dBm) to (-120 dBm), that testifies about deterioration and even failures in radio communication, when (-120 dBm) < RSSI < (-100 dBm), i.e. in area of Ozolnieki place due to strong attenuation of radio signals in forest vegetation appears a dead zone for radio communication.
Fig. 9 Unequal radio coverage of the Riga - Jelgava route for UMTS and EDGE standard (RSSI / RSRP)

Fig. 10 shows the change in RSSI parameter, which characterizes the radio coverage of the route Riga - Jelgava for EDGE (2G) standard, which shows that the conditions of radio coverage are sharply non-uniform, with a lot of areas for which radio communication conditions are at - poor and no signal, that is, for 4G standard, to create a more uniform radio coverage of the route, it is necessary to use the architecture of the cell - Dual layers, co-located BTS.

5. Conclusions

The analysis of the received data shows that the highest signal level is observed within Riga and Jelgava cities, where the quality varied from (-80dBm) to (-60dBm) [2G], from (-80dBm) to (-60dBm) [3G] and from (-90dBm) to (-70dBm) [4G]. For other parts of the track, radio coverage is uneven for all generations of CNMC, with an increase in the number of sites with poor and no signal - increasing with the use of a higher standard CNMC. For example, such sites were observed in the area of Ieceni, Peternieki and especially Ozolnieki, for which RSSI/RSCP levels lay within: from (-110dBm) to (-90dBm) (2G), from (-100dBm) to (-90dBm) (3G) and from (-120dBm) to (-90dBm) (4G). Therefore, to create a more uniform radio coverage of the route, it is necessary either to increase the height of BTS antennas, or increase the transmitting power of transmitting devices, or to use the architecture of honeycomb - Dual layers, co-located BTS. It should be noted that the section of the route in the Ozolnieki region, within which there is a complete cessation of radio communication due to the signal level of the base station is less than the minimum, due to the difficult terrain of the environment: the presence of forest and lowlands.

However, a significant disadvantage of software complexes can be distorted data, due to the use of smartphone models in which the operating system itself may limit the functions of radio modules, reduced radio transmitter consumption, processor power, radio frequency selection depending on the region, etc. in favour of a longer battery life of the smartphone. Before starting the measurements, it is recommended to check the listed factors for full performance...
of the device without reducing mentioned parameters, which is necessary to ensure correct measurement of KPI. In addition, the latest versions of software complexes support measurements of two operators in parallel; it can be implemented using smartphones with two active radio modules - Dual Sim Full Active (DSFA) technology.

References

An Investigation of Axial Load Influence on the Level of Contact Stresses in a Wheel-Rail Pair

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Abstract

Increasing the axial load level is one of the possible ways to increase the carrying capacity of high-loaded areas at railways. However, such an approach may have a negative impact on the service period of the elements in the upper rail structure and rolling stock. To assess the impact of increased axial loads on the level of contact stresses in the railhead, the authors have performed the modelling of interaction in wheel-rail pairs at driving a train in a straight rail line with different levels of axial load. The levels of elastic stresses and deformations have been determined, directions of further researches have been proposed.

KEY WORDS: wheel-rail contact pair, wheel-rail interaction, contact stress, axial load.

1. Introduction

The issue of efficiency in using production capacity [1, 2] and reducing the cost of current infrastructure maintenance is always the most relevant for enterprises with a large value of fixed assets. An example of such an enterprise is a railroad that has a developed infrastructure and requires significant costs for its maintenance.

One of the most capital-intensive parts of the railway infrastructure is the upper structure of the track, which provides train movement.

Increasing the efficiency at the train can occur either by reducing the cost of maintaining current infrastructure, or due to increasing the carrying traffic on operating sections with unchanged current costs, or by providing the increase in traffic intensity to overlap the cost of current maintenance.

Currently, one of the most widely discussed measures to increase the carrying capacity at railways and to improve the efficiency in the use of existing infrastructure is to increase the axial load [3].

Obviously, in terms of the organization in rail transportation, increasing the carrying capacity of each car can reduce the cost of transportation with unchanged costs for current rail retention.

According to it, the issue about the influence of increasing the axial load on the durability of elements in the upper rail structure is relevant.

The experimental [4-7], laboratory [8, 9], and theoretical studies [10-13] can be conducted. Preliminary theoretical studies can reduce the cost of conducting experimental and laboratory studies that are expedient to be carried out only after previous theoretical calculations.

One of the most accepted methods in theoretical studies is the mathematical modelling of physical processes to affect the performance characteristics of the design.

Among mathematical methods for modelling physical processes, one of the most popular methods is the method of finite elements [10-13], to be used in the study.

2. Methods and Course of Research

The task was solved in a volumetric elastic quasistatic setting provided the train movement in a straight rail line.

The interaction of the R65 profile rack following State standards of Ukraine (DSTU) 4344: 2004 and the wheel according to the State Standard GOST 9036-88 (Fig. 1), for the conditions of the axial load 200 kN, 220 kN and 240 kN have been studied. The calculation was performed for the conditions of use substrates KPP-5, sleeper density 1680 pcs/km.

The main mechanical characteristics of the rail material are the elastic modulus in stretching $E = 2.1 \cdot 10^5$ MPa; Poisson coefficient $\nu = 0.3$; The mechanical behaviour of the wheel material was considered to be elastic with the parameters of elasticity: the elastic modulus in stretching $E = 2.1 \cdot 10^5$ MPa; Poisson coefficient $\nu = 0.3$. 
Analysis of the results obtained.
Fig. 2 shows the distribution of the equivalent (according to Mises) stresses at the place of the wheel and rail contact, provided that the 200 kN and 240 kN is an axial load.

As can be seen, increasing axial load by 20% led to an increase in equivalent elastic stresses by 7.69%.

Fig. 3 The distribution of tangent $(t_{xy})$ stresses of the wheel and rail contact, provided the axial load 200 kN – on the left and 240 kN – on the right
Fig. 3 shows the distribution of tangent stresses ($\tau_{xy}$). The minimum negative tangential stresses have been decreased by 6.47%, however, the maximum positive tangential stresses have been increased by 6.8%.

Table presents the value of contact stresses at different levels of axial load. The growth of axial load leads to an increase in contact stresses. Increasing the axial load by 20% leads to an increase in contact stresses by about 7%. All components of stresses increase in proportion. Maximum equivalent stresses are located at a depth of approximately 3 mm below the surface of the railhead and should be a cause of cracks under the rail surface to reduce the service period of the rail.

<table>
<thead>
<tr>
<th>Level of stresses</th>
<th>The level of axial load, kN</th>
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<tbody>
<tr>
<td></td>
<td>200</td>
</tr>
<tr>
<td>$\sigma_x$, MPa</td>
<td>-1020,55</td>
</tr>
<tr>
<td>$\tau_{xy}$, MPa</td>
<td>223,99</td>
</tr>
<tr>
<td>$\sigma_{eqv}$, MPa</td>
<td>624,93</td>
</tr>
</tbody>
</table>

3. Conclusions

Conducted calculations allow evaluating the effect of increasing the axial load to the contact stresses at the place of the wheel-rail contact. The results of calculation in the elastic production show increasing the axial load with 200 kN to 240 kN leads to an increase in maximum equivalent contact stresses from 624.93 MPa to 672.16 MPa. Note, the case of optimal wheel location relative to the rail has been considered in the study. In previous publications [14] it has been shown the wheel displacement relative to the rail during the contact leads to an increase in contact stresses. The level of equivalent contact stresses exceeds the boundary of the non-thermal strengthened rail steel flow. This suggests that to assess the impact of increasing the axial load for the service period of the railway tracks, in particular the rails, it is necessary to research an elastic-plastic production, since in this case, stresses and deformations are not proportional to, and therefore not significant increase in the level of contact stresses can lead to a significant increase in plastic deformations and disproportionate the growth to the durability of rails during the service period.

Therefore, to conclude, it is necessary to conduct further research taking into account the possibility of physically nonlinear behaviour of the material, as well as to take into account the presence of curved sections of the track, where the conditions of contact interaction are different. After the results obtained, it is possible to predict the service period of rails and draw unambiguous conclusions about the impact of increasing the axial load on it.

References


The Use of COTS Technology in Building Reliable and Safe Railway Traffic Control Systems

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Abstract

Railway traffic control systems must meet high reliability and safety requirements. Currently, this is achieved through the use of dedicated technologies. Nevertheless, more and more often one can meet the tendency to build railway automation systems with the use of technologies known as "commercial off-the-shelf" (COTS). An example is the use of specialized controls units, such as HIMA. This is due to, inter alia, the need to reduce the cost of building systems as a result of using standard components from the industrial automation sector. It seems that those components will be increasingly used in railway traffic control systems.

KEY WORDS: COTS technology; reliability; safety; railway traffic control systems

1. Introduction

Railway transport is a branch of land transport, which focuses on moving people and goods by means of rail transport. Managing movement processes is performed by people using specific technical measures. Due to increase in train speed, growing requirements for line capacity, improvement of smoothness and punctuality of train traffic and the reduction of employment, automation of railway traffic control processes becomes an indispensable necessity. Modern technology, in particular information technology and electronics, allows to automate more and more activities in the transport process [8]. Thus, the purpose of railway traffic control systems is to assist people in carrying out specific tasks. Manufactures operating in the railway automation industry are obliged to ensure an appropriate level of reliability and safety, and thus the approval process is mandatory for the railway traffic control systems [7]. The technology adopted then becomes important, as later changes are associated with the need to carry out another time-consuming certification process. Thus, the embrace of the proven and verified safety technology at the system design stage significantly simplifies and shortens not only the design process, but also proving the dependability of the system, understood as meeting the reliability and safety requirements [9]. A good example of this can be the use of the "commercial off-the-shelf" (COTS) technology, which is dedicated to safety-critical systems, and meets the safety requirements, having the necessary approvals. This is due to the fact that the technology has been proven in safety-related systems other than railways. The COTS are standardized systems, produced in large numbers for variety of safety-critical applications, and therefore they are not only cheaper, but also their long production cycle is guaranteed. Obviously, it is necessary to migrate this technology to railway applications in order to meet the specific CENELEC requirements. The authors [10] report that the share of COTS controllers in this sector has reached 25% in 2020.

2. Safety Requirements for the Railway Traffic Control Systems

Railway traffic control systems are safety-critical systems. Therefore, based on the IEC 61508 standards, the European Committee for Electrotechnical Standardization (CENELEC) has developed standards for the railway industry. The recommendations contained in these standards were used by the European Railway Agency (ERA) to publish CSTs (Common Safety Targets) and CSMs (Common Safety Method) for the railway industry.

The methods and techniques included in CENELEC standards are also referenced in the IRIS (International Railway Industry Standard), which was developed under the auspices of UNIFE and with the participation of the largest railway industry manufacturers. IRIS simplifies the process of verification of service quality and standardizes the quality requirements for companies related to the railway market. In addition to the quality management system requirements that are fully applicable to the IRIS standard, it also includes guidelines derived from CENELEC standards [11].

2.1. Hardware Safety

Requirements for the acceptance and approval of safety-related electronic railway traffic control systems are defined in EN 50129 [13]. This standard defines safety as the absence of unacceptable risk. A system is considered safe if the risks associated with its operation are acceptable. For the above-mentioned systems four Safety Integrity Levels
The SIL level is a measure of the number of operations to a fault/error occurrence defined by the Tolerable Hazard Rate (THR). The least restrictive requirements relate to the SIL1, the most restrictive ones apply to the SIL4 (Table).

The EN 50129 standard assumes the need to demonstrate the safety of the system in a document called the safety case. The technical safety report plays a special role in this document. It contains an estimate of the THR for the system and thus determines the safety integrity level that this system meets.

The tolerable hazard rate can be calculated from the equation [4]:

\[
THR = \prod_{i=1}^{n} \frac{\lambda_i}{t_{d_i}^{-1}} \sum_{i=1}^{n} t_{d_i}^{-1},
\]

where \( n \) – the number of channels; \( \lambda_i \) – the failure rate of a channel; \( t_{d_i}^{-1} \) – the safe down rate.

In order to reduce the THR factor, redundant systems are used, in which information is compared in parallel processing channels (most often "2-out-of-2" or "2-out-of-3") [3].

### Table

<table>
<thead>
<tr>
<th>Tolerable Hazard Rate (THR)</th>
<th>Safety Integrity Level (SIL)</th>
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<tbody>
<tr>
<td>( 10^{-9} \leq THR &lt; 10^{-8} )</td>
<td>4</td>
</tr>
<tr>
<td>( 10^{-8} \leq THR &lt; 10^{-7} )</td>
<td>3</td>
</tr>
<tr>
<td>( 10^{-7} \leq THR &lt; 10^{-6} )</td>
<td>2</td>
</tr>
<tr>
<td>( 10^{-6} \leq THR &lt; 10^{-5} )</td>
<td>1</td>
</tr>
</tbody>
</table>

2.2. Software Safety

Technical requirements for software development for railway applications are defined by the EN 50128 standard [1, 12]. This standard recommends the implementation of the "V-model" of development lifecycle, from the software specification stage to software testing. The EN 50128 standard introduces recommendations such as the separation of software and its parameters, tool certification, the need to document software and the need to maintain and implement new software versions.

In the case of software, there are five levels of safety integrity, called SSIL (Software Safety Integrity Level) [2, 12]:

- SSIL 0: The software is not safety related, but software quality assurance (SQA) and configuration management are required. For SSIL 0 level, the code developer can also be a its verifier / validator;
- SSIL 1, 2: The software is related to the safety of the medium level, which requires, in order to guarantee the safety, the implementation of the software production rules. With this level of safety, the roles of the code developer and the validator must be separated;
- SSIL 3, 4: Software is associated with a high level of safety, which forces not only the implementation of software production rules, but also the use of appropriate resources and methods (the use of formal methods, dynamic tests, certified programming environments, simulation methods to validate the model and / or to select tests, etc.).

The standard contains many recommendations in a form of tabular summaries for various areas of software systems, including: software quality assurance, requirements management, data preparation, software design methods, modelling and formalization, software maintenance and implementation.

2.3. Data Transmission Safety

Safety requirements for data transmission that must be fulfilled by railway traffic control systems are specified in the EN 50159 standard [14]. Identification of threats related to data transmission should be started with separation of those system elements for which ensuring safety is crucial. Then, these elements should be analysed in terms of their vulnerability to threats [5].

When using an open transmission system, such as wireless data transmission or the Internet, the safety of information exchange should be based on the approach to transmission system as an untrusted system. This approach should be applied regardless of what internal transmission protection mechanism, safety-related transmission functions or safety-related access protection functions are used [14]. The main threat to the safety of railway traffic control systems, resulting from the untrusted transmission system, is the failure of the receiver to obtain a valid and authentic safety-related message. Such a state can be caused by: repeated message, deleted message, inserting a message by an unauthorized sender, changing the order of messages, message corruption, delay in receiving a message, or/and its masquerading [6]. This creates a potential hazard to the systems, mainly the possibility of appearance data in unknown formats as well as unknown quantities, and the possibility of network attacks by unauthorized users. The EN 50159 standard indicates a number of methods to ensure data safety in systems with an open transmission system, which are
defined as safety-related functions: sequence numbering, using time stamps in messages, defining the time-out, adding to messages sender and receiver identifiers, use of feedback messages, using authorization procedures, using safety codes and cryptographic data protection techniques.

3. HIMA COTS Controllers Dedicated to the Railway Industry

One of the leading suppliers of commercial off-the-shelf (COTS) technology, mainly for the chemical, energy, gas and petrochemical industries, is HIMA. It also offers SIL 4 COTS safety controllers for the railway sector that are CENELEC certified. They are currently used by 50 partners in over 30 countries. HIMA controllers belong to the "Smart Safety Platform", which is the world's first comprehensive solution combining safety and protection.

HIMA safety systems, based on the commercial COTS technology, are mass-produced, at the same time they are standardized and can be used in all railway applications without the need for modification. The HIMax and HIMatrix controllers, belonging to this product group, meet all safety requirements for the railway industry at SIL 4 level, in accordance with CENELEC recommendations:

- EN 50126 - comprehensive for the system;
- EN 50128 - for software;
- EN 50129 - for equipment;
- EN 50155 and IEC 61373 - for rolling stock.

Certified safety for every application, both HIMatrix and HIMax, with TÜV certification, can be directly implemented without the need for additional testing. This platform uses integrated SILworX engineering software that enables the central configuration and programming of HIMA COTS solutions. The intuitive interface of the SILworX environment is also used to diagnose errors, which shortens the implementation process. Additional protection is provided by: access rights management, anti-virus program and firewall. Compared to proprietary solutions, HIMA COTS systems reduce the system lifecycle costs, which is very important in the case of railway traffic control systems. Spare parts are available for the long term - up to 30 years - and can be purchased in a short time. Modern railway automation systems are distributed systems with heterogeneous architecture. Therefore, the communication protocols and interfaces supported by HIMA COTS controllers are of great importance. In this technology, we are dealing with open protocols and support for standard communication interfaces, which definitely simplifies the integration process. In addition, HIMA COTS controllers support IEC 61131 compliant programming languages, which makes them easy to use and maintain, and therefore their operating costs are significantly lower than with proprietary technology.

There are many implementations of COTS technology based on HIMatrix and HIMax controllers [16]. The French company Colas Rail was the first to use HIMA controllers its signalling solutions. German company SafeinTrain, specializing in creating software for rail transport, used HIMA COTS technology to develop a train control and management system. Similarly, the Austrian company RDCS Informationstechnologie, an integrator in the field of railway automation, based on HIMA COTS software and hardware, has developed the ILOCK-RC interlocking system, which has been successfully implemented by the Kazakh Railways (KTZ). Also, the Signalling & Control company, using HIMA components, developed a interlocking system that was used on the Serbian Railway. Another example of the successful implementation of COTS technology may be the use of HIMA controllers by the Russian rail company AT TRANS in the railway traffic control and management system. Solutions of this type have also been used in Australia. Rail Control Systems (RCS) has used COTS technology in level crossing and interlocking systems. The last of the discussed applications of the COTS technology is the evoCROSS level crossing safety system developed by ERB Technologies and implemented in South Africa. These examples confirm the thesis that HIMA's COTS controllers allow for the implementation of safe train control systems, line systems, interlocking systems, remote control, as well as level crossings protection systems.

3.1. HIMatrix Controllers

HIMatrix is a range of universal COTS controllers designed for small and medium scale safety of critical systems used in the railway industry (Fig. 1).

HIMatrix controllers are pre-certified for compliance with CENELEC standards [17]:

- EN 50126:1999 (SIL 4),
- EN 50128:2011 (SIL 4),
- EN 50129:2003 (SIL 4),
- EN 50159:2010,
- EN 50155:2007,

These standard controllers are vibration and shock resistant and have an extended operating temperature range. They can be programmed using the SILworX environment including the following languages:

- Function Block Diagram (FBD),
- Sequential Function Chart (SFC),
- Structured Text (ST),
- C (optional).
The extensive list of supported communication protocols is also worth emphasizing:
- SafeEthernet for CPU and COM guaranteeing SIL4;
- OPC DA (OPC A&E),
  each COM port can additionally support up to 6 protocols: Modbus TCP master / slave, PROFINET and
PROFIsafe, UDP and TCP, CAN bus, PROFIBUS DP master / slave, Modbus RS485 master / slave, ComUserTask
(CUT) and SNTP.

3.2. HIMax Controllers

HIMax is a range of COTS control systems for safety-critical applications, dedicated to use in the railway
industry, with high operating requirements (Fig. 2).

The HIMax controllers are also pre-certified to CENELEC standards, just as the HIMatrix controllers, and can
be programmed taking into account the languages defined in IEC 61131-3. HIMax enables uninterrupted operation of
control systems, and changes in hardware and software. Moreover, tests can be carried out at any time, without
switching off the controllers. Thanks to redundant CPU modules, HIMax is suitable for railway applications requiring
high performance and reliability [15]. HIMax controller communication can be realized with the following protocols:
SafeEthernet (SIL4), bus system (SIL4), OPC DA (OPC A&E), Modbus TCP master / slave, PROFINET and
PROFIsafe, Modbus RS485 master / slave, PROFIBUS DP master / slave, UDP and TCP, ComUserTask (CUT), SNTP
and HART (V7).

4. Conclusions

Currently, the railway automation industry is dominated by safety-related proprietary electronic systems.
Nevertheless, there is a tendency to use COTS technology in this area. This is due to a number of advantages of such a solution, mainly a significantly lower acquisition cost and lower lifecycle costs compared to the proprietary technology. The development of railway automation systems based on COTS technology is possible only if it meets the CENELEC requirements. A good example can be HIMA systems, which have already successfully passed the certification required in this area. The workload of the integrators is then significantly reduced and the risk of insufficient safety compliance is minimized. Pre-certification of HIMA systems allows designers to focus on the functionalities that will be implemented by railway traffic control systems. In addition, any modifications, changes and extensions can be implemented at a much lower cost than in the case of proprietary systems. Another key aspect of the application of this technology is the backward compatibility of software and the long-term availability of hardware components.

References

Efficiency of Environmental Energy Conversion in Internal Combustion Engines. Evaluation of Ideal Thermodynamic Cycles

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Abstract

The energy efficiency of Otto, Atkinson and Miller engines that all belong to rapid internal combustion machines is evaluated in terms of ideal thermodynamic cycles. This approach allows us to conduct a meaningful generalized and demonstrative comparison of these fundamentally different engines. The recent findings suggest that the modern Otto cycle petrol engine has become very similar in function to the Miller engine. This similarity is due to the fact that the Otto cycle engine doesn't use the carburetor system which makes it very similar to the diesel engine. But in order to be able to implement the required set of different speed and traction modes, Otto's engine has to implement the same laws of power management as in Miller's engine. The investigation of the Otto cycle through the prism of Miller/Atkinson cycle provides a possibility to formally better assess the energy efficiency of the Otto engine.

KEY WORDS: internal combustion engine, rapid internal combustion engine, extended working stroke, working cycle, Atkinson-Miller engine, Otto engine, energy efficiency

1. Introduction

Internal combustion engines have long been widely used in a wide variety of machines — both transport and working. Therefore, the efficiency of each such machine should be determined largely by the level of perfection of its own engine [1]. But in our time, the system of views on the perfection of the internal combustion engine has undergone significant changes. In particular, due to environmental concerns, the diesel engine (considered as a slow internal combustion engine) has almost completely lost its position, although its energy efficiency could outweigh the efficiency of other types of heat engines. Therefore, the rapid internal combustion engine (the Otto-engine) — gasoline, for example, has moved to the forefront among heat engines. But the gasoline engine «abandoned» the carburetor system and became a little closer to the diesel engine. But it does not make sense to focus on a diesel engine when identifying the rational laws of power, as the careful dosing of the injected fuel is not accompanied by a calibrated dosing of the air intake. Therefore, there is a need to identify the truly rational laws of power of the rapid internal combustion engine in all possible modes of its operation. We should rely on an idealized, meaningfully transparent and clear interpretation of operating cycles of the Otto-engine with a constant volume of working space [2].

2. Purpose and Methodology

The purpose of the study is to formally determine the potential effectiveness of reducing the ratio of the compression stroke of the fuel mixture to the working stroke of the piston in a rapid internal combustion engine and evaluate the level of perfection of the Otto engine through comparisons with Miller and Atkinson engines. It is advisable to use the most general theoretical concepts that do not contain too specific information and do not obscure the essence of the case with side effects. Miller's engine is technically similar to the Atkinson engine, so there is reason to find a way to contrast the two ones together as one object to the traditional Otto engine. The logic of Saadi Carnot could serve as a model of the approach to the general analysis of heat engine properties [3, 4].

3. Theoretical Background

The study investigates some variations of the thermodynamic Otto cycle that are presented in Fig. 1 (p and p₀ — pressures in the working space and environment, V — the volume of the working space, BDC and BDC — bottom and top dead centres). In the normal Otto cycle, the r—a—c—z—b—a—r section (Fig. 1, a) of the r—a and a—r sections simulate, respectively, the rate of the fuel mixture intake into the working space and the rate of expelling the exhaust gases from it, where the c—z — section displays the process fuel mixture combustion (heat generation process). In contrast, the compression stroke in the Miller engine is mechanically shorter than the working stroke (expansion stroke), see Fig. 1, b: in the Miller Cycle r—r’—a’—c’—z—b—a—r point r’ corresponds to the moment of closing the intake valve; the compression stroke of the working fluid reflects r’—c’ section, that is shorter than the section of z—b expansion (p₀ — is the pressure in the cylinder at the end of the piston stroke to the bottom dead centre in the intake stroke). In general, the Miller engine can correspond to the Atkinson engine, as they both contain the theoretical cycle
Let’s compare the Otto cycle \( 1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 1 \) and the Atkinson (Miller) cycle \( 1' \rightarrow 2' \rightarrow 3' \rightarrow 4' \rightarrow 1' \), Fig. 3. We assume that the mass of the working fluid \( m \) and the amount of heat \( Q_1 \) that appear in the workspace of the Otto engine, and the mass of the working fluid \( m' \) and the amount of heat \( Q_1' \) that appear in the working space of the Atkinson (Miller) engine are correlated as their corresponding volumes \( V_1 \) and \( V_1' \) (remnants of the spent working fluid are not considered):

\[
\frac{m}{m'} = \frac{Q_1}{Q_1'} = \frac{V_1}{V_1'} = \varepsilon. \tag{1}
\]

If the degree of compression of the fuel mixture in the Otto engine equals to \( \varepsilon \), we will follow the logic and keep its value in the Atkinson engine:

\[
\frac{V_1}{V_1'} = \frac{V_1}{V_1'} = \varepsilon.
\]
The value of $e_s$ (see (1) and Fig. 3), if the value of $V_i$ is not changed, can increase the value $e_s = 1$ (as in the Otto engine) and it can be equal to the value $e_s = V_i/V_r = (p_f/p_i)^{1/k} = \lambda^{1/k}$ ($k$ — adiabatic index), that corresponds to the cycle $I'' - 2'' - 3'' - 2 - 1 - I''$ as in the gas turbine engine. We can prove that $p_2 = p_2$, $p_f = p_i$ and $p_2 = p_2 = \lambda$, respectively. In this case, the useful effect of the Atkinson (Miller) cycle will be determined by the coefficient

$$\eta'_u = 1 - \frac{e_s \left( \frac{\lambda}{e_s} - 1 \right) + k(e_s - 1)}{\lambda - 1}.$$  

Thus, in the case $e_s = \lambda$ the Atkinson cycle degenerates into a so-called «gas turbine» cycle (Humphrey cycle), for which (see. (2))

$$\eta'_u = 1 - \frac{1}{e^{1/k}} \frac{k(\lambda^{1/k} - 1)}{\lambda - 1},$$

and in case $e_s = 1$ it is the same as in the Otto engine where

$$\eta'_u = \eta_o = 1 - \frac{1}{e^{1/k}}.$$  

The work $W'$ of the less amount of the working fluid in the Atkinson cycle will be less than the work $W$ of the working fluid in the Otto cycle. In order for these works to be the same, it is necessary to synthesize a new Atkinson cycle with an increased working volume of $V''_i > V_i$ and, accordingly, more heat supplied:

$$\frac{V''_i}{V_i} = \frac{\eta'_u}{\eta_u} = \frac{e_s \left( 1 - \frac{1}{e^{1/k}} \right)}{e_s \left( \frac{\lambda}{e_s^{1/k}} - 1 \right) + k(e_s - 1)} > 1.$$ 

Therefore, a significant increase of the coefficient of performance $\eta'_u$ of the internal combustion engine requires a significant increase in the volume of the working space in the case of the implementation of the Atkinson/Miller cycle based on the Otto cycle.

Considering the ideal Atkinson cycle (Fig. 4: $\Omega$ the range of admissible adiabats), we distinguish between general
(Fig. 4, a) and degenerate (Fig. 4, b) cycles. To illustrate this analysis, let’s take $\varepsilon = 9$, $\varepsilon_0 = 12$, $k = 1.4$ as an example.

**Fig. 4** Types of Atkinson cycles

Regarding the general cycle $1' - 2 - 3 - 4 - 1$ (Fig. 4, a) the final performance should be calculated using the following formula

$$W = \rho_0 c_T V_1 \frac{V_2}{V_1} \left( \frac{1}{\varepsilon_0} \left( \frac{p_1}{p_0} \frac{V_1}{V_2} \right)^k - \left( \frac{1}{\varepsilon_0} \frac{p_1}{p_0} - 1 \right) - k \left( 1 - \frac{1}{\varepsilon_0} \frac{V_1}{V_2} \right) \right)$$

(3)

with the coefficient of performance that is calculated by

$$\eta_1 = 1 - \frac{1}{\varepsilon_0^{k+1}} \left( \frac{p_1}{p_0} - \varepsilon_0^k \right) + k \left( \varepsilon_0 \frac{V_1}{V_2} \right),$$

(4)

where $\rho_0$ and $T_0$ — represent the conditional density of the working fluid that enters the working space of the engine, and the ambient temperature; $c_T$ — is the specific heat of the working fluid at a constant volume. It makes sense to use formulas (3) and (4) in the case of $\frac{p_1}{p_0} \geq \frac{\varepsilon_0^k}{\varepsilon_0} = \varepsilon_0^k$. If $\frac{p_1}{p_0} < \varepsilon_0^k$, the main thermodynamic cycle (Fig. 4, a) degenerates into a cycle with forced heat supply at the end of the expansion cycle of the working fluid (Fig. 4, b). The following formulas are used:

$$W = \rho_0 c_T V_1 \frac{V_2}{V_1} \left( \frac{1}{\varepsilon_0} \left( \frac{p_1}{p_0} \frac{V_1}{V_2} \right)^k - \left( \frac{1}{\varepsilon_0} \frac{p_1}{p_0} \frac{V_1}{V_2} \right)^{1/k} \right) - k \left( 1 - \frac{1}{\varepsilon_0} \frac{V_1}{V_2} \right),$$

(5)

$$\eta_1 = 1 - \frac{k \left( 1 - \frac{1}{\varepsilon_0} \frac{V_1}{V_2} \right)}{1/\varepsilon_0 \left( \frac{p_1}{p_0} \frac{V_1}{V_2} \right)^{1/k} + k \left( 1 - \frac{1}{\varepsilon_0} \frac{p_1}{p_0} \frac{V_1}{V_2} \right)^{1/k}}.$$  

(6)
These formulas (5) and (6) can be applied if 
\[ 1 \leq \frac{V_1'}{V_2} \leq \varepsilon, \quad 1 \leq \frac{p_3}{p_0} \leq \varepsilon_0. \]

4. Research Results and Discussion

The Fig. 5, a illustrates the kind of dependence of the conditional performance of the Atkinson cycle

\[ \omega = \frac{W}{p_0 c_i T_0 V_1} \]

on engine thrust control parameters

\[ \frac{V_1'}{V_2} = \nu \quad \text{and} \quad \frac{p_3}{p_0} = \pi. \]

We consider \( \nu \) as a quantitative value of the working fluid, and \( \pi \) as a qualitative value. The line \( \pi = \varepsilon_0^k = \text{idem} \) divides the chart into 2 parts: the left part that corresponds to degenerate cycles and the right part - to general cycles. Obviously, the function \( \sigma = \sigma(\nu, \pi) \) is not monotonic.

![Fig. 5. Dependence of conditional performance (a) and coefficient of performance (b) of the engine on control parameters](image1)

It is generally accepted that the dependence of the coefficient of performance \( \eta_0 \) on the accepted mode (control) parameters (characteristics) of \( \nu \) and \( \pi \) is non-monotonic, Fig. 5, b. But for each fixed value of the parameter \( \nu \) it is still monotonically increasing. The coefficient of performance \( \eta_0 \) of the Atkinson cycle, in case of specific values of \( \nu \) and \( \pi \) may exceed the coefficient of performance of \( \eta_0 \) of the Otto-cycle with the specified parameters \( V_2 \) and \( \varepsilon \). In the case of \( \pi \geq \varepsilon_0^k \), cycles with the parameter \( \nu = \max \nu = \varepsilon = 9 \) are considered to be the most energy efficient.

In order to decrease the work of \( \sigma \), we should achieve and maintain the maximum value of \( \nu \) (\( \nu = \max \nu = \varepsilon = 9 \)) at first, reducing only the value of the parameter \( \pi \) until further reducing the value of \( \nu \). In this example, the Atkinson cycle efficiency reaches the highest value \( \max \eta = 0.622 \), which is 6 % higher than the \( \eta_0 = 0.585 \) efficiency value in the Otto cycle. But the size of the Atkinson engine will be larger in \( \frac{0.585}{0.622} \approx 0.94 \) times (by a third).

Therefore, if the energy-saving advantages of the Humphrey cycle are noticed in the process of conditional design of the Atkinson/Miller engine, then in the process of regulating the thrust of an already synthesized engine of this type, the advantages of this cycle are no longer traceable. Indeed, modes with the \( \pi = \varepsilon_0^k \) ratio generally do not have an advantage over modes with the \( \nu = \varepsilon \) and \( \pi \rightarrow \pi_{\max} \) ratios (\( \pi_{\max} \) - are physically valid \( \pi \) values).

The \( \nu \) and \( \pi \) parameters are interrelated. The relationship between them is determined by the calorific value of the fuel and how the mixture is formed. You can prepare a mixture of air and fuel in a stoichiometric ratio, and you can do this with excess air. First of all, the calorific value of the fuel, the composition of the working mixture, the ambient temperature, and the geometric degree of compression determine a very specific value of the parameter \( \lambda \). Therefore, \( \lambda \) cannot be arbitrary:
where $H_u$ — is a lower calorific value of fuel; $\alpha \geq 1$ — excess air ratio, $l_o$ — the amount of air required to create a stoichiometric mixture.

The usual Atkinson engine (see Fig. 2) concedes to Otto's engine both on design, and working weight and dimensions, but it is more attractive if taking into consideration the functional weight and dimensions: the four-stroke working cycle is carried out not in two, but one turn of its shaft. Although the planetary-toothed analogue of the Atkinson engine [1] is structurally more compact, its full operating cycle is carried out in two turns of the shaft. And in terms of working weight and dimensions, it is still inferior to the Otto engine. Considering the Otto cycle through the prism of the Miller/Atkinson cycle, we can see that in the absence of carburetion, the usual gasoline engine is significantly closer to the Miller engine on the principle of power control in the case of partial load modes.

5. Conclusions

On the one hand, increasing the efficiency of a heat engine contributes to significant fuel savings and the decrease of environmental hazards during the life cycle of a mobile machine driven by such an energy-saving engine. But the increase in the mass and overall dimensions of the engine due to the embodiment of the energy-saving Atkinson/Miller duty cycle provokes an increase in the mass of the engine so much that it jeopardizes the strength of the structure. Therefore, there is a need to strengthen it: in the first approximation, the mass of the structure increases in proportion to the cube of linear size, but its strength — in proportion to the square of linear size; we consider that each additional mass generates a new mass. For example, excessive dimensions of the car, due to the excessive size of the engine, impair its aerodynamics and thus provoke constant additional energy consumption in the implementation of transport functions. Although, removing the part of the car's volume from its living or cargo space can be interpreted as reducing the potential performance of the car. Excessive weight of the car also leads to increase in resistance to rolling of wheels, worsens its acceleration and brake dynamics, reduces safety level in case of collision with an obstacle... Thus, an increase in the efficiency of a heat engine in this way may not actually be recognized as an improvement through the evaluation of the performance properties acquired by the working or transport machine. The following conclusions are important.

1. Rapid internal combustion of the fuel mixture in a heat engine is the most efficient process of converting heat into mechanical work. The idea of the so-called HCCI engine (Homogeneous Charge Compression Ignition Engine) can rule as a standard, which can hardly be considered completely new in content.

2. The use of the theory of ideal thermodynamic cycles allows us to correctly and clearly explain and evaluate the manifestation of the energy-beneficial effect of the expansion of the working stroke in a rapid internal combustion engine.

3. The increase of the coefficient of performance is forced to be accompanied by an increase in weight and dimensions of the engine due to the lengthening of the working stroke of the piston and therefore negatively affects the properties of the car driven by such an engine.

4. The energy efficiency of the Atkinson/Miller engine in comparison with the Otto engine is noticeable at high load modes. But the car engine usually runs on so-called partial modes.

5. The modern Otto engine is a profitable technical compromise between a two-stroke engine and an Atkinson engine, but in terms of properties it is getting closer and closer to Miller's engine.

References

Economic Externalities of the Panama Metro Network

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Abstract

This research analyses some economic externalities generated by the Panama Metro Network. Vehicle congestions in cities produce annual losses of millions of dollars, affecting productivity sensitively. The social benefits of mass transit systems have a positive impact on the dynamics of metropolitan areas. This paper presents results related to the savings in travel times and their economic benefits, under various projected scenarios. These scenarios are compared with actual data of passenger mobilization of the Panama Metro Network. This paper is divided in 6 section. The first section corresponds to the introduction. The second section contained the general description of the Panama Metro network, both line 1 and line 2. The third section is about general methodology. The fourth section is presented the results and its discussion. The final section corresponds to the conclusion and future work.

KEY WORDS: Panama metro, subway, externalities

1. Introduction

According to Walrand [1], economists defined externalities as the impact on others of some actions when prices do not reflect that impact. In the transportation sector, Van Lier et al., [2] indicated that externalities arise when transport-consumers/producers impose additional costs to the society without having to bear these costs themselves or without having to transfer or pay compensations. Also, externalities are situations in which one agent can be directly affected by the production or consumption decisions of another. Commuter rail and metro stations can have positive effects. Rail and metro systems are characterized by high-performing [3] and environmentally friendly features [4-6] that make them a crucial factor for driving modal split towards public transport modes, thus reducing private car use and related externalities (such as air and noise pollution, traffic congestion and accidents) [7-9]. Profitidis et al., [10] presented a review of the environmental effects and externalities of the transport sector and the concerns in sustainable transport planning and a study about quantification in monetary units and possible effects of eventual internalization of these external costs. Guijarro [11], on the other hand, empirically examined the impact of the negative externalities associated with road traffic for the city of Madrid, Spain. Stetjuha [12], discussed the theoretical foundations of externalities and the peculiarities of their manifestation in transport. Berbey-Alvarez et al., [13-14], presented previous works about the externalities of Panama metro network.

2. General Description of the Panama Metro Network

Currently, the Panama Metro Network has 2 railway lines. Both railway lines 1 and 2 of the Panama Metro have a double track with a gauge of 1,435 mm and right-hand traffic [15]. The track is configured as a railway line fixed directly on the viaduct. UIC54 type rails (54 Kg / m) will be used on the main road and in the Yards and Workshops [16]. The Panamá Metro line 1 (PML1) is a metropolitan subway with subterranean and elevated track sections operated with a catenary-guided transport system. It began its operations on April 6, 2014 [17]. Currently, the line has a length of 16 km, connecting the northern area of Panama City at the San Isidro station with the southern section of the City, to the Albrook station (Fig. 1). This final station connects with the National Bus Terminal of Albrook that serves the overall country and the city. This station is, in addition, quite close to the local airport, Marcos A. Gelabert. At present, the headway is 3.20 minutes between 6:00 am – 8:00 am (i.e. 18 train/ hour), and it is 4.30 minutes (i.e. 14 trains/hour) in off-peak hours [17]. The headway is the time distance between two successive trains on the railway track [18]. The PLM 1 dwelling time corresponds to a range between 20 to 30 seconds. The operating speed at the PML1 is 32 km / h. The maximum speed of the metro rolling stock is 80 km / h [15-17]. At the southern bound, in the Albrook zone, the Panama Metro line 1 has a facility for storage and maintenance of the metro rolling stock with a surface of 10 hectares. Also, the Operations Control Center (OCC) [18] is located at this facility. The metro rolling stock fleet includes trains with 3 and 5 electric coaches with multiple units, with a maximum capacity of 800 and 1000 passengers/train respectively [15-17].
Panama metro line 2 (PML2) has an extension of 21 km and 16 elevated railway stations. Its routes towards the northeast of Panama City. PML2 began its operations on April 25, 2019. Currently, it connects the eastern area of Panama City, beginning at the Nuevo Tocumen station, to the northeast, to the San Miguelito station (Fig. 2). Currently, the headway is 3 minutes (peak hours). PML 2 is a metropolitan subway with elevated track sections operated with a catenary-guided transport system [16]. At the east bound, in the Nuevo Tocumen zone, the Panama Metro line 2 has a facility for storage and maintenance of the metro rolling stock, with a surface of 12 hectares. The rolling stock fleet has 21 trains with 5 electric multiple units' coaches with a maximum capacity of 1200 passengers/train. As in PML1, top speed of the trains is of 80 km/h [15-17]. The trains are fed through a rigid catenary system in 1500 volts in direct current [17]. Currently, the PLM 2 dwelling time corresponds to a range of 20 to 30 seconds [19]. The minimum stop time at the stations is 20 seconds. PLML2 was originally designed to move near 16 thousand passengers’ hours in both directions but it can move over 40 thousand passengers soon. The maximum slope is of 35 mm/m [15], with a top commercial speed of 35 km/h.

3. Methodology

Based on other example of modeling [8, 20-21] the methodology for this research analyzes 2 operational scenarios of public transport in Panama City defined by studies of the Panama Metro [23] (Table 1)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>PML1 in operation. Line 1 starts from San Isidro, which translates into a 16 km length and 17 stations. Restructuring of the Metrobus system. This configuration is maintained until the year 2035.</td>
</tr>
<tr>
<td>D</td>
<td>Both lines 1 and 2 of the Panama metro in operation. Same as scenario C but in 2020 Metro Line 2 is added: La Doña - San Miguelito (green line of the master network). This line was designed with an approximate distance of 19 km and with 12 stations, eight of which were considered in the San Miguelito - Pedregal section. An initial capacity of 12,000 passengers per hour was considered. This configuration is maintained until the year 2035.</td>
</tr>
</tbody>
</table>

For both scenarios, the monetary value of time has been used as a function of the corresponding annual minimum wage in Panama. To establish a preliminary conservative calculation of the economic savings of time for users of line 1 of the Panama metro, we have the following:

\[
A_{h,\text{comp/time}} = \left( T_{vsm} - T_{vcm} \right) \left( \text{Salary}_\text{min} \right) \left( DAP \right); \\
A_{h,\text{comp/time}} = \left( T_{vsm} - T_{vcm} \right) \left( \text{Salary}_\text{prom} \right) \left( DAPE \right),
\]

where \(T_{vsm}\) – road trip time (Shared vehicle platform); \(T_{vcm}\) – Metro total travel time in line 1. The original travel time of line 1 of the Panama Metro corresponded to 23 minutes. With the additional extension from the Andes Station to the San Isidro Station, the time increased to 26 minutes [23]; Salary_min – Minimum hourly wage in Panama ($3.48/hour).
Calculations considering a monthly salary of $613 (22 working days/month, 8 hours/day); Salary_prom_stratum – Average salary per hour, or per minute according to the social; DAP – Yearly demand for line 1 of the Panama Metro; DAPE – Estimated yearly demand by stratum for line 1 of the Panama metro.

4. Results and its Discussion

4.1. Externality of the Line with Scenarios C and D and Minimum Wage

The real demand for line 1 of the Panama metro has been increasing since its inauguration on April 6, 2014 except for 2020 (Table 2). In 2014, annual travel demand was 57.54 million trips per year, in the following year 2015 the annual travel demand increased by 68.97 million, giving a percentage increase over the previous year of 16.58% (Table 2). From there, the annual travel demand evidenced successive percentage increases in the order of 12.47% (2016), 3.34% (2017), 6.34% (2018) and 19.53% (2019). The increase of 19.53% in 2019 was due to the start of operations of PML2 since this line connects with PML1. In the case of 2020, the reason for the drop in demand has been the necessary application of quarantine periods and urban mobility restrictions in Panama City as measures indicated by the Ministry of Health of Panama for reducing infections during the Covid-19 pandemic. Fig. 3 shows the comparison between the real annual demand for trips on PML1 [23-27] 2020, with the European travel standard, which indicates that the construction of a travel line is justifies when the real demand exceeds 25 million trips per year [24, 28]. The total number of trips PML1 from its inauguration on April 6, 2015 to 2020 has been 519.72 million trips (Fig. 3 and Table 2).

Table 2
Summary of the biannual comparative increase in number of trips and percentage

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</tr>
</thead>
<tbody>
<tr>
<td>Real annual demand of line 1-RADL1 (in million)</td>
<td>57.54</td>
<td>68.97</td>
<td>78.80</td>
<td>81.52</td>
<td>87.04</td>
<td>108.17</td>
<td>37.69</td>
<td>519.72</td>
</tr>
<tr>
<td>Annual increase in trips (in millions)</td>
<td>------</td>
<td>11.43</td>
<td>9.83</td>
<td>2.72</td>
<td>5.52</td>
<td>21.13</td>
<td>-70.48</td>
<td>---</td>
</tr>
<tr>
<td>Percentage of annual increase in trips (%)</td>
<td>------</td>
<td>16.58</td>
<td>12.47</td>
<td>3.34</td>
<td>6.34</td>
<td>19.53</td>
<td>-187.01</td>
<td>---</td>
</tr>
</tbody>
</table>

Table 3 shows the real annual demand data used in this research based on operating statistics for line PML1. The real annual demand for line 1 compared to the standard of 25 million trips has been exceeded with a surplus of 230% (2014), 276% (2015), 315% (2016), 326% (2017), 348% (2018), 433% (2019) and 151% (2020).

Table 3
Percentage comparison of the real annual demand of line 1 and European standard

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</thead>
<tbody>
<tr>
<td>Real annual demand of line 1 [30]</td>
<td>57.54</td>
<td>68.97</td>
<td>78.80</td>
<td>81.52</td>
<td>87.04</td>
<td>108.17</td>
<td>37.69</td>
<td>519.72</td>
</tr>
<tr>
<td>Percentage over European Standard</td>
<td>230</td>
<td>276</td>
<td>315</td>
<td>326</td>
<td>348</td>
<td>433</td>
<td>151</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 shows the results of the calculation of the socio-economic externality PML1 for the 2014-2020 periods. To quantify the saving or socio-economic externality, two specific scenarios were selected that were attached to the operational reality of public transport in Panama City. Two scenarios were selected: C and D (Table 1), and minimum wage data for Panama City.

Table 4
Preliminary quantification of the economic externality of Panama metro line 1 2014-2020

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Travel time highway (minutes)[23]</td>
<td>80</td>
<td>69</td>
<td>70</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>67.61</td>
</tr>
<tr>
<td>Travel time subway(minutes)[23]</td>
<td>23</td>
<td>23</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Saved travel time</td>
<td>57</td>
<td>46</td>
<td>44</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>41.61</td>
</tr>
<tr>
<td>Minimum salary/hour</td>
<td>3.48</td>
<td>3.48</td>
<td>3.77</td>
<td>3.77</td>
<td>4.16</td>
<td>4.16</td>
<td>4.30</td>
</tr>
<tr>
<td>Annual real demand (in millions)</td>
<td>57.54</td>
<td>68.97</td>
<td>78.80</td>
<td>81.52</td>
<td>87.04</td>
<td>108.17</td>
<td>37.69</td>
</tr>
<tr>
<td>Real economic value of externalities (in millions of US$)</td>
<td>190.21</td>
<td>184.01</td>
<td>217.86</td>
<td>230.50</td>
<td>271.56</td>
<td>337.48</td>
<td>112.31</td>
</tr>
<tr>
<td>GDP in current prices (in millions of US$)</td>
<td>49,922</td>
<td>54,092</td>
<td>57,908</td>
<td>62,219</td>
<td>65,128</td>
<td>66,801</td>
<td>---</td>
</tr>
<tr>
<td>% Real externalities over GDP (GDP)</td>
<td>0.38</td>
<td>0.34</td>
<td>0.38</td>
<td>0.37</td>
<td>0.42</td>
<td>0.51</td>
<td>---</td>
</tr>
</tbody>
</table>
As seen in Table 4, the economic externalities based on the real annual demand of line 1 of the Panama metro have been increasing from 2014 to 2019, except for 2020, due to the fall of the passenger demand as explained above. For 2014, the estimate value of the socio-economic externalities corresponds to 190.21 million US dollars. As seen, the successive estimates of economic externalities correspond to 184.01 (2015), 217.86 (2016), 230.50 (2017), 271.56 (2018), 337.48 (2019) and 112.31 (2020). After 7 years of operation, the sums of the annual socio-economic externalities of line 1 of the Panama metro add up to a total of 1543.93 million US dollars.

4.2. Externality of Line 1 of the Panama Metro with Scenarios C and D, Percentage of Social Stratum and Income by Social-Economical Stratum

Marinho et al., [33] presents the distribution in percentage and income by social stratum in Panama as shown in Table 5. This information was used in the calculation of the socio-economic externalities in this project. Table 6 shows the low-income US$ month during the period 2014-2019.

Table 5 Percentage distribution and income by social-economical stratum in Panama [33]

<table>
<thead>
<tr>
<th>Stratum</th>
<th>%</th>
<th>Income range US$ month</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>22.2</td>
<td>Greater than 2,565</td>
</tr>
<tr>
<td>Middle</td>
<td>47.6</td>
<td>Between 1,089 and 2,565</td>
</tr>
<tr>
<td>Low</td>
<td>30.3</td>
<td>Less than 1,089</td>
</tr>
</tbody>
</table>

Table 6 Low Income US$ month during the period 2014-2019

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Income US$ hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-income</td>
<td>574.6</td>
<td>663.1</td>
<td>744.1</td>
<td>741.6</td>
<td>769</td>
<td></td>
</tr>
<tr>
<td>Middle-income</td>
<td>3.19</td>
<td>3.68</td>
<td>4.13</td>
<td>4.12</td>
<td>4.27</td>
<td></td>
</tr>
<tr>
<td>Income US$ month</td>
<td>3,586</td>
<td>1,848</td>
<td>1,262</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income US$ hour</td>
<td>3.19</td>
<td>3.68</td>
<td>4.13</td>
<td>4.12</td>
<td>4.27</td>
<td></td>
</tr>
<tr>
<td>Income US$ hour</td>
<td>3.19</td>
<td>3.68</td>
<td>4.13</td>
<td>4.12</td>
<td>4.27</td>
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</tr>
</tbody>
</table>

Table 7 Quantification of the economic externality by socioeconomic stratum of line 1 of the Panama metro 2014-2020

<table>
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<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Saved travel time (minutes)</td>
<td>57</td>
<td>46</td>
<td>44</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>41.61</td>
<td></td>
</tr>
<tr>
<td>Real annual total demand</td>
<td>57.54</td>
<td>68.97</td>
<td>78.8</td>
<td>81.52</td>
<td>87.04</td>
<td>108.17</td>
<td>37.69</td>
<td>519.72</td>
</tr>
<tr>
<td>High-income real demand (22.2%) [23]</td>
<td>12.77</td>
<td>15.31</td>
<td>17.49</td>
<td>18.10</td>
<td>19.32</td>
<td>24.01</td>
<td>8.37</td>
<td>115.38</td>
</tr>
<tr>
<td>Middle-income real demand (47.6%) [23]</td>
<td>27.39</td>
<td>32.83</td>
<td>37.51</td>
<td>38.80</td>
<td>41.43</td>
<td>51.49</td>
<td>17.94</td>
<td>247.38</td>
</tr>
<tr>
<td>Low-income real demand (30.3%) [23]</td>
<td>17.43</td>
<td>20.90</td>
<td>23.88</td>
<td>24.70</td>
<td>26.37</td>
<td>32.77</td>
<td>11.42</td>
<td>157.47</td>
</tr>
<tr>
<td>Externality salary/hour-high-income (14.25)-EHI</td>
<td>173</td>
<td>167</td>
<td>183</td>
<td>193</td>
<td>207</td>
<td>257</td>
<td>83</td>
<td>1,262</td>
</tr>
<tr>
<td>Externality salary/hour-middle-income (9.73)-EMI</td>
<td>253</td>
<td>245</td>
<td>268</td>
<td>283</td>
<td>302</td>
<td>376</td>
<td>121</td>
<td>1,848</td>
</tr>
<tr>
<td>Externality salary/hour-low-income -ELI</td>
<td>53</td>
<td>59</td>
<td>67</td>
<td>77</td>
<td>81</td>
<td>105</td>
<td>34</td>
<td>476</td>
</tr>
<tr>
<td>Externality total in million US$ dollars</td>
<td>479</td>
<td>471</td>
<td>518</td>
<td>553</td>
<td>590</td>
<td>737</td>
<td>238</td>
<td>3,586</td>
</tr>
<tr>
<td>GDP in million US$ dollars (current prices)</td>
<td>49,922</td>
<td>54,092</td>
<td>57,908</td>
<td>62,219</td>
<td>65,128</td>
<td>66,801</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>Real externality over GDP (current prices)</td>
<td>0.96</td>
<td>0.87</td>
<td>0.89</td>
<td>0.89</td>
<td>0.91</td>
<td>1.10</td>
<td>---</td>
<td>5.62</td>
</tr>
</tbody>
</table>

From the strata division of the population, approximately 33% of the externality value corresponds to the high-income segment, 48% to the middle-income segment, and 19% to the low-income segment. This structure is due to the weighing factor coming from the higher salary of the middle-income segment although the estimated annual travel demand of the low statement is higher. Thus, the equivalent externality high-income stratus will be greater compared to the low-income segment, even though the latter has a greater number of estimated trips throughout the entire 2014-2020 period, as can be seen in Table 7 with an estimated total of trips of the low-income segment of 157.47 million, of 247.38 million for the middle-income segment, and of 115.38 million trips for the high-income segment. (see table 7). The total of the estimated externalities of all the socioeconomic segments corresponds to US $ 3586 million and the sum of the percentage ratio of these externalities to the GDP of Panama within the 2014-2020 period corresponds to 5.62% of the GDP.
4.3. Preliminary Socio-Economic Externalities of Line 2 of the Panama Metro

Line 2 of the Panama Metro started operations on April 25, 2019. Prior to this, it was operational during World Youth Journey and the visit of Pope Francisco. From January 22 to 27, 2019, PML2 transported 579,933 passengers. Due to the Covid-19 pandemic, the expected mobility figures for the year 2020 have been strongly affected, being so that already in the month of May, the authorities of the Panama Metro announced that since the social distancing measures were implemented, demand from travelers fell to a minimum of 9% compared to the usual number of users [29]. The authors consider that this situation is a transitory, and once the Pandemic is over, Line 2 will transport the expected passenger volumes.

![Fig. 4 Real monthly travel demand of the line 2 of the Panama metro](image)

Fig. 4 shows the historic data for travel demand from September to December 2019 and for the entire year 2020. As shown in Fig. 4, during the year 2020, line 2 of the Panama metro did not exceed the annual European standard of trips of 25 million trips, due to the Covid-19 Pandemic, which caused restrictions mobility, confinement, virtualization of studies, and increase in teleworking from home and suspension of employment contracts. All these caused the demand for trips on line 2 of the Panama metro not be as expected (Fig. 4).

For the purposes of this research, the authors present the calculations of the socio-economic externalities of line 2 for the year 2020, based on the real annual demand [23] and the minimum wage. Additionally, calculations of the socio-economic externalities are presented for the 2020-D-2035-D scenarios based on the projections of the Panama Metro studies (Table 8).

<table>
<thead>
<tr>
<th>Year</th>
<th>Demand and characteristics (Line 2)</th>
<th>Passenger number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Daily</td>
</tr>
<tr>
<td>2020D</td>
<td>Line 2 with trains of 5 cars and interval of 3.8 min</td>
<td>233,550</td>
</tr>
<tr>
<td>2025D</td>
<td>Line 2 with trains of 5 wagons and interval of 3 min</td>
<td>276,500</td>
</tr>
<tr>
<td>2030D</td>
<td>Line 2 with trains of 5 wagons and interval of 2.7 min</td>
<td>317,340</td>
</tr>
<tr>
<td>2035D</td>
<td>Line 2 with trains of 5 wagons and interval of 2.4 min</td>
<td>334,780</td>
</tr>
</tbody>
</table>

According to scenario D projections, the daily average travel time of a person in public transport was projected in 67.61 minutes [30]. However, by 2020, the average travel time by public transport from the eastern sectors of Panama City to downtown Panama City during peak time is close to 90 minutes and may reach more than two hours [23]. Therefore, the estimates for 2020 have been presented in 4 scenarios. These scenarios are the ideal-real, the real-projected, the most probable and the pessimistic. The four possible scenarios for the calculation of the externalities of line 2 are presented in Table 9. In the general scenario of 2020 D, both lines, 1 and 2 are operating, in addition to the metro bus. The corresponding configuration will be maintained until the year 2035 [31-33].

Finally, scenario 5 presents three projected cases, for years 2025, 2030 and 2035, with three possible travel times. Using this information, it was possible to project the value of the economic externalities, as seen in Table 9, with a growth in the absolute and relative value of the externalities.
Table 9

<table>
<thead>
<tr>
<th>Parameters</th>
<th>2020 D</th>
<th>2020D</th>
<th>2020D</th>
<th>2020 D</th>
<th>2025 D</th>
<th>2030 D</th>
<th>2035 D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time highway (minute) [23, 28]</td>
<td>90</td>
<td>120</td>
<td>67.61</td>
<td>67.61</td>
<td>69.23</td>
<td>68.89</td>
<td>69.94</td>
</tr>
<tr>
<td>Travel time subway (minutes)</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Saved travel time</td>
<td>55</td>
<td>85</td>
<td>32.61</td>
<td>32.61</td>
<td>34.23</td>
<td>33.89</td>
<td>34.94</td>
</tr>
<tr>
<td>Minimum salary/hour [34, 35]</td>
<td>4.3</td>
<td>4.3</td>
<td>4.30</td>
<td>4.30</td>
<td>4.52</td>
<td>4.74</td>
<td>4.98</td>
</tr>
<tr>
<td>Real economic externality value (millions of US$)</td>
<td>77</td>
<td>119</td>
<td>46</td>
<td>175</td>
<td>228</td>
<td>272</td>
<td>311</td>
</tr>
</tbody>
</table>

1: Most probable scenario, 2: Pessimistic Scenario, 3: Ideal-Real Scenario, 4: Ideal-projected Scenario, 5: Projected scenarios

5. Conclusions

Based on the above, it is possible to conclude that, although the investments required for this class of projects are large, especially for small countries like Panama, their recovery based on positive externalities makes them highly profitable from a social point of view. The importance of studying the impact of the externalities of the railway transport sector allows to have an order of magnitude of those social benefits that are not directly tangible. However, they are of vital importance for planning, design, construction, and operation of railway transport networks. This type of research expands the capacities for the comprehensive analysis of the benefits of public transport networks and is understandable for a multiplicity of transport professionals, who can discern these results for strategic decision-making in urban planning.

Acknowledgements

The authors of this paper want to thank: Universidad Tecnológica de Panama (Panama), Transport Academy (Latvia) and Metro de Panamá for the support to this scientific article.

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Reduction of Guiding Forces in Curves - Comparison of Fundamental Solutions

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Abstract

The paper is created within the project which aim is to design a system of active wheelset steering for an electric four-axle locomotive. The goal of the presented study is to prove the benefits of active wheelset steering over other systems used for reduction of guiding forces. A multibody simulation model has been built and a vehicle run in a constant curvature track has been simulated. The maximum values of quasistatic guiding forces were observed and compared for standard vehicle and vehicle equipped with several systems for guiding forces reduction. The simulations results shows that active wheelset steering offers superior properties over the other practically implementable systems and demonstrated the great potential of this active wheelset steering for application on newly developed locomotives intended for operation on the tracks with sharp curve radiuses.

KEY WORDS: electric locomotive, wheel-rail contact forces, curved track

1. Introduction

Force interaction in between rails and railway wheels is one of the most important issues in the development of the new rolling stock. Todays’ effort to build an economic and environment friendly railroad brings a general and sustained demand to reduce wheel-rail contact forces below legislative limits as much as possible. Particular attention is paid to the lateral component of wheel-rail contact forces during passing a curved track, also called guiding forces. Conventional methods of reduction of guiding forces are based on the optimization of suspension characteristics [1, 2], or on mechanic or hydraulic linkages between the various components of the running gear [3]. Because the capabilities of conventional methods are increasingly encountered at their limits, ideas of the utilization of active controlled elements in the wheelset guidance and railway vehicle suspension occur [4-6]. One of the first practical utilization of such systems are active yaw dampers developed by Liebher and offered as an option for Siemens Vectron locomotives [7] (Fig. 1).

![Fig. 1 Active yaw damper on Siemens Vectron MS locomotive for ÖBB, Innotrans fair 2018](image)

2. Materials and Methods

In order to compare the effectiveness of individual methods for reducing of guiding forces, a simplified multibody simulation (MBS) model of an electric locomotive has been created (Fig. 2). The model consists of 7 rigid bodies (car body, 2 bogie frames, 4 wheelsets) that are connected by linear force elements. Wheel-rail contact respects non-linear characteristics of S1002 wheel and UIC 60 rail profiles, forces acting in the wheel-rail contacts are calculated...
using FASTSIM method.

The simulation model is built in 6 different vehicle configurations (see Fig. 3):

- **STD** – Standard, the suspension parameters correspond to the standard 4-axle electric locomotive with flexi-coil type secondary suspension.
- **YFS** – Yaw Flexible Suspension, Fig. 3, a. The characteristics of the primary suspension and wheelset guidance are modified in order to soften the yaw stiffness of the connection between wheelsets and bogie frame.
- **MBC1** – Mechanical Bogies Connection Type 1, Fig. 3, b. One of the classical methods of reducing guiding forces based on the direct mechanical connection of bogie frames [8].
- **MBC2** – Mechanical Bogies Connection Type 2, Fig. 3, c. Mechanical connection of bogie frames by a mechanism. This method works on the similar principle like MBC1, but it has less space demands. Thus, MBC2 can be utilized also on asynchronous locomotives, which have usually a large transformer located between the bogies [8].
- **AYD** – Active Yaw Dampers, Fig. 3, d. Method based on active controlled yaw torque acting between a car body and bogies. The torque is generated by a couple of linear actuators acting in between each bogie frame and car body [9, 10].
- **AWS** – Active Wheelset Steering, Fig. 3, e. Yaw angles of wheelsets towards a bogie frame are actively controlled by actuators [11-14].

Simulations of a vehicle run in the curved track of a radius $R = 250$ m with a superelevation of rails of 150 mm were performed, considering the friction coefficient in the wheel-rail contact $f = 0.4$. The three vehicle speeds corresponding to the uncompensated lateral acceleration $a_y = 0$ ms$^{-2}$, 1 ms$^{-2}$ and -0.65 ms$^{-2}$ were taken into the account. The quasistatic value of guiding force in a constant curvature track without irregularities $Y_{qst}$ was evaluated on all wheels. The maximum value of $Y_{qst}$ is typically reached on the outer wheel of the first wheelset. A vehicle setup and parameters has been sought in which the maximum of $Y_{qst}$ is minimized. Each system was optimized in order to obtain the maximal benefit in guiding force reduction (see Fig. 4).

- **YFS** – Fig. 4, a. The longitudinal stiffness of the primary suspension and the wheelset guidance are modified in order to soften the yaw stiffness of the connection between wheelsets and bogie frame.
- MBC1 Fig. 4, b and MBC2 Fig. 4, c – the stiffness and preload of the bogie coupling element were varied.
- AYD – Fig. 3, d. the force produced by AYD actuators was varied, whereas all actuators were controlled to the same force.
- AWS – Fig. 4, e. the position of wheelsets with respect to the bogie frame was varied. All wheelsets were steered to the same angle.

The goal was to find the optimal setup which gives the maximal possible value of guiding forces reduction for each system. The Fig. 5 and Table 1 thus expresses the theoretical maximum possible effect of reducing of the guiding forces in the curved track of radius 250 m, which can be achieved by assessed methods.

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**Fig. 4 Optimization of the systems for curve radius R = 250 m.** The red numbers indicate the wheel which exhibits the maximal value of quasistatic guiding force. The wheel designation is according EN 14363: a – YFS; b – MBC1; c – MBC2; d – AYD; e – AWS
It is important to note that:

- Contribution of mechanical bogie connections MBC1 and MBC2 to the guiding force reduction will be lower than calculated values. The parameters of mechanical bogie connections should be compromised in the wide range of curve radiiuses.
- For AYD the impact of forces in the actuators on the secondary suspension deflections was not taken into an account. To avoid undesired large deflections of secondary suspension in the lateral direction and transmitting forces via lateral bump-stops, the power of the actuators would probably have to be lower than considered in the simulation. Consequently, a reduction in guiding forces will be probably lower than calculated value.
- The highest reduction of guiding forces shows YFS. However, such reduction is achieved for virtually zero value of the yaw stiffness of the wheelset guidance which drastically affect the stability and lower the maximum speed of the vehicle.

3. Conclusions

The reduction of guiding forces i.e., lateral components of the forces acting in the wheel rail contacts is highly desirable for many reasons.

Because the optimization of suspension parameters faces its limits, a special mechanical or active controlled systems in the running gear occur.

Computer simulations of the electric locomotive run in the constant curvature track of the radius 250 m show that active wheelset steering could bring reduction of guiding forces in the range of 70 to 90 percent. Such results
cannot be achieved by any of the other systems considered in this study. Based on the presented results, it can be stated that AWS is a very promising method of guiding forces reduction which is practically feasible and worth further a more detailed elaboration.

Acknowledgement

This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres, project # TN01000026 Josef Bozek National Center of Competence for Surface Vehicles. This support is gratefully acknowledged.

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Use of Value Management Tools in Public Transport Companies

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Abstract

The current time in which companies carry out their services and services is affected worldwide and for a long time by the Covid pandemic. In view of the increasing complexity of the operation of enterprise systems and their use, the question arises as to how to adapt corporate governance to a complex situation. This must be flexible, flexible, and the ability to make the right and quick decisions is very important, thus reducing the likelihood of possible risks and dangers to a minimum. Within the economic information system, the management information subsystem is in this context a very important tool to support management and decision-making. The paper presents an analysis of management accounting tools with regard to their application in the management of transport companies. Emphasis is placed especially on cost management, their categorization in the specific conditions of transport companies as well as their subsequent use in profit management. To achieve the goal, several methodologies were used, not only in obtaining and processing theoretical knowledge about managerial accounting, but also in other solutions, proposals for the practical use of selected tools of managerial accounting in transport companies. The subject matter was solved with the use of selected qualitative methods, based on induction with an effort to observe, find out the regularity, and draw conclusions and theories in order to obtain narrative outputs. Theoretical outputs are the result of processing available knowledge about managerial accounting and its development, the practical level provides the result in the form of a proposal for the application of selected tools of managerial accounting in the conditions of transport companies operating in the Slovak Republic. The paper can be considered a relevant source of knowledge and understanding of the issues addressed, offers a methodological proposal, applicable in general to companies whose management decides to implement and use management accounting tools.

KEY WORDS: Strategic Management, Balanced Scorecard, Bus Transport Companies, Business

1. Introduction

The conditions in which transport companies fulfill their mission have always been changeable, but now incomparable with anything in the past. In every country in the world, managers must adapt to the situation caused by the Covid pandemic and respond flexibly to its consequences. Its effects apply to all segments of continuous change in society, and change can be considered a certain variation, excitement, irregularity, surprise, something that is expected. Managerial work is therefore clearly more demanding at present, which requires more intensive using of modern manager’s equipment. It is knowledge of change management. Changes in the external environment create the need for a reaction - changes in the internal environment. This phenomenon is caused by the increasing complexity of changes in the external environment and the dynamics of change, which are the main attributes of the formation of a turbulent business environment. An important internal area of transport companies is the so-called value-creating area, producing paradigmatically consumption, but subsequently also benefit. Given the complexity of pandemic impacts, it is essential to manage this area with increased attention and at the same time innovate, so that its potential threats from other crises in the future are minimal. In every company, the creation of benefit is demanding, but in the conditions of transport companies, it is disproportionately more. The reason is the product itself and its specific characteristics, which, due to the characteristics of transport services, limit many foreign currencies of production of a material nature. However, the declining attractiveness of the product in the eyes of consumers is also a fact, which is due not only to individual consumer preferences, but also to new health threats, which manifested themselves as one of the consequences of the COVID pandemic. A limited range of management tools for value-added management thus characterizes the issue of the current management of transport companies. Achieving profitability without negative consequences for those for whom the transport product is intended in the context of the conditions brought by the pandemic is a fact that forces the management of transport companies to look for new alternative methods, with an emphasis on strategic position in the future. In addition to this fact, the need for management innovation is caused by the continued use of the so-called traditional tools for managing value-creating quantities (traditional cost management or their calculation), in the form of a basic purpose, often only operational cost record and calculation system, as a tool for their management, also based on traditional calculation types and methods. Finding alternative management methods requires a sufficient base of information and knowledge that managers can obtain from the external environment, but for the proper management of the organization it is necessary to connect them with the information that arises within the company. At a qualitatively higher level, the information system processes managerial accounting for the needs of management and decision-making. It is one of the ways to optimize the management of transport companies. This management tool has the
ambition to identify possible risks and opportunities, define decision-making alternatives as well as inform management about the results achieved in the context of the desired ones. It fulfills this ambition through various instruments, among which the area of costs and their management has an irreplaceable place. The paper presents an analysis of management accounting tools with regard to their application in the alternative management of transport companies. Emphasis is placed on cost management, their categorization for the needs of management and decision-making in the specific conditions of transport companies, as well as their subsequent use in profit management.

2. Methodology

For the mentioned purpose, the relevant methodology was used, in the acquisition and processing of theoretical knowledge, as well as in other solutions, proposals for the practical use of selected tools of managerial accounting in transport companies. The subject was solved with the use of selected qualitative methods, based on induction with an effort to observe, find out the regularity, and draw conclusions and theories in order to obtain narrative outputs. Theoretical outputs are the result of processing available knowledge about managerial accounting and its development, the practical level provides the result in the form of a proposal for the application of selected tools of managerial accounting in the conditions of transport companies operating in the Slovak Republic. The paper can be considered as a source of knowledge and understanding of the issues addressed, offers a methodological proposal, applicable in general to companies whose management decides to implement and use managerial accounting.

3. Theoretical Background of the Problem

At present, it is very difficult for business managers to ensure the long-term growth of the company or, in general, the very existence of the company in the market. To make the right decisions, a lot of information is necessary, which is important for the management and decision-making of managers in the company. Managerial accounting serves precisely to provide and obtain this information, which will influence the decisions of managers and subsequently also the economic development of the company in the future. In this context, we consider managerial accounting as a necessary source of information for company management [1]. Managerial accounting refers to the part of accounting that deals with information from the internal phenomena of the company, which are associated with the management, development and organization of the company. It is designed mainly for the internal needs of the company, specifically for top managers but also managers at lower levels of management or executive directors. For these reasons, in practice, managerial accounting is also referred to as the company's internal accounting [2]. Managerial accounting deals with the provision of economic information that management needs to make decisions and control its short-term or long-term decisions that affect the future development of its economic activities [3]. Managerial accounting is an area of accounting that supports the management of companies in planning, decision-making, control and analysis. Effective use of managerial accounting by operational management ensures profitable growth of the company [4]. In the English literature, managerial accounting is defined as the process of providing relevant information - financial but also non-financial, which serve managers and employees of the company or. In the organization, for decision-making, resource allocation, and monitoring and evaluating business performance [5]. In the Czech literature, managerial accounting is defined as accounting created for management. According to the author, managerial accounting should primarily serve the management of the accounting unit - managers to make the right decisions, run and develop the company. In order for the decision-making to be correct, managers must have at their disposal the necessary amount of information that is provided by accounting. Managerial accounting represents the consistency between the management and accounting of an accounting entity resp. company [6]. Another author [7] defines managerial accounting as the application of the principles of accounting and financial management for the purpose of creating, protecting, maintaining and increasing value. At the same time, providing this value to groups has their interests in the company. In the case of for-profit as well as non-profit organizations, publicly or privately owned. Managerial accounting is considered by the authors to be a subsystem of the entire corporate accounting system, without which accounting would not be able to fulfill its dominant function [8]. The Institute of Management Accountants (IMA), based in the United States, refers to management accounting as a partnership in making management decisions, but also as an aid in planning and managing management systems. IMA is of the opinion that managerial accounting provides a wealth of expertise for financial accounting, control, but also describes the fact that managerial accounting is also necessary in the formulation and implementation of the company's strategy. Managerial accounting provides MIS with appropriate, clear and unbiased information that helps managers make the right and, in particular, effective decisions. This function can be performed by the MIS only on condition that it is linked to the accounting system of the given company or organization. The MIS must also be integrated into the information system of the company or organization. In many companies, the MIS is created based on inputs and outputs of managerial accounting [9]. MIS must be created with increased database protection [10]. The Chartered Institute of Management Accountants (CIMA), based in London, defines managerial accounting as the application of accounting and financial management principles in order to create, protect and preserve, but also increase all kinds of values in the organization. This organization considers managerial accounting as part of management, which requires the identification, creation, presentation and interpretation of information for the purpose of creating business strategy, planning and decision-making, efficient use of financial resources of companies and increasing the performance of the organization or. Enterprise. American professors understand managerial accounting as a dynamic process of adapting changes to each
other. An assessment of the adjustment process reveals a decision-making process in which accounting strategies are designed to use the company's resources efficiently and monitor the company's performance [11]. Managerial accounting is a term that covers cost accounting, budgeting and calculations, which form the three subsystems of managerial accounting as a whole [12]. The individual subsystems of managerial accounting are described in detail in the second chapter of the thesis. Managerial accounting is also referred to in the literature as an independent form of business accounting, which provides information support to the management system to the business entity. Management accounting is an integrated system of collecting, processing and informing internal users about the income and expenditure of the company in order to ensure effective cost management and obtain a positive financial result [13]. In the literature, we encounter the statement that managerial accounting is a tool that is found in all four basic managerial functions, which include planning, organizing, leading and controlling [14]. In planning, managerial accounting provides managers with various methodological tools for expressing the planned goals of the company. In the second phase of organization, managerial accounting is applied mainly in the economic definition of the company structure. Managerial accounting in the third managerial function plays the most important role, which is management. As part of this managerial function, managerial accounting provides information for the company as a whole, but also important information for evaluating the economy and efficiency of individual products and services of the company. Thus, in the last basic managerial function, in accounting, managerial accounting provides various methodological tools for identifying the identified differences between the planned and actual state [14]. We consider the necessary setting of the SMART goals process to be the basic prerequisites for effective managerial accounting. SMART is an analytical technique for designing goals in business management and planning. This abbreviation comes from the initial letters of the English words: specific, measurable, achievable / acceptable, realistic / relevant and time specific. In translation, this means that objectives should be specific, measurable, achievable / acceptable, realistic and time-specific. In the company, it is necessary to set a process of SMART goals [15]. Managerial accounting is primarily focused on the future, more precisely on its active influence. These are various recommendations, analyzes, estimates. Managerial accounting plays an important role in supporting management in the company by systematically providing appropriate information to support the decision-making process and thus influence the future development of the company [16]. Managerial accounting consists of three basic subsystems: cost accounting, budgets and calculations. In a case study of the "Sunrise Hotels" hotel network, which consists of several hotels in North America, we find that management accounting subsystems are interconnected tools for decision-making and control of a company's activities [17].

3.1. Managerial Accounting in Transport Companies

Managerial accounting is a very effective way to improve the management of transport companies. It represents a strategic alternative for improving all value-creating variables not only in standard but also in various crises, similar to the Covid pandemic. However, its universal form needs to be adapted for companies providing transport services in order to create a specific form of this management tool. In the following section, we will address all aspects that affect the management accounting model for transport companies. An important condition for fulfilling the mission of managerial accounting is a certain modification of parameters, registered and managed in the traditional way. In other words, it is a modification of traditional management and reporting. This is based on a modification of the source input tools. These include, for example, financial and economic analysis. One of the most useful financial analyses is its specific method, as it has the potential to find answers regarding the financial health of any company. In general, the results of the financial analysis are valuable because they represent the company and its success compared to the industry partner (existing and potential), according to the relevant financial data, the company perceives, evaluates, and determines the conditions for the future [18]. Another possibility is to use the potential of financial accounting, based on the legislatively established recording of costs and revenues for the past economic period. The problem, however, does that standard reporting is widespread, but the quality of the identified reporting systems and the results of reporting methods show that there is still considerable room for development point out the fact [19]. Costs are a very important quantity of management and reporting. They are a key part of economic governance. Their amount affects the final profit and the structure from the accounting point of view is shown in the chart of accounts, in which all types are arranged in accounting class number 5. They are grouped into individual groups and designated by the appropriate common names. During the period there is a movement of individual types of costs (as well as revenues). The resulting changes can be recorded in the financial accounting using the relevant accounting documents in the relevant accounts. In practice, this means that a given document on the movement of a certain cargo is settled on the given side, or is to be given to the corresponding account. These cost groups, as well as the allocation of costs to these groups, are carried out in accordance with the accounting rules and are closely related to the prescribed creation of the income statement. Traditional value management is largely determined by the outputs of financial accounting. However, the characteristics of managerial accounting imply the need to concentrate on the following several areas of problems. The detailed differentiation of costs into these cost groups, as they are formed in the accounts, shows that there may be some opacity, which slows down decision-making. Therefore, if the company wants to adhere to the principles of managerial accounting, it must reconsider this breakdown. It is a matter of narrowing the range of cost groups to the most important from the point of view of management. The theory recommends the design of monitoring a maximum of 10 cost types individually and the creation of a single item from the others - other costs. In addition to the above problem, it is necessary to be aware of the level of information provided by the accounting aspect of the breakdown of costs. It proves to be insufficient for management based on the principle of managerial accounting. Profit management also
Managers in the company, in contrast to the management based on financial accounting, guided by the principle of unambiguity and is to comply with the principle of causality, which allows the detection of dependencies on certain developments in the company, in contrast to the management based on financial accounting, guided by the principle of unambiguity and accounting. Managerial accounting is therefore focused on the following cost differentiation:

- **Technological costs** - they are caused directly by performance, therefore they are also called direct. Performance - services enter directly, and therefore are directly attributable to it. They form the calculation basis when calculating the minimum price limit. These include production wages, production material, etc.

- **Service costs** - are costs that are not directly related to the performance, i.e. the performance - the services do not enter directly. They are used for operation as such and include the cost of premises, advertising, etc. Theoretically, they are the biggest loss risk, because if the company did not produce anything, then the reported loss for the period would correspond to the amount of these costs. They are further subdivided into:
  - **Service costs I** are not assigned directly to performance, but depend on individual developments in the company (product group, services, functional circuits, customer groups) to which they are assigned. Assignment does not require the use of a specific key (postage, telephone, office supplies).
  - **Service costs II** are equally dependent on developments in the company, but they cannot be assigned without the use of a specific key or method (representation costs, contributions, taxes). It is also necessary to take into account that the sequence of importance of costs is given by the weight of their importance. This is expressed as a percentage of individual company costs in the company's total revenue, which is 100%. It is also true that the estimate of the order of costs is primarily determined from the income statement, more precisely from accounting class 5, and in the next step it is determined whether the order of costs determined in this way corresponds to the order of costs in the company determined according to their importance. It may be that some costs, which have a high percentage, are not so important for the company from a management point of view and vice versa. It is necessary to consider such a case and create a new hierarchy of costs. The order of costs is also compiled by grouping costs of a related nature into one common group. For example, space costs will include not only the cost of repairs, rent, but also heating, energy, cleaning, etc. In a transport company, in which we respect some specific types of costs, the plan of cost types has the following form, given in Table 1. The plan therefore forms part of the reporting which uses managerial accounting. Separately, although in connection with the differentiation of costs in the chart of accounts would not have much use; it is an intermediary part for the subsequent formation of the reporting apparatus, which serves to manage value-creating variables. It is important to keep in mind that the essence of managerial accounting is profit management. Based on this lesson, it is necessary to think about how profit is generated. It would not be right to imagine under the concept of profit management that it will be ensured only by monitoring this quantity. Profit management means the management of those quantities that create profit, which participate in it. It is therefore logical to consider in the management of profit in the first place the costs and revenues, which contribute to the profitability or loss of the company to the greatest extent. Analytical thinking needs to be continued, because, like profit, costs and revenues are not basic but formed quantities. They therefore need to be differentiated into items that will allow for profit management.

<table>
<thead>
<tr>
<th>Numbers</th>
<th>Cost element plan</th>
<th>Technological costs</th>
<th>Service costs I</th>
<th>Service costs II</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>account number b</td>
<td>c</td>
<td>d</td>
<td>e</td>
</tr>
<tr>
<td>01</td>
<td>direct material</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>personnel costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>depreciation DM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>repairs and</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>maintenance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>other operating costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06</td>
<td>operation overhead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>administrative overhead</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The instrument used for this purpose by managerial accounting is a contribution to the payment, also called a cover contribution, which in its economic interpretation actually means the amount (extent) in which individual groups of activities and costs are covered from planned or actually achieved company results. When calculating the contribution for payment, we proceed as follows:
gross turnover (total sales, sales price or revenues)
  – value added tax
  – items reducing sales

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net turnover

Then the contribution for payment represents the surplus of net turnover (sales prices or revenues - in transport) over direct (power or variable) costs. The annual expression of the payment allowance represents the percentage rate of turnover that must be achieved on average as a payment allowance for the performance (product, service) in order to meet the target profit. Hence the function of the contribution to the reimbursement, which consists, on the one hand, in covering service costs (which, as we have already stated, represents a loss risk) and, on the other hand, in the instrument for making a profit. This is because any occurrence of performance always results in performance costs and a contribution to the payment, but not service costs and profit. Returning to the introductory consideration of the need to monitor the components that contribute to its creation and not just the profit itself, the transport company needs to record net turnover, direct performance costs, service costs and target profit.

The causes of costs, related to their direct or indirect relationship to performance, are reflected in their respective differentiation into performance and service costs, which can still be divided into service I and service II. The reflection of the application of the mentioned principle is Table 2 management accounting reporting, which is used to determine the result.

**Table 2**

<table>
<thead>
<tr>
<th>line</th>
<th>items</th>
<th>range/product</th>
<th>value</th>
<th>period</th>
<th>indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>revenues from transport</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01</td>
<td>other transport revenues</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td>reduction in sales</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>revenues from other activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>consumption mat. and raw materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>net income</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06</td>
<td>production wages</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>other direct costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>performance costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>payment allowance I.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>operational overhead</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>costs of other activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>costs of other activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>service costs I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>service costs II</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>service costs III</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>transmission bridge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>profit loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Within a transport company, there is a possibility within the managerial accounting of the creation of the second level of reporting, which is a supplement to the economic structure with an organizational one. It is based on the observance of certain principles, based not only on the existing arrangement of individual internal company units, but also on respect for the principles of managerial accounting. These include the fact that in the initial steps of implementation, it is necessary to dispense with demanding requirements and focus only on the most important (basic) division. This presupposes the choice of a maximum of five units to which the holder of the responsibility can be addressed. Assuming the choice of one of the following principles: according to services (or production) it is possible to create clearing houses when it is possible to determine for each output or group of outputs the method of implementation, cost structure and calculation procedures. Responsibilities are suitable for centers with clearly defined functional areas, with the division of responsibilities, or if there are different workshops, divisions, or different sales organizations. The breakdown by customer is appropriate if the company has different sales channels or groups of customers (depending on their size). In the transport company, the above differentiation can be interpreted according to the objectives of individual customers' routes and the second level of reporting can be created for passenger liability (within suburban, long-distance, international and irregular), maintenance and repair, administration, technical inspection stations, canteens, clear and recreational facilities. These can later become the starting point for creating an organizational chart of the company. In addition, it is necessary to take into account the existence of such a cost center,
which includes all the functions serving the company as a whole, referred to as the central in-house unit. The activity of a transport company consists in providing the possibility of relocation - transport to various places within the city, its surroundings, within the state and abroad. Thus, groups of customers are created according to which service the customer is interested in, which implies the possibility to take into account the breakdown by customers or groups of customers.

<table>
<thead>
<tr>
<th>Items</th>
<th>Expected impact</th>
<th>Original estimate</th>
<th>The impact of the crisis</th>
<th>Adjusted estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenues</td>
<td>-81 %</td>
<td>15 914 580 €</td>
<td>-12 942 225 €</td>
<td>2 972 355 €</td>
</tr>
<tr>
<td>- Sales</td>
<td>-90 %</td>
<td>15 184 330 €</td>
<td>-12 230 000 €</td>
<td>2 954 330 €</td>
</tr>
<tr>
<td>- fines</td>
<td>-100 %</td>
<td>730 250 €</td>
<td>-712 225 €</td>
<td>18 025 €</td>
</tr>
<tr>
<td>Costs</td>
<td>-13 %</td>
<td>38 176 410 €</td>
<td>-4 976 723 €</td>
<td>33 199 688 €</td>
</tr>
<tr>
<td>Impact on management</td>
<td>36 %</td>
<td>-22 261 830 €</td>
<td>-7 965 503 €</td>
<td>-30 227 333 €</td>
</tr>
</tbody>
</table>

The net impact on the result of the transport company's management for the first half of the year is estimated to increase by eight mil. € (Table 3) and in the following months until the end of the year in the amount of 2.5 - 3 mil. € per month. According to the conservative model, the total impacts of the pandemic on the management of DPB for 2020 are estimated at 26 mil. €.

From the range of ways to succeed, in the article we focused on managerial accounting and the use of its tools with a direct impact on reporting in transport companies. Reporting is an integral part of managerial accounting, as a tool of controlling and controlling is a reliable tool to support management and decision-making in transport companies. It generates an information base for managerial decisions, which is also confirmed by [20] when she claims that it can form a complex system of internal reports and reports synthesizing information for managing the company as not only a whole but also its basic organizational units.

The role of the transport undertaking's management accounting department is therefore to prepare such reports, from which managers will receive the most detailed information. The following procedure should be respected in the design and implementation of the reporting system. Identification of report users and their needs - in terms of content, form, time; differentiation of the report to internal and external users, choice of appropriate report form - printed, electronic or a combination, design uniform design (not frequent changes), distribution of the report - emphasis on the separation of confidential information, the use of feedback from users to improve the reporting system. The content, format and frequency of reporting and reporting depends on the needs of a particular company. To compile a reporting report in the required structure, the disposition of objective information is required. When creating the report, not only information from financial accounting is used, but also alternative sources of information (Fig. 2).

In most cases, companies compile and use monthly and quarterly reporting. They analytically monitor the most significant items of individual costs, revenues, current assets (receivables, inventories) and liabilities. Although the
structure of internal reports may be different, we usually encounter a breakdown into summary reporting and several partial reports according to individual areas of business activities. Summary reporting contains the basic financial indicators of the management of the company as a whole for a given period, their comparison with the planned values, or a comparison with the values of the previous period. [20] showed that the commentary, which draws attention to extraordinary deviations from the planned intention and analyzes their causes, is also very important in the reports. Partial reports are usually divided according to areas into sales, production, personnel, marketing, etc. Their structure is based on the customs and specifics of the company. Summary reporting contains the basic financial indicators of the management of the company as a whole for a given period, their comparison with the planned values, or a comparison with the values of the previous period.

4. Discussion

Transport is an integral part of human society, the development of which is closely linked to the exchange of goods, and thus the development of the transport used to carry out this exchange. Transport companies provide their customers with transport services of considerable importance. The importance of transport services is fulfilled if the requirements that are generally imposed on transport are met. The most important ones are speed, reliability, regularity, safety, fluency, comfort, adaptability. If these requirements are met, the transport becomes important and functional. More specifically, it acquires the following functions: mediation, innovation and social. However, transport companies must constantly defend their position in order to successfully withstand the competitive pressures and effects of globalization. At present, however, in addition to the standard competition, transport companies are facing the impact of the Covid pandemic, which has led to the closure of schools, shops and the introduction of teleworking, which has resulted in a significant loss of passengers. The decrease in revenues of transport companies caused a significant decrease in their revenues. An example of this situation is a transport company operating in the capital of Slovakia, in which the reduced number of passengers caused a drop in sales compared to the same period last year, a decrease in the number of passengers is slightly lower (about 70%) and after analyzing the data in the amount of 4 mil. €, while on these days sales are close to zero. Revenues from city transport services represent almost 40% of revenues every year.

5. Conclusions

Managerial accounting is one of the ways to support efficient management in the company. It is an integral part of modern business management, in which it is linked to its entire process. With its integration of information processing processes, creation of analyzes, business plans and control, it becomes the basis of success in the market. Its task is to process a lot of data and data into clear reports that contain only the most important, high-quality and reliable information. This is because information is currently perceived as one of the key factors in the success of a company, because knowledge and prediction of what is coming to help supports the overall strategic management.

By following these steps, the company avoids various unnecessary obstacles in the implementation of reporting and thus creates a basis on which to build in the implementation of further phases related to the areas in which it intervenes. It is true, as the author [22] claims, that innovations from new technologies, methods and opportunities can bring significant benefits for the company. In order to ensure consistency between traditional accounting and managerial accounting and not to compete with each other, it is necessary to recall the importance of defining a clear relationship between management and managerial accounting. The fact remains that the management decides, bears responsibility and managerial accounting as a controlling tool only supports decision-making with its inspirations, evaluation, analysis and control, gives recommendations. In order to be usable for management, the tools of managerial accounting must also be set up correctly, which also applies to reporting in transport companies. All the benefits of managerial accounting with universal validity can be specified. In the article, we placed the greatest emphasis on the specification in transport companies. We have proposed a way to use this management tool in conjunction with cost management of transport companies for more effective management in the future and better preparedness for various crises, not just the Covid pandemic.

Acknowledgement

This publication was created thanks to support under the Operational Program Integrated Infrastructure for the project: Identification and possibilities of implementation of new technological measures in transport to achieve safe mobility during a pandemic caused by COVID-19 (ITMS code: 313011AUX5), co-financed by the European Regional Development Fund.

References


Analysis of Possible Discrepancies Between the Public Transport Offer and Customers’ Expectations

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Abstract

The work describes the elements of preparing public mass transport offer. The general characteristics of public transport and the environment of the transport system are discussed. Next, the features determining the quality of transport services are described and divergence that may occur during the preparation of the transport offer is indicated. The presented discussion is based on the interfaces (points of contact) between the transport system and its surroundings. The results of surveys on passenger preferences, both those prepared by the authors and those available in the literature were discussed. Based on potential corrective actions, the directions of ensuring compliance of the offer with the clients’ expectations have been presented.

KEY WORDS: public transport; quality in transport; passenger preferences

1. Introduction

Due to the urban development of modern cities, especially the phenomenon known as urban sprawl [1], planning the public transport offer is a difficult task. Cities are now very extensive and people cannot function in them without means of transport – individual or collective. There are many causes of urban sprawl, such as preferences of residents to have their own house and space, as well as economic and demographic reasons [2].

Urban public transport systems are of great importance for large urban agglomerations, enabling fast movement of large passenger flows. Appropriate public transport communication solutions allow to avoid many hazards of modern cities related to traffic accidents and time losses due to traffic congestion. An efficient public transport system can compete with individual transport. However, only those solutions can be competitive and attractive for potential customers, i.e. passengers, that allow to meet specific traffic quality requirements and are in line with the passengers’ expectations. Ensuring the quality of transport services is a source of additional costs of the operation of the urban transport system and therefore it should be based on a certain compromise between what is needed, possible and profitable. For this reason, there are discrepancies in the quality provided and perceived by the client, which will be present in the area of corporate losses. These costs will result from providing unreasonably high quality or from loss of customers. Therefore, it is important to collect information on the needs of passengers and their assessment of transport services in public transport.

2. Description of the Research Area

2.1. Public Passenger Transport

In accordance with European standards EN 13816:2002 [3] and EN 15140:2006 [4], public transport is defined as services, which have the following characteristics:

- They are available to all, travelling individually or in groups;
- They are publicly advertised;
- They have a fixed timetable and period of operation;
- They have permanent routes and stops or specific departure and destination places, or a defined area of operation;
- Their fares are published.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

In cities around the world various transport systems are used, and they are characterised by different theoretical values of the maximum capacity of individual means of transport (Table).
### Table 1. Theoretical maximum capacity of individual means of transport [5]

<table>
<thead>
<tr>
<th>Means of transport</th>
<th>Commercial speed [km/h]</th>
<th>Passenger stream [10^3] pass./h</th>
<th>Efficiency [10^3] pass. km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus, Trolleybus</td>
<td>20 - 25</td>
<td>9 - 10</td>
<td>180 - 250</td>
</tr>
<tr>
<td>Standard tram</td>
<td>10 - 20</td>
<td>12.5 - 18</td>
<td>125 - 360</td>
</tr>
<tr>
<td>Light urban rail</td>
<td>25 - 30</td>
<td>20</td>
<td>500 - 600</td>
</tr>
<tr>
<td>Metro</td>
<td>35 - 40</td>
<td>40</td>
<td>1400 - 1600</td>
</tr>
<tr>
<td>Suburban railway</td>
<td>40 - 50</td>
<td>50</td>
<td>2000 - 2500</td>
</tr>
</tbody>
</table>

The data presented in Table 1 are approximate. The actual capacity of transport systems depends on the detailed characteristics of the infrastructure and on how much the system is loaded with transport tasks.

### 2.2. Processes in Urban Transport Systems

Four groups of processes stand out in the transport system [6]:

- Traffic processes;
- Disruptive and destructive processes;
- Service processes;
- Control processes.

Traffic processes are basic processes resulting from the purpose of transport systems operation. As their result, transport tasks are carried out in accordance with the transport plan. Disruptive and destructive processes are external processes hindering the work of transport systems. Disruptions can be planned or random. Planned disruptions result from the operation of transport systems in complex urban systems. They are caused by changes in the operation of the transport system resulting, for example, from: planned renovation of other systems (sewerage, waterworks), planned manifestations, mass events, street runs. Random disruptions are usually destructive and are related to disruption of the transport system operation due to weather, geological conditions and failures of systems surrounding the transport system. Service and control processes are processes aimed at maintaining the system’s availability to implement basic processes, changes in the implementation of these processes, reactions to disturbances.

Typically, the ability of the transport system to adapt to changing environmental conditions, immunity to disruptions and speed of response to the disruptions is a desirable feature of transport systems and can be the advantage of public transport over individual transport.

### 2.3. Interfaces between the Transport System and its Surroundings

Transport systems, especially in urban space, are not isolated systems. The transport system and its surroundings are in constant close relationship and interact with each other. The surroundings of the transport system are understood as other elements of the socio-economic system, i.e. non-transport sectors of the economy, the society and the natural and artificial environment. In order to determine the interactions between the system and its surroundings, it is necessary to specify:

- Impact of other systems operating within the transport system: water supply system, sewage system, buildings, character and role of the urban area;
- Transport needs coming from the surroundings of the transport system (demand) and transport offer (supply);
- Intentional influence on the system from outside (control), as well as legal regulations, standards and requirements;
- Natural and artificial environment conditioning the possibility and manner of implementation of tasks by the system, and the impact of the system on this environment.

The transport system is in contact with the surroundings in [6]:

- Space;
- Time;
- Transport offer.

The spatial interface signifies the compatibility of the place where transport needs arise with the spatial accessibility of the transport system. Due to the fact that passengers can only get on and off the vehicle at stops and stations, these places take the role of spatial interfaces. The distance from the stop and convenience of reaching it are the key factors in determining if it is possible to use public transport.

The time interface signifies the correspondence between the timetable and the expectations of passengers in terms of journey times and the frequency of public transport. In addition, increased traffic during peak hours or the need to operate night lines should be taken into account.

The transport offer interface signifies the compatibility of the transport system equipment with the expectations and needs of passengers. The first group of compatibility are the characteristics of vehicles: the occupancy rate, equipment elements such as air conditioning, passenger information systems, the possibility of carrying luggage or
bicycle, cleanliness of the interior. The second group are the characteristics of the infrastructure: the density of stops, their equipment, the need to change and facilitation of such changes. The third group consists of elements related to passenger and ticketing information systems: website, applications for mobile devices, ticket machines in vehicles and at stops [7].

The compatibility of the interfaces between the transport system and the surroundings is a prerequisite for the transport task to be performed by the transport system. The interfaces shown, however, do not always coincide with real needs. Discrepancies between the needs of customers and the offer of suppliers are negatively perceived and lead to the loss of the customers, therefore the creation of the transport offer should take into account the needs of the transport system surroundings.

3. Preparation of the Transport Offer in Public Transport and Directions for Ensuring the Quality of Services

3.1. Preparation of the Offer

The transport offer is prepared by the carrier taking into account the needs of the surroundings as well as certain restrictions. When preparing the offer, the carrier encounters a number of constraints related to the availability of the infrastructure, its characteristics and the carrier’s own capabilities, such as the number of rolling stock and its intended purpose. Additional restrictions are associated with obtaining the appropriate permits to carry out transport and meeting other legal requirements. Demand for services is usually increased by marketing and advertising activities. The customers can only use the transport offer if they know about its existence. In addition, in the transport services sector, additional supply of services may create demand.

An additional factor that should be taken into account during the preparation of the transport offer is the intra- and inter-branch competition. Competitors prepare their own offers based on their own research and assumptions and direct their own marketing campaigns to the client. High flexibility in changing offers, adapting to industry standards and continuous testing of the level of the offered services may be decisive for the customer’s choice of a specific offer.

The profit earned from the sale of the transport service goes partly to the service provider – the supplier. In addition, a certain part of the profit remains in the society in the form of taxes on transport activities and infrastructure development. Profit from transport activities is not only simply financial. The society is gaining the opportunity to integrate and to get an access to jobs that were previously inaccessible due to distance in time and/or space. The development of transport and its infrastructure is a stimulant of economic development. New markets are emerging, new investors are coming, and tourism is also developing.

3.2. Quality in Public Transport

In the transport of people, the assessment of the quality of transport services is closely related to passengers’ preferences. These preferences can be presented in the form of an ordered set of criteria. The criteria help to choose a particular way of satisfying a given need. The set of these criteria after determining their order forms a pattern of preferences. The number of traffic quality assessment criteria is not precisely defined. For the client, the quality characteristics of transport services are most often related to, among others, the spatial distance, time and subject of carriage. The most essential are time-related measures of service quality such as punctuality and frequency. Interestingly, the travel time itself is less important for the passenger [8]. The following list presents selected features of the transport service which are usually taken into account when determining its quality:

- Related to spatial distance: accessibility to the transport network, directness, length and elongation of the route, capacity;
- Related to time: speed, availability over time, reliability, frequency, rhythmicity, regularity, punctuality;
- Connected with the object of transport: mass, safety (frequency of accidents and losses), security, passenger comfort, reliability, comprehensiveness of service.

More widely, the elements of the transport quality assessment that are important to the passenger are discussed in the following works [9-18]. The conducted research concerns both the general assessment and preferences of respondents concerning the transport services or they focus exclusively on individual elements of the service in the areas of space, time or transport offer.

For example, according to the research on the equipment of tram rolling stock included in the work [19], the most important elements affecting travel comfort according to the respondents are: thermal comfort, appropriate placement of handrails and handles, and the convenience of getting in and out of the vehicle (Figs. 1 and 2). The research was carried out in the city of Poznań (Poland). The research was carried out in 2015 on a group of 600 people to determine the preferences and habits of passengers traveling on Poznań trams, as well as the assessment of currently used solutions in the passenger area. The questionnaire consists of the 13 questions related to the behavior and preferences of passengers while traveling by tram. The questions in the questionnaire are related to:

1. Frequency of traveling by tram.
2. Preferences regarding the position occupied in the vehicle (sitting or standing).
3. Preferences regarding the location of the space occupied in the tram.
4. The main inconvenience disturbing passengers during the trip.
5. Activities and activities undertaken while traveling by tram.
6. Elements of vehicle construction and equipment that are the most important for passengers.
7. Elements of vehicle construction and equipment that passengers would think should be introduced.
8. Preferences related to the appearance, number and elements of the seats in the tram.
9. Desirable characteristics of seats and seats in the tram.
10. Preferences regarding the possibility of supporting yourself while traveling by tram in a standing position.
11. Evaluation of currently used handles in trams.
12. Evaluation of the use of the backrest instead of the seat allowing to occupy a semi-sitting position.
13. Evaluation of the introduction of vending machines on trams.

It can be pointed out that the elements indicated by the respondents as the most important ones belong to the basic features and elements that enable carrying out the transport service. Elements related to aesthetics and luxury: comfort of seats as well as outside and interior design were indicated by the respondents as less important.

When asked about the elements of vehicle equipment and construction that should be introduced, almost 70% of respondents indicated ticket machines in each vehicle, about 31% a more ergonomic arrangement of handrails and handles, 38% a dynamic passenger communication system (Figs. 3 and 4). Wireless Internet access is the least important for passengers from the group of pensioners. Other passengers consider this service to be important.

A company providing passenger transport services should undertake activities aimed at shaping the quality of the transport offer, that include: introducing an effective quality management system; defining quality policy and its objectives; extending cooperation with subcontractors / clients in the field of quality assurance; introducing a system to take into account the complaints and comments of customers in a timely manner and including this system in their organizational structure; monitoring the customer perception of transport services.

Actions that do not correspond to the actual expectations of the client or those that for various reasons, e.g. technical or economic, cannot be met by the service provider, result in discrepancies between the services provided and expected. Quality assurance is a source of additional costs, but without it arise costs of divergence between the quality provided and perceived by the client, which will also constitute a loss for the company.
4. Conclusions

The way transport companies operate enforces the implementation of activities aimed at the preservation of quality in many areas, including the operating system, economic analyses and service delivery. The preferences of travellers influence the selection of the main criteria for the quality assessment in passenger transport. There are many criteria for assessing the quality of passenger mass transport and it is difficult to develop a generalised measure. In addition, in such a quality assessment, the features related not only to the traffic and the transport process are important, but also other components that make up the transport offer, e.g. accessibility, safety, passenger information. It is possible to measure quality indirectly by assessing the properties that affect its perception.

The areas related to the quality of transport services listed in the paper make it possible to compare the service provided with the way it is perceived. Analysis of the discrepancies between the offer and the expectations in public mass transport can be used to determine losses caused by negative issues depending on the stage of the offer development on which they will be detected. The costs of discrepancies constitute losses for the company, which is why it is extremely important to detect potential issues early and identify the reasons for their occurrence. Eliminating potential causes of these issues, i.e. prevention, is cheaper than correcting their effects. The costs of quality loss may concern both the process of collecting market information about the preferences of potential customers, the preparation process and the provision of services. The potential costs of corrective actions can be eliminated by preventive actions. If potential losses are prevented in advance, they are not generated. These activities are also a source of costs, but they allow to increase the quality of the service provided by the carrier and perceived by the customer. The costs of prevention are significantly lower than the costs incurred to eliminate the effects of negative issues [21-23]. Additionally, thanks to prevention, losing image and negative customer feedback can be avoided.

The research results have been developed for the city of Poznań, but they can be an option to prepare the transport offer expected by the passenger in other Polish cities. This is possible due to the very similar needs of passengers and the equipment of existing public transport systems in these cities.

Acknowledgement

The research was conducted with subsidy for the support and development of research potential for the Faculty of Civil and Transport Engineering at Poznan University of Technology (0416/SBAD/0002).
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General Formalization of the Intellectual System for the Control of the Train Thrust on the Traffic Section

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Abstract

The article is devoted to the formalization of the problem of train thrust control based on the apparatus of neuro-mathematics. The article presents a mathematical neuro-fuzzy formalization of a model for controlling train thrust on a traffic section. The mathematical apparatus of fuzzy logic with the subsequent “training” of the created model is decisive in the creation of an intelligent control system for train thrust on a traffic section. In the process of mathematical formalization, the model was parametrized and an algorithm for calculating the membership functions of the input and output variables of the model was presented. A mathematical formalization of the knowledge base was also made and, as a result, a mathematical formalization of the system of equations, the solution of which constitutes the mathematical meaning of the solution of the problem of train thrust control on the traffic section. To “train” the created model, an adapted error propagation algorithm for a neuro-fuzzy model was used. A common criterion was used as a tuning criterion, which has a simple derivative convenient for further mathematical calculations. The presented mathematical formalization of the intelligent control system for train thrust on the traffic section allows further practical development of an automated control system for train thrust, the basis of which is a neuro-fuzzy controller built on the basis of the proposed fuzzy model and its “training” by experimental data of train movement on this section. Experimental data is expected to be obtained by creating an “intelligent” technological infrastructure of the train section based on Radio Frequency Identification (RFID) technology. The solved problem of the proposed mathematical formalization of train thrust control reflects the intellectual meaning of the train movement process as much as possible.

KEY WORDS: Neuro-fuzzy model, train thrust, membership function, intelligent control system, linguistic term interval, adaptive methods of neuro-fuzzy training, automated control system (ACS), RFID technology.

1. Introduction

The formation of the “intellectual” component of railway transportation is recognized as up-to-date for the development of railway transportation both in Ukraine and in the EU, which is confirmed by the relevant regulatory documents [1]. In particular, the National Transport Strategy of Ukraine for the period up to 2030 has defined the task of stimulating the introduction of innovative technologies (smart infrastructure and smart mobility) and intelligent transport systems [2]. Researches by scientists of Ukrainian Institute of Scientific and Technical Expertise and Information (abbreviated name - UkrISTEI) [3] on the dynamics of scientific publications and their citation, as well as the dynamics of patenting relevant areas in transport, prove that the most promising technologies in the world in the field of transport are: artificial intelligence, big data, 5G-technologies, neural network memory, and the Internet of things. Moreover, according to the authors [3, 7, 8] in the direction of artificial intelligence and neural networks, one of the promising areas of technology development is vehicle control systems.

Most of the solutions and terminology related to intelligent railway transport systems [4] use the terms that coincide in essence with the concept of complex (system) automation and informatization of railway transportation. A significant disadvantage of such developments and terminological definitions is that they lack a mathematical basis that allows the use of artificial “intelligence” in the form of neural network “training” of the corresponding transport (railway) system. The modern mathematical apparatus gives developers such an opportunity – this applies, first of all, to fuzzy mathematical logic and neuro-adaptive methods of training/teaching models built on its basis. The use of such a mathematical apparatus as the basis for designing railway transport systems makes them truly “intelligent” and allows to set and solve problems for which automation and information technologies are only components, and not the basis for solving problems. All of the above fully applies to the task of controlling the traction of a train on a traffic section. Currently, there is no solution to the problem of train traction control based on the apparatus of neuromathematics, which will make it possible to formalize this problem at the level of an “intelligent system”. 
The works of such scientists as V.V. Skalozub, V.P. Soloviev, I.V. Zhukovitsky, K.V. Goncharov are devoted to
the concepts of services, standards and architecture of intelligent transport systems (ITS), transport and railway
telematics, general principles of construction and use of global satellite radio navigation systems, as well as information
security in ITS. Improvement of train traction modes and modeling of optimal train driving modes are considered in the
works of V. V. Skalozub, A. P. Ivanov, S. V. Myamlin, and V. V. Zhizhko. In these works, the optimal traction modes
of a train are determined by the criterion of reducing the cost of electricity consumed for the traction of freight trains by
choosing rational train management modes. In A. P. Ivanov’s scientific developments, models based on fuzzy sets are
presented to reproduce the variability and uncertainty of factors affecting train driving modes; algorithms for forming a
base of fuzzy rules based on the characteristics of train traffic defined in real trips that allow to choose rational traction
modes by means of fuzzy control; a set of algorithms and software for calculating rational train driving modes based on
cost indicators. In the work of L. A. Mugynstein, I. A. Yabko, A. E. Ilyutovich, the energy-optimal traction calculation
of train movement is considered.

The mathematical foundations of fuzzy modeling and neuro-adaptive methods of training models are
investigated by T. L. Saaty, M.S. Syavavko et al.

2. Main Material Presentation

Mathematical formalization of the problem of controlling train traction in a traffic section by means of a fuzzy
logic model with its subsequent “training” by neuro-adaptive methods is the aim of this investigation.

To achieve this goal, it is necessary to determine the number and term intervals of input and output variables of
the model, construct membership functions, and determine the mathematical apparatus for adapting (training) the
formalized model.

In our case, the task is set for such mathematical formalization of train traction control, which would reflect the
intellectual meaning of this process in the traffic section as much as possible.

In order to parameterize the fuzzy logic model, the relationship between the input and output variables of the
train traction control model in a traffic section will be considered. Here is a list of input fuzzy variables:

- \( X_1 \) – train speed;
- \( X_2 \) – time delay of movement;
- \( X_3 \) – train weight;
- \( X_4 \) – train length;
- \( X_5 \) – accumulated traction power;
- \( X_6 \) – accumulated electric braking power;
- \( X_7 \) – accumulated mechanical braking power;
- \( X_8 \) – crosswind and headwind speed;
- \( X_9 \) – ppm of lifting slope;
- \( X_{10} \) – ppm of descent slope;
- \( X_{11} \) – train speed limit;
- \( X_{12} \) – position of the driver's controller.

But the original fuzzy variable is:

- \( Y \) – acceleration (braking) of the train.

In this case, it is assumed that all fuzzy variables are linguistic variables with such term-intervals:

\[
\{Y\}_j \quad \text{the set of term intervals of a variable } Y,
\]

\[
\{X_i\}_j \quad \text{the set of term-intervals of a variable } X_i, i = 1 \ldots 12, \quad j = 1 \ldots 8 \text{ where } i \text{ – is the number of input variables of the model,}
\]

\( j \) – the number of term intervals of the corresponding variable.

These dependencies form the basis for constructing a production fuzzy model of traction control in a traffic area.

Let’s define the corresponding fuzzy variables using term-intervals and construct membership functions for
them.

For this purpose, an expert table, which is the result of a survey of experts dealing with the problem of train
traction control on a scale from 1 to 16, is built.

The above survey is summarized in tables corresponding to the initial indicator and 12 input indicators [5].

The corresponding tables according to [6] are reduced to a row defined as follows:

\[
k_j = \sum_{i=1}^{8} b_{ij}, \quad j = 1, 16. \quad (1)
\]

Having selected the maximum element:

\[
k_{\max} = \max k_j, \quad (2)
\]

every \( b_{ij} \) is converted into \( c_{ij} \) in accordance with the formula:
Membership functions that correspond to the stage of phasification of variables of a fuzzy train traction control model in a traffic section can be defined as follows:

$$\mu_j = \frac{c_{ij}}{c_{i\text{max}}}, \quad c_{i\text{max}} = \max_i c_{ij}, \quad \text{where} \quad i = \{1, 8, 1, 16\}. \quad (4)$$

In this case, the results of calculations of membership functions and their graphical appearance are as follows (Fig. 1).

![Graphical view of fuzzy variable membership functions based on calculation results](image)

Their general appearance indicates the triangular shape of the belonging functions of the corresponding variables.

The creation of triangular functions belonging to fuzzy term-intervals of the universal set of the train traction $U$ of the control model in the traffic section is carried out by using the following functional expressions [6]:

$$\mu_j(U) = 1 - \frac{1}{K_j - 1} U, U \in [0, K_j - 1], j = 1; \quad (5)$$

$$\mu_j(U) = \frac{1}{j - 1} U, U \in [0, j - 1], j = 2, K_j - 1; \quad (6)$$

$$\mu_j(U) = \frac{K_j - 1}{K_j - j} - \frac{1}{K_j - j} U, U \in [j - 1, K_j - 1], j = 2, K_j - 1; \quad (7)$$

$$\mu_j(U) = \frac{1}{K_j - 1} U, U \in [0, K_j - 1], j = K_j. \quad (8)$$

Analytical expressions of belonging functions approximated from piecewise linear belonging functions shown graphically in Figure 1 have the above form if the problem of controlling the traction of a train on a traffic section has eight terms in the input and output fuzzy variables:

$$\mu_1(U) = 1 - \frac{1}{7} U, U \in [0, 7]; \quad (9)$$

$$\mu_2(U) = U, U \in [0, 1], \quad \mu_3(U) = \frac{7}{6} - \frac{1}{6} U, U \in [1, 7]; \quad (10)$$
The construction of a fuzzy model of train traction control in a traffic section based on at least eight term intervals of fuzzy variables is due to the need for accurate modeling of possible situations of train traction control in a traffic section.

Further implementation of the fuzzy model of train traction control in the traffic section provided for the creation of a knowledge base of the “IF-THEN, OTHERWISE” type. In mathematical formalization, it looks like this:

\[
\begin{align*}
\mu_n(U) &= \frac{1}{2} U, U \in [0, 2], \\
\mu_n(U) &= \frac{7}{5} - \frac{1}{5} U, U \in [2, 7]; \\
\mu_n(U) &= \frac{1}{3} U, U \in [0, 3], \\
\mu_n(U) &= \frac{7}{4} - \frac{1}{4} U, U \in [3, 7]; \\
\mu_n(U) &= \frac{1}{4} U, U \in [0, 4], \\
\mu_n(U) &= \frac{7}{3} - \frac{1}{3} U, U \in [4, 7]; \\
\mu_n(U) &= \frac{1}{5} U, U \in [0, 5], \\
\mu_n(U) &= \frac{7}{2} - \frac{1}{2} U, U \in [5, 7]; \\
\mu_n(U) &= \frac{1}{6} U, U \in [0, 6], \\
\mu_n(U) &= 7 - U, U \in [6, 7]; \\
\mu_n(U) &= \frac{1}{7} U, U \in [0, 7].
\end{align*}
\]

(11) (12) (13) (14) (15) (16)

Based on the formalized knowledge base, a system of fuzzy logical equations that link the vector of input variables and certain values of the output variable of the fuzzy model of train traction control in a traffic section can be built:

\[
\begin{align*}
\bigcup_{i=1}^{12} \bigcap_{j=1}^{8} (x_i = X_j) \Rightarrow Y = y.
\end{align*}
\]

(17)

To “train” the created model, an adapted error propagation algorithm for the neuro-fuzzy model was used. As the tuning criterion a common criterion \( \varepsilon \) was used, which has a simple derivative that is convenient for further mathematical calculations:

\[
\varepsilon = \frac{1}{2} (y_i - y_i^\ast)^2,
\]

(19)

where \( y_i \) and \( y_i^\ast \) — the real and calculated value of the output variable (acceleration-braking) of the fuzzy model of train traction control in the traffic section.

The use of mathematical methods for “training” models of fuzzy mathematical logic involves setting up the parameters of models, which are the following:

- \( c \) — compression-stretching parameter of the function of belonging of the input variable to the linguistic term of the output variable of the knowledge base at the \( t \)-step of “training”;
- \( b \) — coordinate of the maximum function of belonging of the input variable to the linguistic term of the output variable of the knowledge base at the \( t \)-step of “training”;
- \( w \) — weight of the decision-making rule at the \( t \)-step of “training”;

\[
\mu_{mf} = \bigcup_{i=1}^{12} \bigcap_{j=1}^{8} \mu_{mf}^j,
\]

(18)
To configure these parameters, a system of recurrent relations that minimize the criterion was used (19):

\[ w_j(t+1) = w_j(t) - \eta \frac{dE_i}{dw_j(t)} \]  \hspace{1cm} (20)

\[ c_i(t+1) = c_i(t) - \eta \frac{dE_i}{dc_i(t)} \]  \hspace{1cm} (21)

\[ b_i(t+1) = b_i(t) - \eta \frac{dE_i}{db_i(t)} \]  \hspace{1cm} (22)

where \( j = 1 \div 12, \ i = 1 \div 8 \).

The significant role in the creation of intelligent railway transport systems is played by intelligent infrastructure on the railway traffic section. Of particular importance are software and hardware tools that provide identification of objects moving along the site or located on it. For this purpose, in most cases, RFID technology is used.

WebSphere Premises Server RFID (here and further in the text Premises Server) - is an enterprise-class solution that combines and analyzes information coming from radio frequency and other sensors in real time. In addition, this solution includes the tools for secure messaging, data management, and systems needed to deploy a scalable sensor data management solution that creates the intelligent infrastructure of a railway section.

Hardware RFID solutions for train movement on a section consist of several types of sensors and conversion devices, such as RFID tags and readers, visual indicators, switches and sensors. One more variant is a GPS device – a type of sensor that can provide information about the location of rolling stock. To connect and exchange data with devices, a controller is needed to operate them.

The ultimate RFID controller transmits data to the Premises Server, which acts as an intermediary between end devices and enterprise servers. Premises Server processes the data and converts it into data that is relevant for use in particular in traction calculations for the train section.

A message bus that consists of WebSphere Connection Server Micro Edition i Enterprise Service Bus appears between the ultimate RFID controller and the servers that have been used.

Thanks to such architecture, the data is transmitted from the ultimate RFID controller to the servers securely and smoothly.

Fig. 2 Architecture of an intelligent system on a railway section

Fig. 2 demonstrates a typical architecture of an intelligent system on a railway section for information support of its functioning. Information is accumulated on the integration server, and control calculations and simulations are performed on the railway's corporate server or on-board locomotive.
3. Conclusions

The presented mathematical formalization of the intelligent train traction control system in the traffic section allows to continue the further practical development of the automatic train traction control system, the ground of which is a neuro-fuzzy controller built on the basis of the proposed fuzzy model and its “training” by train data on this section.

The primary training of the neuro-fuzzy model is implemented on the basis of the data of simulation experiments of the system-dynamic model of the train thrust on the traffic segment.

Further developments include the creation of an intelligent infrastructure for the railway traffic section for neuro-fuzzy “training” of the proposed fuzzy model.

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Engineering Design of a Tyre-rail Adapter for a Light Road-rail Vehicle

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Abstract

Road-rail vehicles are type-approved transport means, which can drive on roads and on terrain. However, they are also equipped by attachments, which allow them to move on a railway track. Such vehicles play an important role in the track management and they are used for various purposes, mainly during tracks building processes and carriers of rails, sleepers even entire track sections, for welding processes etc. Moreover, there are many applications, when road-rail vehicles allow performing needed intervention for tracks maintenance. For this, a road-rail vehicle is equipped by various superstructures such as a simple flatbed, tipper, or more specialized superstructures such as mowers, aerial platforms and many others. Recently, there are several ways to transmit a driving force from a power-train to wheels. The article is focused on design of a tyre-rail adapter to be mounted on a light road-rail vehicle. The novelty of the design consists in its possibility to change the wheelbase of the vehicle axles for different railway tracks gauges. Then, the considered light vehicle could fulfill various working tasks in a country, where more railway tracks gauges occur.

KEY WORDS: light road-rail vehicle; tyre-rail transmission; engineering design, tyre-rail adapter

1. Introduction

Road-rail vehicles have in the sphere of rail vehicles certain special state because of their specific characteristics. It relates both with design and usage. They are vehicles, which are commissioned for operation on roads, however, they can also move on rail tracks. In these days, we can meet these vehicles still more often, because they progressively replace older traction vehicles as well as track maintenance machines [1, 2].

Among the road-rail vehicles, diggers are the most widely used and known. They are operated mainly by building companies for repairing [3, 4] and reconstruction of railway tracks as well as for building of railway tracks subgrade.

In principle, the design solution of road-rail diggers is the same. On the rotating superstructure of a wheeled chassis of a digger, a driving engine together with accessories is located together with power-train of hydraulic system and counterweight. It is added by a rail chassis, which allows to move the digger on a railway track. There are several types of transmission of the driving force from the drive-train to wheels. Similar to diggers, also other road-rail vehicles use an additional chassis (or an additional drive-train).

In term of driving properties of road-rail vehicles, it is important to ensure sufficient contact of rail wheels of a vehicle with rails, because as it is known, in case of rail vehicles, the rails support as well as guide a vehicle in the track. In the wheel/rail contact are generated forces [5-7], which have to be taken into account in the case of any modification of vehicles to be operated on railway tracks.

2. Road-Rail Vehicles and Forces Transmission

In literature, we can find several aspects to divide the road-rail vehicles. The most suitable approach is to divide them according to Bado [8], i.e. division according to the transmission of driving and braking forces from a vehicle to the rails. Thus, we recognize three basic type of the forces transmission.

1. The forces transmission is ensured by friction of tyres against a rail head (“tyre-rail”).
2. The forces transmission is ensured by friction of tyres against a railway axle of a vehicle (“tyre-wheel”).
3. The forces transmission is ensured by railway wheels of a vehicle (“wheel-rail”).

This work is aimed at design of an adapter of the first type, i.e., the forces transmission will be ensured by means of friction of tyres against a rail head, type “tyre-rail”. The working principle of this system is described below.

2.1. A System of the Forces Transmission “Tyre-Rail”

In the case of the forces transmission in the type “tyre-rail”, driving and braking forces are transmitted from a
vehicle to a rail head. The vehicle is equipped by tyre wheels for driving on a road as well as by railway wheels for running on a railway track. The vertical load (forces) are distributed between tyres wheels and railway wheels, however, the majority of the vehicle mass is carried by tyre wheels. The railway wheels serve mainly for guiding of the road-rail vehicle. Examples of such types of road-rail vehicles are depicted in Fig. 1 and Fig. 2.

![Fig. 1 A “tyre-rail” vehicle FriLiner](image1)

![Fig. 2 A “tyre-rail” vehicle based on a Praga V3S lorry](image2)

Some road-rail vehicles have loaded only one road axle, as we can see in Fig. 3. It is an older road-rail vehicle, which is based on a Praga V3S lorry. The rail vehicles profile is usually exceeded in the lower part of the vehicle, therefore requirements in such track sections must be met, e.g. a running vehicle is in this section lifted and it runs through it by inertia.

The main properties of this system can be described as following:
- The advantage is cost, because a vehicle is structurally simple.
- In this system, a contact between tyres and rails happen, therefore, tyres are more worn and they have to be changed more often.
- Driving axle as well as gearboxes are still in the operating, therefore, they are more worn.
- The reverse speed is limited by the gear ratio of the reverse grade, because it uses the vehicle gearbox. Some vehicles are equipped by the additional reverse gearbox, which eliminates this disadvantage.
- Tyres have grater running resistances in comparison with railway wheels, therefore, it leads to higher fuel consumption [10].

2.2. Railway Infrastructure in a Particular Region

The main idea of the presented work is to design a light road-rail vehicle, which could be operated on as most track gauges as possible. In the case of the Slovak Republic, quite large track net includes the standard track gauge of 1435 mm. Moreover, there are also tracks with the broader track gauge of 1520 mm and with the narrow track gauge of 1000 mm. The track with broad gauge is in the east of the Slovak Republic and it is heading to the Ukraine, which has also railway tracks with the track gauge of 1520 mm.

The goal is to design a conceptual solution of an adjustable wheelgauge for a light road-rail vehicle. Regarding to railway track gauges, it is required, that the vehicle will be able to adjust the wheelgauge for the track gauge from 1000 mm and 1520 mm. Such a vehicle would be able to operate on all broad railway tracks, on standard railway tracks of 1435 mm as well as on the most narrow railway tracks of 1000 mm (Fig. 3). A narrower track gauge than 1000 mm is not required due to small number of such railway tracks.

![Fig. 3 A map of Slovak railway tracks with various track gauges](image3)

3. Modification of a Multicar M31 Hydrostat Vehicle to a “Tyre-Rail” Road-Rail Vehicle

A Multicar M31 Hydrostat belongs to smaller and lighter versatile lorries, which are currently produced. This vehicle has the smaller wheelgauge only 1327 mm. Basically, it can be used for material transport. However, it has a SWV500 device for quick changing of attachments. These attachments can be applied during individual year seasons according to needs. The basic vehicle design as a tipper is shown in Fig. 4.
The wheelgauge depends on dimensions of tyres. The vehicle has approved these tyre dimensions:
- 225/75 R16;
- 285/65 R16;
- 315/55 R16;
- 325/60 R15.

The vehicle has been chosen by the reason, that it has a small wheelgauge and small vehicle contours, which are necessary to use it also on narrow railway tracks with the track gauge of 1000 mm.

As it is described above, in the case of the “tyre-rail” road-rail vehicle, driving and braking forces are transmitted by friction of tyres against rails. Railway wheels are intended to guide the vehicle and partially to carry it. Fig. 5 shows the contact of tyres with rails in the case of three track gauges, i.e. for the narrow track of 1000 mm, the standard track of 1435 mm and broad track of 1520 mm. As it can be seen, in the broad track as well as the standard track, tyres are in the full contact with the rail head. On the narrow track, the contact is only partial and it is about 50%. After a consultation with an expert designer from a company, which produces road-rail vehicles, such a vehicle would be able to transmit all forces sufficiently also on the narrow track. A certain problem can occur during running in curves. However, the chosen Multicar M31 vehicle has an all-wheel drive system. Thus, a smaller contact patch of one wheel would be compensated by the opposite wheel [13], which would have bigger contact patch in comparison with running in a straight track.

The designed tyre-rail adapter consists of a main frame, on which, two adjustable additional adapters are mounted. They can adjust positions in the axis direction due to grooving. This will ensure changing of the wheelgauge. Two hydraulic double-acting cylinders are the other parts of the adapter. These cylinders allow to change a position of additional adapters against the main frame. The entire adapter is lifted and released by means of another two hydraulic cylinders, which are mounted by one end part to the road-rail vehicle frame and by the other end part to the adapter main frame. The design of the adapter is shown in Fig. 6.

The tyre-rail adapter has also other necessary components, among which, electromagnetic keys are included. They will lock the adjustable parts of the adapted in individual positions for narrow, standard and broad wheelgauges not to change these defined positions during running on the railway track. Obviously, the vehicle with the adapter will be added by others components, among others, there are valves, hoses and source of hydraulic pressure of a hydraulic system, additional electric system for control, vehicle lighting and others.

The designed road-rail vehicle includes two adapters, one for the front axle and one for the rear axle. It will have three positions for considered track gauges and the wheelgauges will be possible to change, when the vehicle will rest of road wheels (tyres). In this position, adapters will be lifted and the total weight will be carried by the road wheels. For this vehicle design, controlling of adapters, i.e. lifting, adjusting and locking will be fully automatically from a vehicle cabin. It is really a considerable advantage of the system. Visualisations of the lower part of the designed road-
rail vehicle with adapters in the front and rear parts are shown in Fig. 7 and Fig. 8. These figures depict adapters in the released position (Fig. 7 left and Fig. 8 left), i.e. for running of railway tracks as well as in the lifted position (Fig. 7 right and Fig. 8 right), when it moves on roads.

![Released adapter](image1) ![Lifted adapter](image2)

**Fig. 7** The designed tyre-rail adapter in the front part of the road-rail vehicle

![Released adapter](image3) ![Lifted adapter](image4)

**Fig. 8** The designed tyre-rail adapter in the rear part of the road-rail vehicle

![1000 mm](image5) ![1520 mm](image6)

**Fig. 9** The designed tyre-rail adapter in the rear part of the road-rail vehicle

The visualisation of the designed railroad vehicle with the tyre-rail adapter is shown in Fig. 9. This figure depicts the vehicle on the railway track with the track gauge of 1000 mm (left) and with the track gauge of 1520 mm. The vehicle can be re-railed on locations, where a road is approximately in the same level as a railway track, i.e. practically on every railway crossing. However, these places have to be large enough to steer the vehicle into the longitudinal position with the railway track. This is other advantage of the designed vehicle, because thanks to its small dimensions, in principle, there are not any limits and it can be performed anywhere.

The future research activities in this field will be focused on developing an idea to also design an adapter, which would be based on a different principle of the forces transmission, namely the adapter type “tyre-wheel”. Subsequently, these designs will be compared and evaluated their advantages and disadvantages and resulting benefits for using on the chosen light lorry.

Another activities will be aimed at analysis of the adapter structure in term of strength by means of the finite element method [14-16]. As the adapter body is loaded by the vehicle weight as well as by the loads of transported goods or loads of used superstructure, it should meet all requirements in the long term operation point of view [17].

The vehicle will run on the railway track at certain speed. From this, a different dynamic response results in comparison with its operation on roads [18-20]. Therefore, besides the mentioned strength analyses, dynamic simulations using a multibody model should be performed. Then, an implementation of a finite element body to a multibody model of the vehicle will help to simulate the real operation conditions as much as possible.

4. Conclusions

The goal of the presented work was to introduce a description of road-rail vehicles. There are written basic properties and characteristics of these special transport means, which are applied mainly in track management. Road-
rail vehicles are used for maintenance of railway track, for works during railway track building processes, for special purposes in repairing and for many other activities. The road-rail vehicles design is based on standard road vehicles, the most often on lorries, because they can be equipped by various superstructures. In addition, lorries include a powerful source of energy, which can be also used for actuation of attachments of road-rail vehicles.

The other part of the article presents a design of the adapter, which is intended to be mounted on a light road-rail vehicle. The adapter is the “tyre-rail” and its main advantage is a possibility of a wheel gauge adjustment. Such an adjustable wheel gauge of the road-rail vehicle is favourable for such localities, in which, railway tracks with various track gauge exist. It is also the case in the Slovak Republic. In addition, compact dimensions of the designed road-rail vehicle allow to operate it practically anywhere.

Acknowledgement

This work was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 023ŽU-4/2020: Development of advanced virtual models for studying and investigation of transport means operation characteristics.

The work was supported by the Slovak Research and Development Agency of the Ministry of Education, science, Research and Sport of the Slovak Republic in Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. VEGA 1/0558/18: Research of the interaction of a braked railway wheelset and track in simulated operational conditions of a vehicle running in a track on the test bench.

References

Evaluation of the Performance of Motor Transport Enterprises of Urban Agglomerations in the Region

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Abstract

The authors have developed a methodology to evaluate the performance of motor transport enterprises in urban agglomerations of the region, which is based on the use of multivariate correlation and regression analysis. With modern software, methods that were previously unavailable due to the complexity of the software application can be used in economic analysis. To improve the management of transport structures of urban agglomerations in the region, the level of development and stage of reforming of the transport and road system should be taken into account. Supply of new buses and minibuses, development of the transport and road network, preferential taxation of passenger transport enterprises contribute to improving the quality of public services. At the same time, the profitability of enterprises is ensured in the amount sufficient for the renewal of their fleet of vehicles. The expediency of using the integral indicator in monitoring the quality of passenger transport services in urban agglomerations of the region is justified from the scientific point of view. The integral indicator of service quality assessment allows to make scientifically substantiated decisions on optimization of limited resources of carriers and the budget of urban agglomerations.

KEY WORDS: transport, monitoring, integrated quality assessment, services, urban agglomeration.

1. Introduction

In the leading countries of the world, the formation of the infrastructure of the road transport market is specially addressed, taking into account the risk and innovation aspects, as well as economic responsibility, flexible management and optimization of costs and the use of resources in order to maximize profits [1, p. 178]. The use of market mechanisms and tools makes it possible to develop and implement an optimal strategy for the development of passenger transport services, to create an optimal structure of the economy of urban agglomerations, to put the monopolists in the market on the back foot, to develop a mechanism for stimulating personal responsibility for the achieved indicators, to support competition, to ensure the quality and efficiency of management decisions [2].

The development of passenger transport services is crucial for the economy of urban agglomerations. Motor transport companies also play a significant role in the development of the social sphere of the territory. Therefore, the importance of the formation and development of the regular passenger road transport services market for urban agglomerations can hardly be overestimated. The subjects of this market, especially small business structures, have a high susceptibility to innovation and innovative development. Therefore, today, in the challenging conditions, complicated by the COVID-19 pandemic, it is business structures that can play an important role in strengthening the social significance of the ongoing transformations in the economy of urban agglomerations. This is especially the case when problems of productive employment in urban agglomerations is addressed.

2. To Assess The Quality of Passenger Transport Services in Urban Agglomerations, It Is Advisable To Monitor and Use an Integral Indicator of the Quality of Services Provided

Improving the quality of transport services provided to consumers, as well as improving these services by regular passenger road transport in urban agglomerations are challenged by such problems as the poor financial condition of transport enterprises; the inability to predict and plan activities in the medium and long run due to insufficient level of software and methodology; the poor level of facilities and resources; the underdevelopment of the automation system of the transport process management, etc.

Investments in the development of the regular passenger road transport services market necessitate the
development of a methodology for evaluating the performance of road transport enterprises in urban agglomerations of the region that would be understandable for practitioners. This scientifically justifies the feasibility of investing in a particular enterprise or service. Reducing investment risks, improving the quality of passenger road transport by the effective use of various forms of their implementation with consideration to the features of specific territories, developing a transport network and making available labor resources, etc. also helps.

Such issues as improving transport laws, mechanisms of interaction between transport operators and local executive authorities of urban agglomerations, as well as the establishment of new standards for the provision of transport services in urban agglomerations, including regular passenger road transport services gain ground today. It is these services that have social and economic significance for the local economy and depend on the existing features of the management and organization of passenger road transport that necessitate the assessment the performance of road transport enterprises in urban agglomerations of the region.

In the conditions of market relations and the formation of competitive relations, the organization of regular passenger road transport affects the whole system of providing transport services to the population, ensures the smooth operation of economic actors and sectors of the economy, improves transport accessibility, and also creates the basis and contributes to improving the efficiency of transport services in urban agglomerations.

Analysis of the quality of regular transport services is important for consumers; it requires research on the problems of service organization and management [3, p. 806]. Currently, the regular passenger road transport services market is facing multiple challenges, addressing which is considered a priority for accelerating the socio-economic development of territories and improving the quality of transport services provided in urban agglomerations.

During the study, we found that the regular passenger road transport services system finds its expression in the formation of an independent network of public and private passenger transport enterprises in urban agglomerations of the region.

Market relations are formed on the basis of a self-regulating market, which is considered the main regulator of the activity of a motor transport enterprise. In our opinion, the will of the state authorities that manage the economic processes in the territory should not be underestimated. The local authorities and the transport market combine the process of forecasting, managing and meeting the needs of the economy of the territories and the people for transport services, as well as performing freight forwarding and other types of transport services.

The demand for transport services includes, in addition to the actual volume and safety of traffic, the availability of various options to meet them, etc. At the same time, consumer demand combines the needs of sales channels, consumers, and non-profit entities, while public demand takes into account the needs of employees, shareholders, citizens, and public enterprises that affect their activities. In general, the activity in the transport services market is carried out in compliance with the basic principles of functioning of this market; the main elements of the transport services market are considered to be demand, supply and transport tariff. On the other hand, the alignment of supply and demand is considered important, and the market tariff acts as the main regulator in achieving balance. In addition, the increase in prices for transport services contributes to the improvement of the financial results of enterprises.

The purpose of regulating the regular passenger road transport services market is creating a civilized transport services market in urban agglomerations of the region, which ensures high quality of services provided, cooperation of market participants in the territory.

The regular passenger transport services market in urban agglomerations of the region comprises a competition-based mechanism in the transport process in order to meet the needs of the people of the territory in passenger transport. Such transportation management significantly affects the effective development of the services provided to the people. Also, the goal of maximizing the profit is taken into account.

The aim of operation of the market system is maximizing profits; it does not take into account the social significance of passenger transportation. Therefore, the involvement of the governmental institutions ensures a balance between the social and market principles of spatial development. The study of foreign experience in providing road transport services allowed us to specify the tasks of passenger transport management in the territory. This is necessary to regulate the quality of passenger service, save transport costs and stimulate economic development, as well as ensure road safety.

In general, the purpose of governmental regulation is improving the quality of services provided and the well-being of the people of urban agglomerations in the region. Achieving these goals is possible with a competent approach to the study of this problem. However, the analysis of the current state of road transport services suggests prerequisites for improving the efficiency and ensuring the competitiveness of passenger transport and establishing various links based on the efficient organization of the management of regular passenger transport in urban agglomerations of the region.

We have identified the existing features and problems of the formation and development of the regular passenger road transport services market in modern conditions, taking into account the parameters of the economic potential of the territories, the availability of rolling stock and route network, the state of the transport infrastructure in the implementation of passenger road transport, etc.

Now in urban agglomerations, individual transport is developing rapidly. However, bus transport, unlike individual transport, has a high passenger capacity, which contributes to 8-15 times space savings compared to passenger cars. At the same time, passenger bus transportation requires 3-5 times less energy than private transport. Therefore, one of the important challenges is increasing the attractiveness of passenger road transport, which can be addressed by optimizing the route network, increasing the frequency and filling the rolling stock, providing conditions for the use of the high-speed characteristics of passenger transport.
The main problems of the development of regular passenger transport include moral and physical aging of the existing fleet of buses; the imperfection of the regulatory framework; insufficient reimbursement of costs to carriers; the unreasonable and non-transparent for the inspection bodies pricing mechanisms, etc. Another important issue is improving the management of passenger road transport in the transport services market of urban agglomerations of the region, taking into account the role and importance of various types of owners. We have found that in management of regular passenger road transport services, interaction between local government authorities and transport business structures is weak, there is no unified management approach to the organization of regular passenger transport management, including in the local executive authorities. At the same time, to improve the organization of transport management it is important to focus on the level of development and reform of the transport and road system; purchase of new buses and minibuses; development of the transport and road network; preferential taxation of passenger transport enterprises; ensuring the profitability of enterprises in the amount sufficient to update the fleet of vehicles, and others.

Conducting market research is necessary, in which questionnaires are used to discover the preferences of consumers of transport services in urban agglomerations of the region, people's reaction to changes in the fare [4, p. 790]. It is advisable to assess the competitive advantages and ensure the high competitiveness of regular passenger bus services. Today, a characteristic feature of the regular passenger road transportation services market is the complexity of assessing the needs of customers for these services. In general, we believe that the regular passenger transport services market in urban agglomerations of the region is being formed and developed. Only those transport business structures that use modern methods of strategic management achieve significant results in making a profit compared to other enterprises of this important type of economic activity.

According to the authors, an important problem in organizing regular passenger road transport in urban agglomerations of the region is the growth of the shadow sector in this industry, as well as the need to ensure a sufficiently high level of competition as a factor in improving the quality of transport services and reducing tariffs, taking into account the development of appropriate organizational, economic, technological, regulatory and methodological support.

The opinion of the authors, in modern conditions, the issues of assessing the efficiency of the transport sector in view of the quality of transport services, are of particular importance. Therefore, we have conducted an integral assessment of the quality of regular passenger road transport services on seven surveyed bus routes in the metropolitan areas.

The methodology based on the use of standards established for the integrated assessment of the quality of transport services is of particular interest. The integral exponent \( K_{\text{INTEGRAL}} \) is calculated by the formula:

\[
K_{\text{INTEGRAL}} = k_1 \times k_2 \times k_3 \times k_4 \times k_5
\]

where \( k_1 \) – rolling stock filling rate; \( k_2 \) – relative time expenditure factor for the movement of passengers; \( k_3 \) – regularity factor of rolling stock traffic; \( k_4 \) – dynamic change factor of traffic accidents; \( k_5 \) – service quality factor for the route.

We determined the service quality factor for the route was using a unique mathematical apparatus – the methods of paired comparisons and prioritization. Its use allowed us to quantify such a qualitative indicator as the quality of service on the route. A survey of experts involved in passenger transport in a particular urban agglomeration was used.

The analysis of various existing lines of the economic assessment of the quality of passenger transport has revealed that the most appropriate methodological approach for the assessment is the use of an integral indicator.

Using this approach, we conducted an assessment of the quality of the regular passenger road transport services on seven surveyed bus routes of a particular urban agglomeration. The results of the evaluation are shown in Table.

### Integrated assessment of the quality of the regular passenger road transport services for seven surveyed bus routes of a particular urban agglomeration

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>The relative filling rate of buses – ( k_1 )</td>
<td>1</td>
</tr>
<tr>
<td>Relative time expenditure factor for the movement of passengers – ( k_2 )</td>
<td>2</td>
</tr>
<tr>
<td>Regularity factor of movement – ( k_3 )</td>
<td>3</td>
</tr>
<tr>
<td>Dynamic change factor of traffic accidents – ( k_4 )</td>
<td>4</td>
</tr>
<tr>
<td>Service quality factor for the route – ( k_5 )</td>
<td>5</td>
</tr>
<tr>
<td>Integral transport service quality factor – ( K_{\text{INTEGRAL}} )</td>
<td>6</td>
</tr>
<tr>
<td>Quality assessment of the service</td>
<td>7</td>
</tr>
<tr>
<td>Route rating by transport service level</td>
<td></td>
</tr>
</tbody>
</table>

According to the authors, to assess the effectiveness of regular passenger road transport, the indicators that characterize the implementation of the transport process and the main criteria for effective management in the market of road transport services should be taken into account. At the same time, in the authors' opinion, it is expedient to calculate the socio-economic effect of improving the quality of passenger bus transportation in order to ensure profit in all passenger...
motor transport business structures. Safety of transportation as an important component of the services provided to passengers and the rational use of all types of resources in the conditions of competition between passenger transport business structures should also be taken into account.

During the study, we have also developed economic and mathematical models of the volume of services provided by regular passenger road transport in urban agglomerations of the region, taking into account the factors affecting the development of these services, and also determined the forecast volumes of regular passenger transport services provided in general for the regions of the country until 2030.

For the development of economic and mathematical models, the factors influencing the demand for regular passenger road transport services were selected based on a survey of experts and the people living in urban agglomerations of the region. Multivariate correlation and regression analysis were used.

The models were constructed based on the formula (2):

\[ Y = a_0 + a_1 X_1 + a_2 X_2 + a_3 X_3 + a_4 X_4 + a_5 X_5, \]  

where \( Y \) – the volume of regular passenger transport services provided, million rubles; \( a_0, a_1, a_2, a_3, a_4, a_5 \) are constants; \( X_1 \) – urban population rate, \( \% \); \( X_2 \) – average family size, persons; \( X_3 \) – average monthly salary, rub.; \( X_4 \) – rate of the individual transport, units per 1000 people; \( X_5 \) – density of the road network, km/sq. km.

In general, for a megalopolis, the equation is as follows (3):

\[ Y = -1428 + 16,18 X_1 + 41.97 X_2 + 0.0463 X_3 - 0.07269 X_4 + 3085 X_5. \]

The correlation coefficient was 0.9654. It means that the presented equation (3) takes into account 96.54% of the factors that affect the volume of regular passenger transport services provided to the population of the urban agglomeration.

Next, we have calculated forecast values of the volume of regular traffic in general for the urban agglomerations of the region for the period up to 2030.

The average annual growth rate of traffic volume was 1.58% for the region. According to the authors, the obtained forecast results can be used by managements dealing with organizing regular passenger road transport and scientific justification of the parameters of their development for the long term.

The authors believe that the primary objective of the concept of the development of the regular passenger road transport services market in the urban agglomerations of the region is the technical modernization and re-equipment of road infrastructure facilities [5, p. 281]. To solve these issues, priorities for the development of the system of organizing regular passenger transportation should be formed, covering a wide range of interrelated technical and technological, economic and environmental, social and organizational issues in these agglomerations [6, p. 712].

During the study, we have justified and identified priority areas for the development of the regular passenger road transport services market, taking into account the improvement of the mechanism for providing these services, the development of entrepreneurship in this market, as well as the formation of a rational structure of the rolling stock fleet for the provision of regular passenger transport services in urban agglomerations of the region.

In modern conditions, an important parameter in assessing the functioning of the regular passenger road transport services market is the development of entrepreneurship. In our opinion, to improve the development of entrepreneurship, the following mechanisms and directions should be used: in the field of regular passenger road transport services; development of mechanisms for financial and credit support for business entities; creation of a program, legal and organizational framework for the development of entrepreneurship; use of public-private partnership mechanisms; development of mechanisms for information and consulting support for entrepreneurs; introduction of mechanisms for operational monitoring and control of the effectiveness of measures taken in the field of entrepreneurship; provision of tax incentives by entrepreneurial transport structures, etc.

In general, the development of entrepreneurship in the regular passenger road transport services market is becoming one of the main factors for ensuring economic growth and improving the standard of living of the population, as well as transport accessibility in urban agglomerations of the region [7, p. 855].

Improving the efficiency of regular passenger road transport is achieved by solving the following major tasks: improving the financing of modernization, developing the facilities and resources of passenger road transport, updating fixed assets, obtaining a positive effect of self-organization of market participants, improving regulatory and legislative acts on coordinated behavior of market participants, reducing the negative impact of transport on the environment and human health, improving the process of safe provision of regular passenger bus services, and others. In order to solve these problems in the organization of regular passenger road transport, we consider it important to form a rational structure of rolling stock, taking into account the improvement of the quality of transport services.

We have designed the structure of the rolling stock fleet on routes in urban agglomerations of the region. For their service, buses of small and medium passenger capacity are recommended to use. In addition, in order to streamline the activities of market participants in the provision of regular passenger road transport services, we studied the interaction of passenger transport businesses with local government authorities and proposed 3 blocks of measures to improve the efficiency of providing transport services to the population on regular bus routes:

- **Block 1. Expansion of the information space.**
  - 1.1. Creation of a system for informing transport operators about their planned profitability.
1.2. Selection of the main performance indicators in the created information system.

1.3. Implementation of the methodology for assessing the transport quality.

The advantages obtained during the implementation of the first block of measures are as follows. Transport operators have the opportunity to plan investments in the expansion of production, and the authorities can set transport service standards and tariffs in accordance with the profitability of carriers. All changes are based on accurate data obtained using predictive modeling techniques.

Block 2. Formation of fair competition.

2.1. Streamlining the list of requirements for transport operators.

2.2. Demonopolization of the passenger transportation market.

2.3. Transition to the distribution of routes in accordance to the methodology for assessing the service quality of regular transport.

2.4. Establishing mutual responsibility for the implementation of the planned volume of traffic between transport operators and local public authorities

The advantages obtained during the implementation of the second block of measures are as follows: increasing the interest of transport operators in ensuring the quality of regular transportation and servicing unprofitable routes; reducing the burden on the budgets of various levels – the regional budget and the budget of urban agglomerations; stimulating the development of small businesses; increasing the number of transport operators.

Block 3. Formation of a more centralized system of public transport services management

3.1. Expanding the functions of organizers of transport services for the population of urban agglomerations in the region.

3.2. Elaboration of transportation tariffs based on passenger traffic planning and subsidizing of transport operators.

3.3. Implementation of the quality management methodology for regular transportation.

3.4. Using an algorithm of efficiency improvement of passenger transport services management in the urban agglomerations in the region.

The advantages obtained from the implementation of the measures of the third block are as follows: making informed management decisions based on more complete information; relieving information channels; increasing the speed of making management decisions; improving the manageability of the system; efficient distribution of passenger flows and optimizing the development of the regular transportation system of urban agglomerations in the region.

3. Conclusions

To assess the quality of passenger transport services in urban agglomerations, it is advisable to monitor and use an integral indicator of the quality of services provided.

The implementation of the priority measures that were justified in the course of the study contributes to improving the efficiency of the management of regular passenger transport on bus routes, meeting the needs of people with proper quality, as well as creating new jobs, proportional development of territories, improving transport activities, culture and the level of well-being of local people, improving the spatial development of urban agglomerations in the region.

References


How to Make Public Transport System Safer During the Pandemic and after

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Abstract

Current article try to find the answer to the question - how to make public transport system safer during the pandemic and after? Introduction shows the effect of pandemic to transport sector and to public transport system in particular. Second chapter deals with the recommendations for adapting the public transport system to the COVID-19 challenge, ensuring its sustainability. The short framework should help to return the public transport system to sustainable position. Third chapter deals with technologies for disinfection developed by Riga Technical University and partners, to reduce the effect of pandemic. These technologies are automated and robotic equipment for air and surface disinfection; disinfection gate and equipment for surface, as well as, air disinfection with UV radiation and ozone. Authors hope, that all offered devices could be used in different premises to make public transport system safer from the epidemiological point of view by making the working environment cleaner from viruses and helping all the employees to feel safer.

KEY WORDS: public transport, disinfection, sustainability, covid-19, safety, health, public transport system, solutions, technology, equipment, prototype, device, pandemic

1. Introduction

The global transport and logistics system turned out to be one of the most affected areas as a result of the COVID-19 pandemic. The negative consequences are based on various factors: the closure of state borders, the imposition of restrictions on the movement of people and goods, the rupture of supply chains, and a decrease in demand and purchasing power. The combination of these factors affected all types of transport - from the use of personal and public transport in cities to the implementation of passenger and freight transport both within countries and between them. The scale of the negative consequences depends on the type of transport and the state's integration into the world transport and logistics system. During the pandemic, 90% of flights were canceled in the EU countries; there was a decrease in the volume of passenger traffic by cars by 60 - 90%, and by public transport by 50%. Today, the countries are in a transitional stage: in the transport sector, there is an adaptation to the updated operating conditions and a gradual recovery after the crisis. Nevertheless, there are still a number of risks. The anticipation of the next wave of a pandemic, an increase in the number of cases of COVID-19 in some regions of the world, a partial restoration of previously lifted restrictions and other factors create further uncertainty regarding global transport and logistics systems. At the same time, the uncertainty concerns not only the timing of the return to pre-crisis indicators, but also the future image of the transport sector in the post-coronavirus world as a whole. The rapid spread of coronavirus infection around the world has led to the development of a global health crisis, overloading national health systems and serious economic consequences. A noticeable flip side of the measures to contain the infection was, in particular, the cardinal restriction of transport activity [1].

In economic terms, the COVID-19 pandemic has led to a dramatic reduction in revenues of public transport enterprises from ticket sales, in exceptional cases reaching 90%, as well as an increase in additional costs associated with disinfection measures and ensuring social distance both in transport itself and at infrastructure facilities. For example, lockdown introduced in the UK in March 2020 resulted in a 95% reduction in London tube rides. This is confirmed by data from the popular Citymapper Mobility Index [2] application for smartphones, which provides information on public transport. There has been a more than 90% drop in travel since the onset of the crisis in many major cities around the world.

The results obtained by authors in [8], show that some measures, such as the increase of supply and vehicle disinfection, result in a greater willingness to use public transport in post-COVID-19 times.

Authors of [9] conclude, that strategies to control the spread of COVID-19 should include reducing the number of people in indoor spaces, more intense disinfection of transport vehicles, and requiring people to wear masks.

Therefore, it is possible to conclude, that disinfection is actual and necessary part of the future public transport system to be able to ensure its sustainability.

Aim of current article is to show how to make public transport system safer during the pandemic and after by offering modern solutions and devices for disinfection of different objects of public transport system.
2. Recommendations for Adapting the Public Transport System to the COVID-19 Challenge, Ensuring its Sustainability

Public transport plays a strategically important role in the life of large cities. Therefore, the key task of operators in this area is to maintain operations and maintain the minimum required level of service. At the same time, the public transport system should be considered as a high-risk environment for the following reasons:

- A large number of people in a confined space;
- Application of air recirculation systems;
- Lack of the possibility of full control to identify carriers of infection;
- The inevitability of contact with surfaces (ticket machines, handrails, door handles, etc.).

There are the list of recommendations on how to prepare transport networks for the pandemic and ensure the safety and well-being of staff and customers. It is necessary to implement the following measures:

- Integrate the preparation of the transport industry into the planned anti-crisis management procedures;
- Conduct an inventory of licenses and staff audits to identify personnel who could be deployed as contingency personnel in critical positions;
- Check the availability of consumables, the necessary equipment for protection against the virus and for disinfection; draw up a plan for their distribution and replenishment;
- Check stocks and supply chains of consumables such as fuels, lubricants or spare parts, and, if possible, consider a list of alternative suppliers;
- Follow up on relevant communications from authorities to keep abreast of the latest recommendations in a country or region. To reduce the risk of contamination of public transport personnel, the following steps should be taken:
  - Provide employees interacting with customers with isolated information counters;
  - Shield drivers cabs with special panels;
  - Temporarily restrict ticket checks, as controllers run a high risk of infection [1].

To maintain passenger safety standards, transport companies are providing distance-keeping measures [3], such as increasing the number of routes and publishing real-time updates on public transport congestion so that passengers can plan their travels in less loaded vehicles. Other measures include the mandatory use of face masks, the provision of disinfectants and frequent cleaning of trains and buses, checking the temperature at the entrance, and automatically opening all doors at stations to prevent passengers from coming into direct contact with surfaces [1].

To ensure the sustainability [6] of public transport system, three solutions for the disinfection of different objects of public transport system are offered here and can be a part of [5]. It can help to adapt the public transport system to the challenge of COVID-19 [4].

3. Solutions for Disinfection

The term "disinfection" means a set of measures aimed at destroying pathogenic microflora - causative agents of diseases (viruses, bacteria) and their waste products (toxins). The main task of disinfection measures is to prevent the spread of infection by blocking all possible transmission mechanisms. The first disinfection measure can be considered the actions of a primitive man, when, after cutting the carcass of an animal, he tried to remove the remnants of blood (in fact, a foreign substance) from his hands. The next important step is to strive to keep clean not only yourself, but also the surrounding space. The simplest actions - washing, cleaning the premises, using certain plants - helped to some extent to protect against diseases, but without basic knowledge of microbiology and virology, the effectiveness was extremely low. Medical minds were in constant search of ways to prevent infectious diseases and destroy their pathogens. At the end of the 19th century, chemists came to the rescue, proposing a number of drugs that are active against viruses, bacteria and other protozoa microorganisms. Since the beginning of the twentieth century, sanitary and epidemiological institutions began to be actively created in developed countries, however, there was no question of the systemic nature of the disinfection measures carried out by them: active actions began only after the identification of a focus of dangerous infections. Later, with the growth of cities and an increase in population density, it became clear that disinfection should be of a preventive nature: it is easier to prevent an epidemic than to localize the identified focus and eliminate the consequences [10].

Disinfection is a set of measures aimed at destroying pathogens of infectious diseases and destroying toxins on objects in the external environment to prevent them from getting on the skin, mucous membranes and wound surfaces. It is one of the types of disinfection. Disinfection may not completely destroy them, but it reduces the number of microorganisms to an acceptable level. The destruction of the infectious principle in the external environment does not eliminate the main sources of infection (unrecognized micro carriers). Therefore, disinfection plays a significant role only in the general complex of anti-epidemic and anti-epizootic measures [11].

Riga Technical University and partners in the frame of the project [7] have developed automated and robotic equipment for air and surface disinfection. This equipment can be used for disinfection purposes in public transport system to make it safer from the epidemiological point of view. Many tasks have completed to be able to achieve the goal. Some of them are:

- Development of a disinfectant sprayer for a mobile robot;
- Development of a machine vision system for the identification of objects for disinfection;
– Development of control system for mobile disinfection robot;
– Mobile disinfection robot testing in real conditions;
– Development of disinfection gates and evaluation of their operation in real conditions;
– Development of innovative high frequency electrodeless UV radiation lamps;
– Development of equipment for surface and air disinfection with UV radiation and ozone and testing of its efficiency in laboratory conditions.

Fig. 1 shows 3D models of developed disinfection devices.

Fig. 1 3D models. A - Mobile disinfection robot; B- Disinfection gates; C – Solution for air and surfaces disinfection with UV-radiation and ozone

3.1. Automated and Robotic Equipment for Air and Surface Disinfection

A properly functioning disinfectant sprayer and technical documentation for it (3D model, specification, working drawings of parts, instructions for use) have been developed. The operation of each nozzle is independent; this means that 1 to 10 nozzles can be operated simultaneously. The distance between the vertical columns can be easily changed for the sprayer by adjusting the width of the room, corridor or door to be disinfected. It is also possible to change the height of the nozzles above the floor by adjusting the sprayer to disinfect specific objects (door handles, electrical switches, etc.)(Fig. 2).

Fig. 2 Development of disinfectant sprayer for mobile robot. Technology readiness level TRL7
The sprayer is mounted on a mobile robot and tested in operation (Fig. 3).

Testing results shows, that mobile robot with intelligent vision system and object recognition system are working correctly. Disinfectant sprayer also is good in experiments. It is possible to conclude, that this device can be used in different premises to make public transport system safer from the epidemiological point of view by making the working environment cleaner from viruses and helping all the employees to feel safer.

3.2. Disinfection Gate

A prototype disinfection gate has been developed. The gate consists of two identical parts. Ultrasonic liquid evaporators (12 pieces on each side of the gate) turn the liquid into a mist. With the help of fans, the steam enters the disinfection zone through the air ducts (Fig. 4). Five diffusers on each side of the gate ensure an even distribution of the escaping steam. To turn on the machine, a person must approach the hand (do not touch) distance sensor on the front panel of each side of the gate. The signal from the sensor enters the microcontroller, which activates both sides of the gate (a wireless connection is established between them) for 30 sec. If necessary, the disinfection time can be changed. The device was tested in operation under real conditions.
Current device also can be used in different premises to make public transport system safer from the epidemiological point of view by making the working environment cleaner from viruses and helping all the employees to feel safer.

3.3. Equipment for Surface and Air Disinfection with UV Radiation and Ozone

Developed equipment for surface and air disinfection with UV radiation and ozone (Fig. 5). The device uses 28 mercury lamps that emit UV radiation (254nm). The lamps are placed horizontally in a vertical shaft with mirrored walls to concentrate the generated radiation to the maximum. The room air enters the shaft with the help of four fans, moves down along the UV radiation lamps, is disinfected (with UV radiation and ozone) and exits to the bottom of the unit. UV radiation and ozone also disinfect the floor under the unit. The body and steel plate on the top of the machine protect your eyes from direct UV radiation. This allows people to be in the room during the operation of the lamps without UV goggles. Tests have shown that the plant effectively destroys Escherichia coli, Staphylococcus aureus, bacteriophage phi6 and Semliki forest virus; the disinfection efficiency of the exhaust air is 99.99999%. Many UV lamps and powerful fans provide air disinfection in large rooms in a short time (400 m³/h). As elevated ozone concentrations can pose a risk to human health, ozone measurements have been carried out in the room when the equipment was switched off and in operation. The average concentration of ozone during the 2 hours of operation of the equipment in a 250 m³ room with forced ventilation did not exceed 50 μg/m³, which is acceptable and safe for human health. Ergonomic tests of the equipment have been performed. The device operates relatively quietly (65dB at a distance of 1m).

![Fig. 5 Equipment for surface and air disinfection with UV radiation and ozone (TRL 7). Testing its efficiency in laboratory conditions](image)

Current equipment shows high efficiency and also can be used in different premises to make public transport system safer from the epidemiological point of view by making the working environment cleaner from viruses and helping all the employees to feel safer.

4. Conclusions

The urban public transport sector experienced a drop in demand for services against the background of restrictions on the movement of citizens, but an additional factor was also the reluctance of people to use collective vehicles due to the increased risk of infection. At the same time, the need to maintain the quality and frequency of the provision of socially significant services while introducing mandatory precautions has led to an increase in companies' costs in the face of reduced passenger traffic and revenue, which has become the subject of government attention and one of the main directions of state support for such transport enterprises.

In a post-pandemic situation, it is highly likely that the population will avoid using public transport due to the high risk of infection and will choose individual forms of mobility. Therefore, bicycles (ordinary or electric) and micromobility facilities can be more widely used. The preference is likely to shift towards personal transport to the detriment of public transport.

Despite the uncertainty that during the pandemic began to characterize the development of every sphere of human life, it is necessary to use the crisis as an opportunity to develop the transport industry in a more sustainable direction. The search for ways out of the crisis stimulates the development of innovative solutions that are safer, more environmentally friendly and efficient.

Alternative modes of transport are becoming a worldwide trend. They reduce the use of potentially hazardous public transport. New York and Philadelphia have seen significant increases in cyclists (more than 50% in Philadelphia) since the start of the pandemic. The largest bicycle suppliers in the United States, due to the sharp increase in sales, faced a shortage of the most common models. The UK Cyclists’ Association reported a sharp increase in demand for repair services.

In order to ensure the quality development and improvement of the passenger transport industry, it is likely that the increased number of transport routes due to the pandemic will be maintained, which will improve the quality of transport services. New procedures for cleaning and disinfecting public transport facilities will be preserved in the future,
which will make transport more attractive and safe. The digitalization of the industry will develop faster, including the introduction of mobile applications for route planning, contactless payments, and the use of artificial intelligence in the management of public transport enterprises.

In other hand, the COVID-19 pandemic could be the starting point for global changes in the transport sector, as it fundamentally changes the established habits and order in the industry. Thus, the period of challenges and threats can be seen as a unique opportunity for governments to facilitate the transition to more sustainable modes of transport.

Authors hope, that all offered devices could be used in different premises to make public transport system safer from the epidemiological point of view by making the working environment cleaner from viruses and helping all the employees to feel safer.

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/4/20/658 “Adapting the public transport system to the COVID-19 challenge, ensuring its sustainability”).

References

Model of Competitiveness Formation of Railway Enterprises in the Conditions of Market Liberalization

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Abstract

The formation of a country's competitiveness directly involves developing the railway market, which is often key to the state. The case of Ukraine is an example when the competitiveness of the railway market project on the country's general state. The ongoing but slow process of liberalization of the railway market in Ukraine requires implementing a model for forming the railway companies' competitiveness seeking to operate in the free market. It proposes based on the analysis of an experience of the European countries and the Ukrainian realities of allocating bottlenecks of the railway and designing the corresponding actual model of competitiveness of the railway transport enterprises in the conditions of market liberalization. This work aims to improve the existing system of market competitiveness and facilitate the process of integration of railway enterprises into the liberalized market to increase the overall level of Ukraine's competitiveness on the world stage.

KEYWORDS: competitiveness formation; model; railway; freight transportation; market liberalization; Ukraine.

1. Introduction

The level of a country's competitiveness, i.e., the level at which it can compete with other countries in the context of various indicators, are assessed comprehensively. Independent evaluators rate the level of competitiveness of countries to objectively understand the level of development in the world market [1]. As it knows, logistics has always been an integral tool for ensuring the functioning of the world and human life. Each time new global challenges emphasize the importance of logistics development and its importance in countries' competitiveness. For example, while for EU countries the issue of competitiveness is acute, but at the level of implementation of ERTMS or "green" corridors as tools to increase critical indicators of this competitiveness, for some countries, the issue of competitiveness begins from the moment of market liberalization [2, 3].

The market of railway services occupies a significant share of influence on forming the ability to compete. Railways are often a strategically important logistical element for countries. Yes, this situation is relevant for Ukraine, but the level of development of its railway services market is underdeveloped despite the available potential. Scholars highlight the main problems of the Ukrainian railway market, including market monopoly, unfavorable economic environment, politicized interests of stakeholders, outdated and non-interoperable railway infrastructure, inefficient mechanisms for managing and controlling market activities, lack of independent tariff and safety regulators [4-6]. Accordingly, this negatively affects the level of competitiveness of Ukraine. In order to improve the current market situation, the Government is slowly implementing liberalization processes, which include many reforms and restructuring of the leading market player. Undoubtedly, the primary reason for such changes was the Association Agreement between Ukraine and the EU [7], which provides for overcoming the market monopoly and its liberalization, as well as other strategies of the Government in this direction, aimed at the central market player - JSC "Ukrzaliznytsia" [8]. At the same time, few people talk about private railway companies, which have a genuine interest in entering the market of railway services, but no relevant plan developed. The experience of European countries shows that such logistics operators can ensure a significant share in the country's competitiveness in the context of the logistics component, but they need the appropriate tool. Therefore, the purpose of this study is to create a model of forming the competitiveness of railway enterprises in market liberalization, which will help accelerate the integration of logistics enterprises into new conditions and improve the existing system of market competitiveness. Based on the analysis of European experience and taking into account the Ukrainian market of railway services, the development of the tool is proposing.

2. Implementation of the Model of Competitiveness Formation of Railway Transport Enterprises in the Conditions of Market Liberalization

2.1. Diagnosis of the Railway Services Market of Ukraine

Analyzing the state of the railway services market in Ukraine today, it noted that the market is representing by
the leading player JSC "Ukrzaliznytsia," which is the only provider of passenger railway services and the largest freight operator in the market. The board structure of JSC Ukrzaliznytsia is quite complex, as the company is a state monopoly and concentrates a vast number of different activities. To assess JSC "Ukrzaliznytsia" scale, the company is the largest employer and one of the largest taxpayers in the country [8]. At present, the company is in vertical restructuring, which is one of the prerequisites for Ukraine's integration into the European transport space. Such changes are necessary because JSC "Ukrzaliznytsia" has many divisions, which does not allow the company to operate effectively.

Even though JSC "Ukrzaliznytsia" in terms of turnover and length of the railway network occupies a leading position in the European market, its activities are primarily unprofitable, and the impact of the pandemic along with the unstable economic situation further affected the company's performance. The leading indicators of financial and operating activities are presented in Figure 1, which bases on official information provided by JSC "Ukrzaliznytsia" in its reports [8].

![Infographics of the leading indicators of JSC "Ukrzaliznytsia"

The railway industry is vital for the country and directly affects its overall efficiency and turnover. Accordingly, market liberalization adopts as one of the priority areas for Ukraine's development. Thus, the market expects to increase the number of private logistics companies of railway transport and new stakeholders, which already can enter the market, but which stop in front of numerous entry barriers [9].

If we analyze the country's competitiveness at the international level, which determines within the IMD World Competitiveness Ranking, we can conclude that Ukraine has a steady trend of concentration among the last places in the ranking [1]. Therefore, the improvement and restructuring of such a vital link as the railway are essential for its economy and competitiveness.

### 2.2. Model of Competitiveness Formation of Railway Transport Enterprises in the Conditions of Market Liberalization

Analyzing the primary document that guides European countries in the railway market, namely Directive 2012/34 / EU of the European Parliament and the Council and planning monitoring reports on the development of the rail market under Article 15 (4) of Directive 2012 / 34 / EU of the European Parliament and of the Council [10-12], which demonstrate the results of development and activity of the railway market of the EU countries, it offers the model of competitiveness formation of the railway transport enterprises in the conditions of market liberalization. Such a model accumulates the main components that are primarily taken into account in the activities of the EU countries and focuses primarily on private railway companies that need a push to enter the market. The main elements that allow assessing the competitiveness of railway transport enterprises in individual blocks should include:

- productivity (volumes of freight and passenger flows in the context of capacity and needs of the state);
- safety (compliance with established safety standards and independent regulation of licensing, certification of access to railway infrastructure);
- delivery (compliance with the standards of timeliness, reliability, flexibility, quality, completeness of cargo,
and comfort of receiving the service by passengers or cargo owners);

- development (continuous improvement of activity, activity within the limits of modern tendencies, "new" normality and low touch economy);
- finance (financial efficiency of logistics activities, the ability to independently finance future needs, to carry out investment activities).

This model can be used on three levels:

- railway industry (concerns the infrastructure operator, infrastructure support, and its development);
- railway enterprises, operators (logistics enterprises that will operate and provide railway transportation services based on a "free" market);
- railway service (applies to specific logistics services provided by a logistics provider).

Each level can successfully denote as macro, micro, and local.

Ensuring the interaction of such components at a specific level will provide new railway companies with market share, which will focus on quality railway services by modern standards.

In Fig. 2 the graphic interpretation of the offered model of formation of competitiveness of the enterprises of railway transport is represented.

![Fig. 2 Model of formation of competitiveness of railway transport enterprises in the conditions of market liberalization](image)

The interdependence of the elements is essential, which will ensure a synergy effect and, as a result, the successful functioning of the private sector. In this case, the level of competitiveness of enterprises and the country will increase.

### 2.3. The Role of State Support in the Mechanism of the Model of Formation of Competitiveness of Railway Transport Enterprises in the Conditions of Market Liberalization

Undoubtedly an essential factor is the support of the state. According to EU countries, about 70% of investments in the railway sector make with the state's support (6). In turn, if we analyze the volume of investments in logistics in Ukraine in recent years, which reflects in the State Statistics Service, we can observe the uneven investment (Table).

<table>
<thead>
<tr>
<th>Year</th>
<th>Capital investments together, thousand UAH</th>
<th>Capital investments at the expense of the state budget, thousand UAH</th>
<th>Share of public investments in total,%</th>
<th>Consumer price indices for transport goods and services, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>50078332</td>
<td>131857</td>
<td>0.2633</td>
<td>112.9</td>
</tr>
<tr>
<td>2019</td>
<td>43792846</td>
<td>107546</td>
<td>0.24558</td>
<td>97.6</td>
</tr>
<tr>
<td>2020</td>
<td>26488238</td>
<td>312377</td>
<td>1.17930</td>
<td>102.7</td>
</tr>
</tbody>
</table>

If we analyze investments in the railway, then only in 2021 will the state finance this critical industry for the first time in the history of Ukraine's independence. Thus, the Ukrainian government recently approved the consolidated financial plan of JSC Ukrzaliznytsia for 2021. Due to such co-financing, it planned to upgrade the railway rolling stock partially, increase bottlenecks' capacity in the infrastructure, and repair and modernize the tracks [9].

The practice of supporting domestic logistics by states is widespread. For Ukraine's logistics, such steps are apparent but difficult to implement due to the instability of the macroeconomic situation and the additional negative impact of the pandemic, which provoked a reformatting of cash flows. At the same time, improving the railway infrastructure is strategically essential for Ukraine.
3. Conclusions

Thus, the model of forming the competitiveness of railway transport enterprises is a prerequisite for facilitating the entry of new service providers into the market, especially in the case of a market with an initial stage of liberalization. This model envisages the integrated application of the main components and the interaction of the state with the private sector. Thanks to a coordinated mechanism and synergy, logistics companies will be able to navigate the market faster, which can improve the quality of railway services, upgrade and modernize rolling stock, attract investors and improve Ukraine's image as a reliable international player in the railway market.

If we talk about applying the proposed model for the most significant existing operator in the railway market of Ukraine, JSC "Ukrzaliznytsia," the described mechanism will benefit the monopolist. Logically, with the increasing level of liberalization of the Ukrainian railway services market, the number of stakeholders will also increase. In turn, JSC "Ukrzaliznytsia" will focus on specific areas of activity after its restructuring and improve the structure of services and "not spray" on additional but unprofitable services. Due to the increase of investment attractiveness and the general increase of railway transportation capacities, JSC Ukrzaliznytsia as a state carrier will also benefit in the context of exchange activity, which the company seeks to engage in shortly.

For Ukrainian realities, the application of European experience in the liberalization of the railway market is an essential element for understanding the prospects of the industry and infrastructure opportunities. However, only by combining marketing support for market restructuring, comprehensive formation of the competitiveness of private and state-owned enterprises, and the government's support will it be possible to achieve efficiency.

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Smart City Approach in Logistics and Transport in the Czech Republic

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Abstract

The ever-increasing rate of urbanization and population growth in cities requires cities to provide quality transport services, create new transport infrastructure, quality logistics and maintain the overall standard of living in the city. As the population grows, so does the demand for transport and logistics, as does transport itself, including its negative effects. The negative effects of traffic in the city are mainly traffic congestion, air quality pollution by exhaust gases or vibrations and noise. Addressing the increase in traffic and logistics, especially in the city centre, can be very challenging due to lack of space. The problems that arise due to the growing population density of cities can be solved by a relatively new idea of smart city. Smart city represents the solution of these problems using modern computer technologies and acquired data. The aim of the article is an insight into the smart city approach in logistics and transport in the Czech Republic. The article uses resources from publicly accessible databases, such as Scopus database, Web of Science database and other sources of information in the context of smart city approach in transport and logistics.

KEY WORDS: smart city approach, smart transport, smart city logistics, intelligent transport system

1. Introduction

In today's world, where the human population on Earth is still growing, it can be observed that the rate of urbanization is also increasing. This phenomenon can be caused by several reasons. The main reason is moving for a better job or for better services for city residents. Cities are vital in social and economic terms around the world and, as a whole, have a huge impact on the environment. To further describe the development of smart city, it is also important to be aware of the development of the human population, which is still growing [1]. For the first time, the population of the Earth was over one billion in 1804. This was preceded by constant growth as it is today. Exceptions were fluctuations caused by plague epidemics or other disasters. Another billion have been added in 123 years. As population growth continues to rise, the intervals have gradually shortened. Billions more were added after 32, 15 and 13 years. From 5 billion, which was reached in July 1987 to October 1999, according to the United Nations, this was the shortest interval, namely 12 years. According to the United Nations, 7 billion people in the world were reached in 2012. The world should exceed the 8 billion mark in 2023. In 2050, the estimated population is nine billion. While in the cities in 1800 lived 3% of the world's population. Today it is already 55%. Furthermore, the percentage of the urban population is expected to continue to grow [2]. In 1950, it was the only metropolis in the world (New York) with a population of more than 10 million. In connection with population growth, it is also logical that as early as 1975, there were five such agglomerations. There are already 23 of them in 2015. This information shows that there is a constant increase in population and also a large migration of people to cities. From these assumptions, it is clear why a large number of scientific institutions are now engaged in smart city research. The growth of large cities has changed the way we think about mobility and transport operations of megacities, which over the years receive a larger population, which will require increased investment in infrastructure, mobility, technology, traffic management, logistics [3-4]. The Desa study [5] revealed that in 2016, 45% of cities had a population of between 5 and 10 million inhabitants. It is estimated that by 2030, 10 of these city centres will become megacities. The same survey found that between 2016 and 2030, the population is expected to increase in all size classes of the city, while for the rural population the estimate will decrease slightly. By 2030, therefore, cities with at least 10 million inhabitants will have an estimated population of 730 million, representing 8.7% of the world's people [6].

The concept of smart city has been seriously discussed since 2008 due to the financial crisis. This is because smart city deals with both the efficiency and optimization of energy use, as well as the improvement of the city administration or transport infrastructure thanks to the public online availability of information and data or services offered by the city. Another possibility is the interest of technology companies, which comes from times of crisis, when they saw the concept as a new source of income. Due to this, it is possible to meet with criticism of the smart city concept. However, it must be said that if there are limits to the extent of smart emotion, then this is a good and beneficial idea [7]. Smart city is a concept leading to the sustainable development of a city or municipality. This is achieved by introducing modern technologies in the management of the city in order to improve the quality of life and streamline the management of public affairs, whether in the field of transport, energy, waste management or water management. Increased efficiency is usually achieved through the use of information and communication technologies [8]. The European Commission describes smart
cities as follows. A smart city is a place where traditional networks and services are provided more efficiently using digital and telecommunications technologies for the benefit of their citizens and businesses [9]. According to the magazine IT Systems, smart city deals with efficiency and optimization of energy use, transport infrastructure or improvement of city administration [10]. An important activity within the smart city is the sharing of collected information across various fields in the city. Information can be collected using sensors and transducers. These are then connected to sensor networks. Based on the amount of data and their subsequent analysis, ideally in real time, it allows the implementation of defined actions to solve problems that may occur. The interconnection of products, services and people into one whole takes place through the so-called Internet of Things. Today is so favourable for the introduction of smart city, because the availability of sensors or hardware is no longer so financially demanding. Furthermore, smartphones, which the majority of the population owns today, can be used in the solution [10].

The movement of goods into a smart city is economically critical. Therefore, understanding the relationship between the logistics of the flow of goods and the operation of smart cities is essential in implementing the policy of future cities. Emerging intelligent logistics is considering the inclusion of disruptive technologies, such as smart sensors in the Internet of Things environment [11]. The growing increase in the need for passenger and freight transport in both interurban and urban contexts over the last two decades has led to profound impacts on the human and natural environment. To mitigate the consequences, decision-makers consider various intelligent logistics solutions that do not always lead to the desired impacts [12]. Nowadays, city urban logistics is undergoing profound changes with the expansion of the urban population and the explosion of e-commerce. Smart urban logistics can not only provide an efficient delivery service, but also reduce congestion, CO₂ emissions, etc. [13]. Academies and the logistics industry have recognized that one of the major challenges of smart urban logistics is the integrated stakeholder involvement and development of effective decision-making tools to improve its global performance [14].

2. Smart City in City Management

One of the most important topics in the field of smart city is the management and administration of the city. In the context of smart city, the management and administration of the city is called Smart Administration and Management or the Smart Government or the eGovernment is used. The smart management of the city is that the citizens of the city have an overview of how the city manages finances and can also influence them. This makes the entire city budget transparent, which makes it possible to prevent overpriced public contracts or corruption. Influencing public finances by the citizens of the city or individual city districts is a necessary part of this concept. Citizens should be able to express what a priority is for them, through referendums, civic associations or public discussions.

Online platforms are beginning to be used to decide on the city budget or new city projects, which aim to improve group decision-making. This process is called participation. It is that people, citizens of the city, should be involved in decisions that affect them. Voting can take place using several voting methods. A frequently used method in this poll is the modern voting system, the so-called Janeček's Method of Democracy 2.1 [15]. In this method, everyone has two positive votes and one negative vote. Thanks to this, it is possible to reduce possible populism or the advantage of the informed voter over the uninformed. Voting can take place directly on the city's website and residents express their vote via computers, smartphones or tablets. Verification via SMS or social networks avoids the risk of re-voting by irresponsible voters. The platform can also be used to send e-mails related to city problems or various alerts. So far, this platform is in the pilot phase of testing. For example, it is used in New York as well as in Czech smaller cities. From this it can be evaluated that the issue of smart city management does not only concern large cities and agglomerations, but also smaller cities [15-16]. Another example of smart city management can be communication between the city administration and citizens via smartphones or tablets. For example, the English city of Bradford has created an application for its citizens that citizens download to their mobile devices. Thanks to the application, citizens can then follow the latest events in the city. There is also an application for advertising vacancies in the city or various sports events that take place in the city. Residents are informed through the application when waste collection will take place and are asked not to forget to prepare waste for collection. The application allows to pay various fees by redirecting to the city's website. Last but not least, the application offers the possibility of reporting a problem. Such as broken roads, sidewalks or broken lamps [17-18].

3. Smart City in Transport and Logistics

Transport is a key factor in the functioning of society and almost every city is affected by its negative effects. In order for transport in the city centre to be as efficient and as environmentally friendly as possible, it is important to manage it effectively. The city aims to improve transport mainly to eliminate time and economic losses in the city, to improve travel comfort or to improve the environment for citizens. Decision support systems for smart cities have been proposed in the world literature because they can face different applications problems such as electro mobility [19], logistics [20], convenience [21], cyber security [22] or transport [23].

3.1. Intelligent Traffic Management

The basic prerequisite for the functioning of efficient transport is the centralization of data from intelligent transport systems. The individual systems are for parking, collection of fees, payment of fares, multimodal movement
of goods and persons, administration and maintenance of roads and so on. This data is processed in one superior system, the traffic control centre, which processes and evaluates it. Up-to-date information is provided to traffic administrators and road users via information boards or a web interface. The data is then stored in a uniform format and is available several years back. The data is then used by traffic engineers and traffic modelling experts. Thanks to data collected in the past, there is no need to perform time-consuming and people-dependent measurements of traffic flows and traffic surveys. This data can then be used to design or dimension a new intersection or road so that the resulting design is as efficient as possible and suits the actual operation [24].

Another important function of the traffic control centre is the possibility of traffic management. During the day, congestion develops in different parts of the city. The most appropriate solution for regular congestion is their early detection and subsequent mitigation of predefined scenarios that are in the system. This may be a change of signalling at traffic lights, where the busy direction will be preferred. Another option is to display the traffic situation on information boards above the road and early warning of drivers against congestion.

The quality and integrity of the input data is crucial for the correct operation of the traffic control centre. If the data is damaged due to a failure, the values can be calculated from previous measurements. However, if the data is damaged by incorrect measurements, it is unusable. Therefore, for subsequent work with data, it is crucial to have all sensors and sensors properly installed, correct initial setup and calibration [24].

3.2. Carsharing

As the name implies, this is an approach to mobility in the city, which consists in sharing cars. Carsharing belongs to the system of gentle modes of transport, which also includes, for example, public or bicycle transport. Unlike a classic car rental, there is the advantage that the car can be rented at any time, while the method of renting is simpler. Cars can be provided either by private companies that lend the car to the end customer, or through car sharing companies where the car owners are individuals and the company is only an intermediary [25-26].

The service is advantageous for those drivers who do not have their own car and at the same time do not drive a large number of kilometres a year. Carsharing works on a system of demand for mobility, which means that the customer only pays for the time and distance when he actually used the car. Thanks to carsharing, it is possible to reduce the number of cars in cities, where one vehicle that is shared can replace ten to fifteen private vehicles. This has a positive effect not only on traffic in the city, but also on the environment, as the amount of exhaust gases in the air is limited. In most cities, vehicles of carsharing companies are also favoured in parking in the city centre [26-27].

In order to be able to use carsharing by Car4Way (in the Czech Republic), it is first necessary to register online, prove the necessary authorization to drive a vehicle and pay a deposit. Based on this, a user card is issued, which is used to unlock the car. The car rental itself takes place through an application on a smartphone. Car4Way provides vehicles of various categories, from small city vehicles to commercial vehicles. The customer will find the nearest vehicle in the application, which he will book for the time that the vehicle will need, this time can be several days. The answer to the reservation is an SMS, which contains the exact location and license plate of the vehicle. The customer unlocks the car with a card and can start driving. Any refuelling takes place via a refuelling card, which is part of every vehicle. At the end of the journey, the customer leaves the vehicle in his destination and is ready for other customers [28].

Carsharing company Revolt (in the Czech Republic) is a company that provides vehicle sharing only in selected parts of Prague, unlike other carsharing companies that rent vehicles for longer trips outside the city. Specifically, these are Holešovice, Vinohrady, Bubeneč, Dejvice, Hradčany, Malá Strana, Smíchov, Vyšehrad, Staré Město, Nové Město, Josefov, Karlin and Žižkov. The company has electric vehicles. This gives vehicles the advantage of being able to park for free in the residential blue and purple zones. It is a suitable alternative to individual passenger transport, where parking in the city centre is a big problem. Parking is also facilitated by the fact that these are very small vehicles. At present, Revolt has 20 electric cars, 50 electric scooters and 24 electric motorcycles [29].

The main means of transport used by Revolt is a small, characteristic yellow electric car. This is a Chinese electric cars from the Jiayun brand, which the company has chosen as the most suitable for homologation in the Czech Republic. The vehicle is simple, minimalistic and very small. It is a suitable means of sharing in the city. The vehicles are registered in the L7e category, which means that they are registered as heavy quad bike. It follows that vehicles can be so small because not so much emphasis is placed on safety features. According to the company, however, the safety features are still sufficient for traffic in the city. The vehicle measures 2.2 meters in length, 1.3 meters in width and 1.6 meters in height. The vehicle has space for 2 people and a luggage compartment for two suitcases. The vehicle equipment includes infotainment with navigation, heating or air conditioning, but the use of the equipment negatively affects the range. The maximum range of the vehicle is up to 120 km and the maximum speed is 80 km/h, which is, according to the company, sufficient for city traffic. The vehicle has an easily replaceable battery. This is an advantage, as soon as the company sees a vehicle with less than 30% of the battery, it sends technicians and they replace the battery with a charged one. The vehicle is hidden from the user until the battery is replaced [30].

Borrowing takes place through the Revolt carsharing application, which is free to download on smart devices. For successful registration, it is necessary to fill in the e-mail, telephone number, enclose current photos of the identity card, driving license together with a photo of the applicant for verification of personality. After activating the account, the user will see a map with free vehicles, the first time he clicks on the vehicle, information such as battery status or license plate will be displayed. After the second click, the application already offers to unlock the car. Then the ride itself is allowed. After driving, the vehicle's battery status must be recorded in the application, the windows must
be closed, the ignition must be switched off and the parking brake applied. After getting out of the vehicle, the user ends the ride in the application, which locks the vehicle and is ready for further use, and at the same time determines the price for the service, which takes place according to the time of car rental [31].

3.3. Bikesharing

Bikesharing in Czech language is known as shared bikes. Compared to the classic bike rental, the advantage of bikesharing is that the bike can be rented and returned at any time of the day. It is a suitable complement to public or individual car transport in the city. The main problem in cities is very heavy traffic. This is related to the creation of congestion and the slowing down of the transport itself or the production of harmful emissions in the form of exhaust gases, noise or vibrations. At the same time, current cities are expected to grow further. The question is how comfortable its population will be able to move around the cities, as there will not be as much space or money to build more bypasses or more jet roads. Bicycle transport is a suitable solution to these problems. It ensures the sustainable development of urban mobility for the city. It is a vehicle with zero carbon footprint. It eliminates urban congestion, building cycling infrastructure is not as costly as road transport and does not require as much space in city streets. It also has a positive effect on the health of the population, both directly, improving the physical condition of users and indirectly as a result of reducing harmful substances from the exhaust gases of road transport vehicles. Modern technologies have also added to the great expansion of bikesharing in recent years, thanks to which bicycles can be tracked and protected from vandals or paid for thanks to them. These are technologies such as GPS, Bluetooth, RFID and mobile payment systems [32-33].

Fourth generation shared bikes are currently in use. This means that all communication with the service provider or bike rental takes place using the application on the smartphone. Alternatively, the bike can be rented via SMS. This can be demonstrated at Rekola (in the Czech Republic). First, the customer needs to register for the shared bike application in the city. After registration, a new customer will usually receive discount coupons. The application then displays a map of the city with marked free bikes that can be rented. After arriving at the given bike, the QR code is read using the application (in the case of renting via SMS, the bike number is written), and a number combination is displayed immediately, which unlocks the number lock. After unlocking the lock, the bike is ready to ride. The customer is required to return the bike after the ride in the zone marked in the application. If he fails to do so, he is invited to do so within two days; otherwise another customer does so on his behalf. To return the bike, it is necessary to responsibly lock the bike to something fixed, take a picture and specify the position where the bike is located. Rekola allows you to pay for this service either as a lump sum and you pay for the rental period. Or it allows for a monthly or annual subscription, where rides up to 30 minutes are free. The advantage is that the company operates in more than one city and the user is thus not tied to a specific city where he can use the service [34].

4. Conclusion

The primary goal of smart city is to ensure a sustainable model of development, a high level of quality of life, security and the best use of energy in the city. This is to be achieved by using the latest new technologies. The concept of quality of life is very broad, also different in different scientific disciplines. The concept of quality of life can be taken as a set of material aspects of life, such as health, social relations, quality of nature, living conditions and personal well-being of an individual. The article dealt with the historical development of the population and the degree of urbanization in the world up to the present. This geographical development is closely related to the emergence of the smart city concept. Furthermore, the concept of smart city was described and individual industries in the city where it is possible to use smart city technology were analysed and described. The article then focused in more depth on smart solutions in the context of transport and logistics in the Czech Republic; carsharing and bikesharing were given as examples.

Acknowledgements

This article is published within the realization of the project “Cooperation in Applied Research between the University of Pardubice and Companies, in the Field of Positioning, Detection and Simulation Technology for Transport Systems (PosiTrans)”, registration No.: CZ.02.1.01/0.0/0.0/17_049/0008394.

References

Train Driver Reliability Analysis with the Use of HCR and Train Simulation Program

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Abstract

The article presents the manner of using a train simulation program in order to obtain data required for train driver reliability analysis using quantitative methods. Analyses of this type usually face the problem of the lack of statistical data, on which the quantitative methods of human reliability analyses are based. Hence the idea for obtaining data with the use of a simulation program proposed in the article. Data of this type cannot replace the recording of events in real conditions, and the characteristics obtained on its basis can be used for reference purposes only. Such approach has a major advantage, however, which is obtaining relatively easily available material making it possible to carry out quantitative human reliability analyses, at least at the preliminary stage. Actions involved in driving a rail vehicle – which are operational in nature by definition and there is usually a time deficit during their performance – were selected as the area of analysis. This provides the basis for the analysis of the train driver’s tasks using the HCR method. In order to obtain essential data (concerning the time of performance of operator actions), the MaSzyna program was used. It is worth noting the added value of the work carried out, namely the demonstration of the suitability of the HCR method for train driver reliability analysis during the performance of basic operator actions.

KEY WORDS: Human Reliability Analysis; Human Cognitive Reliability; train simulation program

1. Introduction

Human reliability analysis (HRA) was first used in order to analyse the safety of nuclear power stations in the 1960s. In 1983, Swain and Guttmann developed a technique for human error-rate prediction (THERP), which assumed a division of human behaviours into different processes and tasks, and identified the sequence of fault events in the form of an event tree (called the HRA tree). In 1994, Kirwan demonstrated that the primary objective of HRA should be the assessment of risk caused by human errors and control of such errors. This is why he isolated three processed in HRA methods: damage identification, determining the frequency of its occurrence, and designing methods for preventing damage [11].

Currently, human reliability analysis is so widespread that it is used across numerous industry sectors. It has found particular application in the power industry (nuclear power industry), the aviation industry, the maritime industry, and the medical industry. Depending on the type of industry in which it is used, different methodologies are used or even individual names introduced [7]. Literature distinguishes as many as 27 HRA methods. They can be symbolically divided into generations – the first and second one, and among them, we can distinguish those based on expert judgement [5].

In the first generation of HRA methods, emphasis is put on analysing, predicting, and limiting human errors with the use of qualitative and quantitative statistical methods. The first-generation HRA methods include: THERP, ASEP (Accident Sequence Evaluation Program), HEART (Human Error Assessment and Reduction Technique) and SPAR-H (Simplified Plant Analysis Risk – Human) [9].

The HCR (Human Cognitive Reliability) method, which was used in the research presented here, is also one of the first-generation methods. Its choice was determined by certain advantages listed by study authors [4, 11], such as the speed of application and ease of use. Moreover, according to [3], the method constitutes an effective way to quantitatively determine the numerical relations describing the relationship between humans and machines.

Human reliability analyses are carried out in a qualitative and quantitative form. The qualitative approach does not specify the value of the numerical parameters, but characterises the phenomenon under analysis and the object of study in a descriptive manner in order to identify human errors and their reasons. This way, it is possible to take action reducing the likelihood of the occurrence of such errors [12].

The HCR method is a quantitative one. Methods of this type consist in the processing of the collected data in such a way as to obtain information and formulate conclusions with the use of statistical analysis and mathematical analysis. The data provided may be statistical data on human errors. A problem might occur when, for various reasons, there is no actual statistical data and its collection is impossible. Hence the idea of using simulation programs in order to
obtain data for human reliability analyses. Such data cannot replace the recording of events in real conditions, and the characteristics obtained on its basis can be used for reference purposes only. However, it may constitute relatively easily available material supporting the execution of HRA at the preliminary stage.

Actions involved in driving a rail vehicle – which are operational in nature by definition and there is usually a time deficit during their performance – were selected as the area of analysis. This provides the basis for the analysis of the train driver’s tasks using the HCR method. In order to obtain essential data (concerning the time of performance of operator actions), the MaSzyna program was used. A detailed description of the program can be found on the program developers’ website (https://eu07.pl/).

The aim of the article is to present the results of a preliminary study of the possibility of using a train simulation program in order to obtain data required for train driver reliability analysis using quantitative methods. It is worth noting the added value of the work carried out, namely the confirmation of the suitability of the HCR method for train driver reliability analysis during the performance of basic operator actions. It should be noted, however, that the obtained results do not constitute train driver reliability assessments. Chapter two introduces basic information about the HCR method. Some essential information on the capability of the MaSzyna simulation program, used to carry out the research, is also provided. Chapter three presents the results of the identification of the tasks performed by the train driver, the way of using the MaSzyna simulator to conduct the research, and selected results of human error estimation. Chapter four presents the final remarks.

2. Materials and Methods

2.1. HCR Method

The HCR method is one of the first-generation HRA methods. It makes it possible to estimate the likelihood human/operator error as a function of a deficit of time for the performance of a task and depending on the type of action performed. What is also taken into account is the operator’s experience, level of stress, and the ergonomic quality of the place in which the control process takes place. In order to estimate the likelihood of error, the following factors are taken into consideration:

- internal: education and specialist courses, experience, IQ;
- external: working conditions, stress.

The selection of the above-mentioned factors is made based on the analysis of events taken into account during the administrator’s work [6].

The type of action performed is classified in compliance with Rasmussen’s Skill-Rule-Knowledge (SRK) model, i.e. the cognitive level at which it is executed. This means that each action can be categorised into one of three groups: skill-based actions, rule-based actions or knowledge-based actions. Skill-based actions are more routine, they are based simply on learned behaviour patterns. Rule-based tasks are usually more complex and their performance process may be described using the “if-then” implication. Knowledge-based behaviours are the most abstract and non-routine ones. They largely require the involvement of the operator’s knowledge or even their creativity. In the mathematical model of the HCR method, the impact of the type of action performed is taken into account with the use of coefficients. The values of these coefficients were provided in Table 1.

<table>
<thead>
<tr>
<th>Cognitive model coefficients related to the type of actions performed according to cognitive levels. Prepared based on [11]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive level of action/task execution</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Skill-based</td>
</tr>
<tr>
<td>Rule-based</td>
</tr>
<tr>
<td>Knowledge-based</td>
</tr>
</tbody>
</table>

The mathematical model of the HCR method also includes empirical correction coefficients ($K_1$, $K_2$, $K_3$), which are used to estimate the average time that is usually sufficient for the performance of the task. They express the impact of the key factors shaping human/operator reliability on the likelihood of the operator making an error. These factors include: the operator’s professional experience, stress generated by the task performed, and the ergonomic quality of the workstation. The values of the correction coefficients were provided in Tables 2, 3, and 4.

Table 2

Correction coefficients of the HCR method for the operator’s professional experience [2]

<table>
<thead>
<tr>
<th>Operator’s experience level</th>
<th>Coefficient value ($K_i$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert, extensive experience</td>
<td>-0.22</td>
</tr>
<tr>
<td>Average knowledge and training</td>
<td>0.00</td>
</tr>
<tr>
<td>Novice, minimum skills</td>
<td>0.44</td>
</tr>
</tbody>
</table>
In the HCR method, the likelihood of human/operator error is determined using the following formula [2, 11]:

\[
P(t) = \exp\left( -\frac{t - B}{t_{0.5}} \right)^c,\]

(1)

where \( P(t) \) – value of the likelihood of human/operator error; \( A, B, C \) – coefficients dependent on the type of action according to the cognitive level: skill-based, rule-based, knowledge-based; \( t \) – time available for task performance; \( t_{0.5} \) – average time necessary to choose and execute appropriate actions, whereas [2, 11]:

\[
t_{0.5} = t_{0.5,\text{nom}}(1 + K_1)(1 + K_2)(1 + K_3),\]

(2)

where \( t_{0.5,\text{nom}} \) – average time necessary to choose and execute appropriate actions under standard conditions; \( K_1 \) – the operator’s professional experience; \( K_2 \) – level of stress generated by the task; \( K_3 \) – ergonomic quality of the workstation.

Average time \( t_{0.5,\text{nom}} \) is obtained based on simulation measurements, analyses or expert assessment. In the method, it is assumed that \( t/t_{0.5} \geq B \). If \( t/t_{0.5} < B \), then the likelihood of error is assumed to be 1.

To sum up, the execution of human reliability analysis using the HCR method can be recapitulated in the following six basic steps [4]:

1. Specify the tasks that need to be carried out by the operator, e.g. using the Hierarchical Task Analysis method.
2. Classify the type of tasks into the skill-based (SB), rule-based (RB), and knowledge-based (KB) categories.
3. Determine the average time necessary to choose and execute appropriate actions under standard conditions.
4. Specify the time available for task performance, within which action needs to be taken, for each task.
5. Calculate the time necessary to choose and execute appropriate actions, assuming correction coefficient values \( (K_1, K_2, K_3) \).
6. Estimate the likelihood of human/operator error, assuming coefficient values dependent on the type of action.

2.2. Basic Information about the Simulation Program

MaSzyna is a Rail Vehicle Simulator developed in 2001. The primary purpose of the program is to imitate the process of driving a rail vehicle so as to enable the user to put themselves in the role of a train driver in the Polish railway network. The user can choose from the following rail vehicles in the program:

- more than forty electric and diesel locomotives;
- several electric multiple units;
- a rail trolley;
- a railbus.

Each vehicle has a separate scenario assigned, characterised by a set of system attributes and environment attributes for the journey, i.e. scenery, route length, and landform features. The user may define the atmospheric conditions in which the vehicle will be driven (precipitation, time of the year and time of the day, the exact time, fog).
The latest edition of the simulator provides more than 150 scenarios to choose from. Trunk lines with speeds ranging from 120 to 160 km/h and picturesque local railway routes are available. There is also an option to choose from “manoeuvring” scenarios, where the user may take on the role of an industrial plant employee working at a shunting yard or a railway siding [8].

The following functionalities of actual vehicles are included in the program: turning the battery on/off; raising the pantographs; DVD and ATP resetting; high-speed circuit-breaker switching; moving the reverser forward by one position; moving the reverser back by one position; opening doors; control desk lighting; train lighting; radio channel setting; air brake; power controller; activating the horn; displaying the timetable. Example images of the train driver’s cab from the MaSzyna program were presented in Fig. 1.

![Example screenshots from the MaSzyna program](image)

Fig. 1 Example screenshots from the MaSzyna program [8]

### 3. Results

#### 3.1. Identification of Tasks Performed by the Train Driver

The tasks performed by the train driver were identified in compliance with the principles of Hierarchical Task Analysis (HTA) [1, 10]. It is a method of analysis consisting in dividing key tasks into subtasks, at any given level of detail. Each subtask or operation is defined by the purpose, input conditions, and actions required in order to achieve the purpose. This makes it possible to present the individual actions and their interrelationships in an illustrative manner. Within the analyses discussed in this article, three key tasks were distinguished:

1. Preparation for work.
2. Preparation for driving.
3. Driving the rail vehicle.

The basic tasks are performed in a specific order, i.e. they form a certain process of performing the transport task. From the basic tasks distinguished, a number of subtasks (ST) were distinguished, i.e.: four involved in the preparation for work, five involved in the preparation for driving, and five involved in driving the rail vehicle (Fig. 2).

![The division of tasks involved in driving a rail vehicle](image)

Fig. 2 The division of tasks involved in driving a rail vehicle

The subtasks can be performed in any order and their execution may consist in performing a single action. The primary task is operating the power controller used by the train driver to control the speed of the vehicle. Other essential tasks include reacting to the signals of the railway traffic control systems and carrying out orders of the train manager and dispatcher. The primary task is adjusting the speed of the vehicle to the transmitted signal and correctly reacting to...
dubious (incorrect) signals. The train driver also has to react to the signal generated by the dead man’s vigilance device and deactivate it every sixty seconds. Reacting to the dead man’s vigilance device signal is an example of a single-action task. At train stations, the train driver is required to open and close doors, providing the time needed for passenger exchange.

3.2. The Manner of Use of the MaSzyna Simulator

The research was carried out on the Alakowice – Bałtyk Plaża route section with the use of the EN96 – Elf rail vehicle model. The type of train selected was ROJ55331 – a regional, domestic, slow passenger train, with multiple units and carriages, with electric traction. The weight of the train is 164 tonnes and its length – 84.324 m. The train consists of four vehicles. The maximum permissible speed of travel \( V_{\text{max}} \) is 160 km/h, and the minimum \( V_{\text{min}} \) – 50 km/h. The train driver is required to set the radio to channel 2 (R2). According to the timetable, the line is a double-track line [8].

The task was to determine the average time necessary to choose and execute appropriate actions under standard conditions \((t_{\text{sum}})\) and the average time necessary to choose and execute appropriate actions \((t_{\text{op}})\). These time values, and – as a result – the likelihood of train driver error calculated based on these values, depend on various factors (operator’s experience, stress), including external factors such as atmospheric conditions. Therefore, the research was divided into three major parts (with the train being driven by an expert, an average train driver, and a novice) and differentiated according to atmospheric conditions. It was assumed that the automatic mode is the expert (train driven by a computer algorithm available in the program), the average person is a person who knows railway traffic regulations divided into three major parts (with the train being driven by an expert, an average train driver, and a novice) and differentiated according to atmospheric conditions. It was assumed that the automatic mode is the expert (train driven by a computer algorithm available in the program), the average person is a person who knows railway traffic regulations and train driving procedures, and the novice is a person who knows the program very well, but has only basic knowledge of train driving regulations. None of the program users had a train driver’s licence. The task was to drive the vehicle along the Alakowice – Bałtyk Plaza route section in various atmospheric conditions, namely:
- during rainfall (at daytime);
- on a sunny day;
- at nighttime;
- during fog (at daytime).

During the simulation, measurements were carried out manually with the use of a stopwatch with the accuracy of 0.01 s. The individual controlling the simulator, who took on the role of the train driver, was supposed to execute the order of deactivating the dead man’s vigilance device the moment a light signal appears. The task of the person taking the measurement was only to turn the stopwatch on or off at the time of reaction. The time between the light signal and the start of emergency braking determined the time available for task performance. Seven measurements were taken during each journey. Four journeys were made, each lasting about 6-7 minutes.

3.3. Analysis Results

In order to present the potential of using the simulation program, only some of the analysis results were selected. They are related to the train driver’s reaction to the dead man’s vigilance device (basic task 3: driving the rail vehicle), which consists in deactivating the signal generated by the switch.

The dead man’s vigilance device (DVD) is a safety system which is activated when the speed of the vehicle is 10% higher than the maximum permissible speed and it works independently of the elements mounted on the tracks (as opposed to the ATP). Automatic train protection (ATP) is another railway safety system, which reduces the risk of hazards related to ignoring the semaphore’s “stop” signal. The working principle of the ATP consists in generating a signal with the frequency of 1 kHz and transmitting it to a sensor. The sensor remains inactive until the moment the rail vehicle runs over an ATP resonator. The resonator is usually located about 200 m before the semaphore. The train driver is first informed with a light signal, followed by a sound signal. Both in the case of the DVD and the ATP, if the train driver does not react after the set amount of time, emergency braking is activated [8].

The time available for task performance was recorded from the moment the train driver is informed about the start of emergency braking determined the time available for task performance. Table 5 presents the measurements of task performance times in different external (atmospheric) conditions. It was assumed that these conditions have a considerable impact on the visibility of the track and traffic control devices, which might in turn affect the speed of decision-making by the train driver.

During the measurements of the reactions to the dead man’s vigilance device, it was assumed that they need to be carried out at nighttime, at daytime, during rainfall, and during fog. Just like in the case of the measurements taken during preparation for driving, the tests were conducted with the use of the EN96 vehicle simulation model. It was assumed that the factors affecting the results obtained include atmospheric conditions, the operator’s experience, and stress. The time available for task performance was 5 seconds. High average time values were recorded during fog, which indicates that difficulties in track observation (and attempts not to make a mistake when reading the semaphore signals) significantly absorb the train driver’s attention.
Table 5
Results of the measurements of the time of reaction to the dead man’s vigilance device for three train drivers in the simulation program

<table>
<thead>
<tr>
<th>No.*</th>
<th>Nighttime</th>
<th>Daytime</th>
<th>Rain</th>
<th>Fog</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N**</td>
<td>P**</td>
<td>E**</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>3.71</td>
<td>1.24</td>
<td>0.93</td>
<td>1.57</td>
</tr>
<tr>
<td>2</td>
<td>2.48</td>
<td>2.03</td>
<td>1.27</td>
<td>2.98</td>
</tr>
<tr>
<td>3</td>
<td>3.91</td>
<td>1.36</td>
<td>2.24</td>
<td>2.3</td>
</tr>
<tr>
<td>4</td>
<td>3.72</td>
<td>1.83</td>
<td>0.89</td>
<td>1.85</td>
</tr>
<tr>
<td>5</td>
<td>3.5</td>
<td>0.83</td>
<td>1.5</td>
<td>1.33</td>
</tr>
<tr>
<td>6</td>
<td>2.55</td>
<td>0.77</td>
<td>0.76</td>
<td>2.55</td>
</tr>
<tr>
<td>7</td>
<td>3.3</td>
<td>3.46</td>
<td>1.23</td>
<td>3.66</td>
</tr>
</tbody>
</table>

$t_{avg} = 3.31 \cdot 1.65 \cdot 1.26 = 5.35$ s

Next, based on Tables 2, 3, and 4, $K_1$, $K_2$, and $K_3$ values were determined. For example, for the “novice”, the following characteristics were assumed: minimum skills, extreme risk situation, and excellent ergonomic quality of the train driver’s cab; skill-based actions. In order to calculate the error of the reaction to the dead man’s vigilance device by the novice train driver in nighttime conditions, it was assumed that: $t_{0.5}\text{nom} = 3.31$ s, $t = 5$ s. In compliance with these assumptions, the following result was obtained:

$t_{0.5} = 3.31 \cdot (1 + 0.44)(1 + 0.44) \cdot (1 + (-0.22)) = 5.35$ s

$P(t) = \exp\left(-\frac{5}{5.35} \cdot 0.7 \cdot 0.407\right) = 0.6$.

The tabular compilation of the results obtained using the HCR method for each of the experience levels during different atmospheric conditions was presented in Table 6.

Table 6
Results of the estimation of the likelihood of human error during the reaction to the dead man’s vigilance device in different external (atmospheric) conditions based on the results of simulation tests

<table>
<thead>
<tr>
<th>External conditions</th>
<th>Likelihood of error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice</td>
<td>Average person</td>
</tr>
<tr>
<td>Nighttime</td>
<td>0.6</td>
</tr>
<tr>
<td>Daytime</td>
<td>0.18</td>
</tr>
<tr>
<td>Rain</td>
<td>0.41</td>
</tr>
<tr>
<td>Fog</td>
<td>0.59</td>
</tr>
</tbody>
</table>

4. Conclusions

The results of the preliminary research on the use of a train simulation program show that it is possible to use:
- programs imitating actual transport processes as sources of information for quantitative train driver reliability analyses;
- the HCR method to estimate the likelihood of train driver error during the performance of basic operator tasks.

In spite of the fact that the research results have shown adequate representation of the impact of the conditions in which the tasks are performed on train driver reliability, it should be noted that the characteristics obtained on their basis can be used for reference purposes only and cannot replace the recording of events in real conditions. This is why a continuation of the research presented here is recommended, in the form of:
- conducting major research on a statistically significant number of licensed train drivers;
- comparing research results with actual data, i.e. data obtained in real conditions.

The advantage of the approach presented in the article is the opportunity to obtain relatively easily available
material making it possible to carry out quantitative human reliability analyses, at least at the preliminary stage.

Acknowledgement

The research was conducted with subsidy for the support and development of research potential for the Faculty of Civil and Transport Engineering at Poznan University of Technology (0416/SBAD/0002).

References

Moisture Content Control in Heavy Fuel During the Process of Emulsification with a Help of Capacitive Sensors

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Abstract

Application of fuel-water emulsions instead traditional heavy fuels is an effective technology that enables soot and nitrogen oxide emissions to be reduced at the same time, while fuel consumption can be reduced up to 10 %. Water content in the fuel-water emulsions can be varied from 10 % up to 30 % and is under control during the process of emulsification. Capacitive principle of moisture measurement remains a forward-looking among all indirect methods, applied for moisture measurement in oil products. Main task of the research is to get linear static function for the fuel-water emulsion water cut meter with four capacitive sensors. Method of Least Squares and general linear regression instruments had been used for that purpose. Graphs of the new static function for different moist fuels helped to conclude that it can be far more effective then initial static functions, suggested previously. Prototype product of the water cut meter had been developed with a purpose to fulfill multiple moisture measurements and check the workability of the new static function. Values of moisture content for the new static function and closest analogues had been compared with a help of dispersion analysis. New static function provided minimal dispersions of repeatability and adequacy and minimal value of F-test. Values of both dispersions for modified static function were significantly lower, so as F-test value was more than two times smaller in comparison with initial static function of a water cut meter, what proves better workability and robust properties of a new linear static function.

KEY WORDS: fuel-water emulsion; capacitive water cut meter, linear static function, general linear regression, dispersion analysis

1. Introduction

For different internal combustion engines fuel efficiency is critical and emission requirements of NOx, CO2 and other harmful emissions have become more and more stringent. Significant results in toxicity reduction of diesel engines’ exhaust fumes were received by application of fuels with water and alcohol additives. Water introduction into the cycle of internal combustion engine is used to reduce calorific intensity and intensify the process of combustion. Water-fuel emulsion is a system, which includes water (dispersed phase with 0.1…10 μm diameter of droplets) and diesel fuel as a dispersion medium [1-3]. It can be received with application of homogenizers or dispersers, typically separately from fuel equipment. Water content in the fuel-water emulsions can be varied from 10 % up to 30% and is an object of strict control during the process of emulsification [4].

Currently significant part among the means of measurement, which control substances’ properties and composition, is occupied with capacitive measurement tools which use capacitive sensors. The process of searching the new ways of their optimization, using different criterions, is under constant continuation. ‘Successful’ modifications of capacitive sensors appeared years ago [5, 6] with an idea to fulfill capacitive measurements using two or several positions for one of the capacitor plates with further direct comparison. It helps to eliminate parasitic capacitances almost completely, compensate leakage currents and reduce the influence of fringe electric fields. Main task of the research is in receiving robust linear static function for comparison method of moisture measurement, described in [7] and provide its’ effective application for the process of water-fuel emulsion moisture control.

2. Materials and Methods

In capacitive sensors, where one of the capacitor plates should be placed in two or several positions [5], we take empty sensor at first, where change of electric capacitance ΔC0 should be defined before and after the distance between two plates had been changed. Then we define the change of electric capacitance ΔC1 when capacitive sensor is filled with tested substance for the same positions of the capacitor plates. After that relation ΔC1/ΔC0 should be calculated. In this method only the accuracy of capacitor plates positioning would influence the uncertainty of measurements.

As it was just mentioned, static function of the moisture meter should be described with formula:

\[ W = K \cdot \frac{C_1 - C_4}{C_2 - C_1}, \]
where $K$ is a normalizing coefficient [7], equal to $K = 28.599$ when we take the values of electric capacitances, equal to 15 pF for $C_1$, $C_4$ and 50 pF for $C_2$, $C_3$ when capacitive sensors are empty.

To check the behavior of a static function (1) with different types of moist substances, we took four values of dielectric permittivity for imaginary dehydrated fuels ($\varepsilon_n = 2.0$; $\varepsilon_n = 2.5$; $\varepsilon_n = 3.0$; $\varepsilon_n = 3.5$) and four values of moisture content ($W = 0%$; $W = 10%$; $W = 20%$; $W = 30%$). Values of dielectric permittivity for moist substances, necessary to calculate the values of four sensors’ capacitances, were estimated with a help of universal Wiener equation [8]. Values of capacitances $C_1$, $C_2$, $C_3$, $C_4$ and calculated values of moisture content, defined with a help of static function (1) are given in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>$W$, %</th>
<th>$\varepsilon_n$</th>
<th>$C_1$, pF</th>
<th>$C_2$, pF</th>
<th>$C_3$, pF</th>
<th>$C_4$, pF</th>
<th>$W_{calc}$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.0</td>
<td>30</td>
<td>100</td>
<td>168.4</td>
<td>50.52</td>
<td>19.56</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>37.5</td>
<td>125</td>
<td>215.85</td>
<td>64.76</td>
<td>20.78</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>45</td>
<td>150</td>
<td>248.15</td>
<td>74.45</td>
<td>18.71</td>
</tr>
<tr>
<td></td>
<td>3.5</td>
<td>52.5</td>
<td>175</td>
<td>287.05</td>
<td>86.12</td>
<td>18.31</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
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<td></td>
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<td></td>
<td></td>
<td>33.13</td>
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<td>32.31</td>
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<td>31.51</td>
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<td>8.78</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>7.262</td>
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<td>30</td>
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<td></td>
<td></td>
<td>48.78</td>
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<td></td>
<td></td>
<td>58.28</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>67.68</td>
</tr>
</tbody>
</table>

Graphs of received static functions for different moist substances and their comparison with an ideal linear static function are given on Fig. 1.

![Fig. 1 Graphs, received for initial static function (1)](image1)

![Fig. 2 Graphs, received for modified static function (5)](image2)

As we can see, all static functions, received with a help of equation (1), are nonlinear, and calculated values of moisture content are significantly different from nominal in all points, except $W = 0%$. So, at first equation (1) should be linearized.

### 3. Theory/Calculation

To receive linear dependence between moisture content $W$ and $(C_3 - C_4)/(C_2 - C_1)$ relation method of Least Squares had been used:

$$a + b \cdot W = (C_3 - C_4)/(C_2 - C_1), \quad (2)$$

where $a$ and $b$ – unknown coefficients of a first-order polynomial (2).

When building a system of conditional equations (3) we took average values for $(C_3 - C_4)/(C_2 - C_1)$ relation (Table 2).

$$\begin{align*}
a + b \cdot 0 &= 1, \\
a + b \cdot 10 &= 1.298, \\
a + b \cdot 20 &= 1.662, \\
a + b \cdot 30 &= 2.116.
\end{align*} \quad (3)$$
Table 2

Average values for the relation \((C_3-C_4)/(C_2-C_1)\)

<table>
<thead>
<tr>
<th>W, %</th>
<th>(\varepsilon_n = 2.0)</th>
<th>(\varepsilon_n = 2.5)</th>
<th>(\varepsilon_n = 3.0)</th>
<th>(\varepsilon_n = 3.5)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1.307</td>
<td>1.301</td>
<td>1.295</td>
<td>1.289</td>
<td>1.298</td>
</tr>
<tr>
<td>20</td>
<td>1.684</td>
<td>1.669</td>
<td>1.654</td>
<td>1.640</td>
<td>1.662</td>
</tr>
<tr>
<td>30</td>
<td>2.158</td>
<td>2.130</td>
<td>2.102</td>
<td>2.075</td>
<td>2.116</td>
</tr>
</tbody>
</table>

System (3) had been solved in traditional way:

\[
[XY] = 4, \quad [XY] = [YY] = 60, \quad [YL] = 1400, \quad [YL] = 60.076, \quad [YL] = 109.7,
\]

\[
Q = \begin{bmatrix}
[XX] \\
[XY] \\
[YX] \\
[YY]
\end{bmatrix} = 4 \begin{bmatrix}
60 \\
1400
\end{bmatrix} = 2000, \quad Q_x = \begin{bmatrix}
XL \\
[XY] \\
[YL]
\end{bmatrix} = 60.076 \begin{bmatrix}
60 \\
109.7 \\
1400
\end{bmatrix} = 1924.4,
\]

\[
Q_b = \begin{bmatrix}
[XX] \\
[XY] \\
[YX] \\
[YL]
\end{bmatrix} = 4 \begin{bmatrix}
60 \\
109.7
\end{bmatrix} = 74.247, \quad a = \frac{Q}{Q} = 1924.4 \frac{2000}{1924.4} = 0.9622, \quad b = \frac{Q}{Q} = 74.24 \frac{2000}{1924.4} = 0.0371.
\]

Calculated values of moisture content \(W\), received from a first-order polynomial (2), are given in Table 3.

Table 3

Values of moisture content \(W'\)

<table>
<thead>
<tr>
<th>W, %</th>
<th>(\varepsilon_n = 2.0)</th>
<th>(\varepsilon_n = 2.5)</th>
<th>(\varepsilon_n = 3.0 (W'))</th>
<th>(\varepsilon_n = 3.5)</th>
<th>(\Delta W)</th>
<th>(\Delta W^*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0019</td>
<td>0.0019</td>
<td>0.0019</td>
<td>0.0019</td>
<td>0.0019</td>
<td>0.0019</td>
</tr>
<tr>
<td>10</td>
<td>9.294</td>
<td>9.132</td>
<td>8.970</td>
<td>8.809</td>
<td>-0.1030</td>
<td>-0.1030</td>
</tr>
<tr>
<td>20</td>
<td>19.456</td>
<td>19.051</td>
<td>18.647</td>
<td>18.270</td>
<td>-1.353</td>
<td>-1.353</td>
</tr>
<tr>
<td>30</td>
<td>32.232</td>
<td>31.477</td>
<td>30.722</td>
<td>30.035</td>
<td>-0.722</td>
<td>-0.722</td>
</tr>
</tbody>
</table>

Values of \(W_m\), calculated with a help of static function (5)

<table>
<thead>
<tr>
<th>W, %</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.268</td>
<td>0.268</td>
<td>0.268</td>
<td>0.268</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>10.230</td>
<td>10.045</td>
<td>9.859</td>
<td>9.674</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>20.850</td>
<td>20.470</td>
<td>20.085</td>
<td>19.723</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>30.658</td>
<td>30.211</td>
<td>29.476</td>
<td>29.280</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values of \(W', \Delta W\) and \(\Delta W^*\) were used for calculating discrepancies \(\Delta W\) and \(\Delta W^*\) between nominal points of moisture content and values of the first-order polynomial (2) and approximate these discrepancies by applying instruments of general linear regression [9]. Discrepancies \(\Delta W = W' - W_{\text{nominal}}\) between nominal points of moisture content (Table 3, column 1) and values of moisture, taken for \(\varepsilon_n = 3.0\) (table 3, column 4, bold), are given in column 6 of Table 3. To approximate values of discrepancies \(\Delta W\), a sum of four functions (1, \(W\), \(W^2\) and \(W^3\)) was taken with appropriate coefficients, defined with a help of Mathcad software (function linfit (x, y, Y)).

\[
\Delta W' = 1.019 - 0.269 \cdot W + 0.00527 \cdot W^2 + 0.000112 \cdot W^3,
\]

\[
\Delta W^* = 1.019 - 0.269 \cdot \left(\frac{C_3 - C_4}{C_2 - C_1} - a\right) + 0.00527 \cdot \left(\frac{C_3 - C_4}{C_2 - C_1} - a\right)^2 + 0.000112 \cdot \left(\frac{C_3 - C_4}{C_2 - C_1} - a\right)^3
\]

Formula (4) provides ideal approximation of the discrepancies \(\Delta W\), as it can be seen from Table 3, columns 6, 7. Taking it into account, we can build modified static function for a water cut meter (5). New values of moisture content, calculated with a help of formula (5), are given in Table 3. We can see the graphs of received static functions for different moist substances on Fig. 2. If we compare Fig. 1 and Fig. 2, it would be possible to say that modified static function (5) is far more effective then initial static function (1) and static function, received from a first-order polynomial (2).
4. Experiments

Sensors of an instrument measuring transducer were assembled from four identical fluoroplastic rings with slots to insert flat stainless steel plates, which were glued to the internal surface of appropriate pair of fluoroplastic rings with a help of super glue gel and soldered with wires to create four capacitive sensors (Fig. 3).

\[
W_n = W' - \Delta W' = \left\{ \begin{array}{l}
\frac{(C_1 - C_4 - a)}{b} - 1.019 + 0.269 \cdot \frac{(C_1 - C_4 - a)}{b^2} - 0.00527 \cdot \frac{(C_1 - C_4 - a)}{b^3}, \\
-0.000112, \\
\frac{(C_1 - C_4 - a)}{b} + 1.019 + 1.269 \cdot \frac{(C_1 - C_4 - a)}{b^2} - 0.00527 \cdot \frac{(C_1 - C_4 - a)}{b^3}.
\end{array} \right.
\]

\(W_n = -1.019 + 1.269 \cdot \frac{(C_1 - C_4 - a)}{b} - 0.00527 \cdot \frac{(C_1 - C_4 - a)}{b^2} - 0.000112 \cdot \frac{(C_1 - C_4 - a)}{b^3}.\)

To carry out experimental researches with a purpose to check the workability of a static function (5) and estimate the provided level of moisture content measurements' uncertainty, it was necessary to get stable reference samples of oil products with different dielectric permittivity values \(\varepsilon_n\) in dehydrated state and values of moisture content, equal to \(W = 0\%\), \(W = 10\%\), \(W = 20\%\) and \(W = 30\%\) respectively. We used diesel fuel with \(\varepsilon_n = 2.01\) and mazut with \(\varepsilon_n = 2.67\) for that purpose. Stable reference samples of diesel fuel and mazut with 10 \(\mu\)m diameter of water particles had been received by adding appropriate water volumes with a help of second class precision pipette [10] and 30 minutes mechanical mixing on \(n = 3200\) rpm.

Process of moisture measurement was performed in accordance with substitution method, when the value of the quantity being measured is not found directly from a reading of the measuring instrument, but rather from the magnitude of the standard, which is regulated in such a way that the reading of the measuring instrument remains the same when the quantity being measured is replaced by the standard. Commonly known, that its' application eliminates systematic errors and provides high accuracy, and substitution method is extensively used in measuring electrical quantities, such as resistance, capacitance and inductance. Connection scheme of the devices, included into the process of moisture measurement, is given on Fig. 4.
From the very beginning, part of instrument measuring transducer with two capacitive sensors $C_1$ and $C_2$ (reference channel) was filled with original (with traces of water) sample of oil product (Fig. 5, a). Both capacitive sensors of the reference channel were one by one connected to the input of capacitance into dc-voltage transducer and appropriate dc voltage values were taken from the screen of a digital voltmeter and fixed by operator.

Then variable air capacitor (reference capacitor or standard) was connected instead capacitive sensors. Its capacitance had been slowly changed in correspondence with method of substitution up to the moment till dc voltage value on the voltmeter’s screen became equal to the values, detected before (Fig. 5, b). After that standard capacitor was disconnected from the transducer and its capacitance was measured with the help of accurate RLC-meter on 10 kHz frequency. The same process took place for capacitive sensors in measuring channel, filled with moist samples of oil products (Fig. 5, d). As a result, ten multiple measurements of electric capacitance had been received from each capacitive sensor. Oscilloscope helped to control the correct work of the capacitance into pulse duration transducer. At first, it helped to choose correct operating mode of the secondary transducer, when duration of rectangular pulses is in straight proportion with $C_1$, $C_2$, $C_3$ and $C_4$ capacitance values on all range of their variation. Besides, presence of the oscilloscope was necessary to detect possible oscillation stops when measuring big moisture content (over 20%).

**Fig. 5 Process of moisture measurement:** a – connection of the first part of instrument measuring transducer (sensors $C_1$ and $C_2$ with dehydrated diesel fuel) to the input of a secondary capacitance into dc-voltage transducer; b – reference capacitors’ connection instead of sensors $C_1$ and $C_2$; c – measuring the capacitance of a reference capacitor with a help of RLC-meter; d - connection of the second part of instrument measuring transducer (sensors $C_3$ and $C_4$ with moist diesel fuel, $W = 20\%$) to the input of a secondary capacitance into dc-voltage transducer

Measured values of capacitances for the sensors $C_1$, $C_2$, $C_3$ and $C_4$ are given in Table 4.

**Table 4**

<table>
<thead>
<tr>
<th>No of experiment</th>
<th>Moisture content $W$, %</th>
<th>Diesel fuel, $r_n = 2.01$</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$, pF</td>
<td>$C_2$, pF</td>
<td>$C_3$, pF</td>
<td>$C_4$, pF</td>
<td>$C_5$, pF</td>
<td>$C_6$, pF</td>
<td>$C_7$, pF</td>
</tr>
<tr>
<td>1</td>
<td>30.22</td>
<td>94.69</td>
<td>125.34</td>
<td>40.62</td>
<td>159.45</td>
<td>51.24</td>
</tr>
<tr>
<td>2</td>
<td>30.61</td>
<td>94.81</td>
<td>125.21</td>
<td>40.30</td>
<td>160.11</td>
<td>50.96</td>
</tr>
<tr>
<td>3</td>
<td>30.29</td>
<td>95.16</td>
<td>125.64</td>
<td>40.36</td>
<td>159.66</td>
<td>50.84</td>
</tr>
<tr>
<td>4</td>
<td>30.48</td>
<td>94.73</td>
<td>125.82</td>
<td>40.29</td>
<td>159.74</td>
<td>51.11</td>
</tr>
<tr>
<td>5</td>
<td>30.41</td>
<td>94.79</td>
<td>125.70</td>
<td>40.32</td>
<td>159.91</td>
<td>51.03</td>
</tr>
<tr>
<td>6</td>
<td>30.36</td>
<td>94.91</td>
<td>125.49</td>
<td>40.59</td>
<td>159.86</td>
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</tr>
<tr>
<td>7</td>
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<td>94.98</td>
<td>125.66</td>
<td>40.44</td>
<td>159.72</td>
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</tr>
<tr>
<td>8</td>
<td>30.31</td>
<td>95.11</td>
<td>125.21</td>
<td>40.26</td>
<td>159.84</td>
<td>51.36</td>
</tr>
<tr>
<td>9</td>
<td>30.42</td>
<td>94.73</td>
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<td>40.32</td>
<td>159.79</td>
<td>51.01</td>
</tr>
<tr>
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<td>40.41</td>
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</tr>
<tr>
<td>Mean value</td>
<td>30.58</td>
<td>94.81</td>
<td>125.50</td>
<td>40.39</td>
<td>159.81</td>
<td>51.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No of experiment</th>
<th>Mazut, $r_n = 2.67$</th>
<th>Diesel fuel, $r_n = 2.67$</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
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</thead>
<tbody>
<tr>
<td>$C_1$, pF</td>
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<td>$C_3$, pF</td>
<td>$C_4$, pF</td>
<td>$C_5$, pF</td>
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<td>41.16</td>
<td>127.56</td>
<td>168.46</td>
<td>54.08</td>
<td>213.86</td>
<td>70.36</td>
</tr>
<tr>
<td>2</td>
<td>41.29</td>
<td>127.64</td>
<td>168.04</td>
<td>54.21</td>
<td>214.21</td>
<td>70.24</td>
</tr>
<tr>
<td>3</td>
<td>41.36</td>
<td>128.12</td>
<td>168.54</td>
<td>54.66</td>
<td>214.10</td>
<td>70.08</td>
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<td>4</td>
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<td>127.74</td>
<td>168.22</td>
<td>54.71</td>
<td>214.36</td>
<td>70.21</td>
</tr>
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<td>41.40</td>
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<td>168.11</td>
<td>54.32</td>
<td>214.02</td>
<td>69.96</td>
</tr>
<tr>
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<td>127.94</td>
<td>168.01</td>
<td>54.39</td>
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<tr>
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<td>41.19</td>
<td>127.90</td>
<td>168.14</td>
<td>54.56</td>
<td>213.76</td>
<td>70.22</td>
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<td>10</td>
<td>41.31</td>
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<td>168.03</td>
<td>54.41</td>
<td>213.90</td>
<td>69.08</td>
</tr>
<tr>
<td>Mean value</td>
<td>41.29</td>
<td>127.83</td>
<td>168.21</td>
<td>54.42</td>
<td>213.97</td>
<td>70.05</td>
</tr>
</tbody>
</table>
We can see the graphs of a static function (5) with mean values of $C_1$, $C_2$, $C_3$ and $C_4$ capacitance on Fig. 6.

![Graph showing static functions for diesel fuel and mazut](image)

Fig. 6 Experimental static functions, taken for diesel fuel and mazut

Analyzing Fig. 6 we can conclude that static function (5) is completely workable.

5. Results and Discussion

Moisture measurement uncertainty can be estimated by using the method of mathematical programing. If some function $f(x)$ is continuous, it’s possible to find maximal and minimal values of $f(x)$ inside the limit value of function’s argument error. Absolute uncertainty of moisture measurement can be calculated as a half difference $\Delta f = (f_{\text{max}}(x) - f_{\text{min}}(x))/2$. Maximal and minimal capacitance values were taken from the results of ten random measurements in mazut with 30% of moisture content: $C_{1\text{min}} = 41.16$ pF, $C_{1\text{max}} = 41.40$ pF, $C_{2\text{min}} = 128.09$ pF, $C_{2\text{max}} = 127.56$ pF, $C_{3\text{min}} = 270.41$ pF, $C_{3\text{max}} = 271.04$ pF, $C_{4\text{min}} = 87.39$ pF, $C_{4\text{max}} = 88.26$ pF. After substituting these capacitances into formula (5), we receive maximal and minimal values of moisture content: $W_{\text{max}} = 30.235\%$, $W_{\text{min}} = 29.633\%$. Value of absolute moisture measurement extended uncertainty would be equal to $U(W) = (30.235 - 29.633)/2 = 0.301\%$, what is very good for a capacitive water cut meter.

Besides extended uncertainty estimation, the robustness of a static function (5) in comparison with initial static function (1) was checked. Calculated values of moisture content with mean values of sensors’ capacitances can be found in Table 5.

<table>
<thead>
<tr>
<th>$W_{\text{nominal}}, %$</th>
<th>$W_{\text{calculated}}, %$</th>
<th>$\bar{W}_f$</th>
<th>$\bar{W}_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static function (1)</td>
<td>Static function (5)</td>
<td></td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>Mazut</td>
<td>$W_{\text{nom}}$</td>
<td>$W_{\text{cal}}$</td>
</tr>
<tr>
<td>0</td>
<td>0.000</td>
<td>0.000</td>
<td>0.268</td>
</tr>
<tr>
<td>10</td>
<td>9.297</td>
<td>9.005</td>
<td>9.151</td>
</tr>
<tr>
<td>20</td>
<td>19.823</td>
<td>18.962</td>
<td>20.318</td>
</tr>
<tr>
<td>30</td>
<td>31.453</td>
<td>31.861</td>
<td>20.703</td>
</tr>
</tbody>
</table>

To compare the robustness of the results in tables 11 – 14 it would be rational to use dispersion analysis. At first two values of error mean square (dispersions of repeatability) should be calculated (6):

$$S_{\text{rep}}^2 = \sum_{i=1}^{n} \sum_{j=1}^{m} (W_{i,j} - \bar{W}_j)^2 / (n \cdot m - 1).$$

Formula (8) requires mean values of moisture content $\bar{W}_j$ to be calculated. Appropriate values are given in Table 5. For static function (1) and static function (5) respectively:

$$S_{\text{rep}}^2 = \frac{(0.000 - 0.000)^2 + (9.297 - 9.151)^2 + (9.005 - 9.151)^2 + (19.823 - 19.393)^2 + (18.962 - 19.393)^2 + (31.453 - 31.657)^2 + (31.861 - 31.657)^2}{2 \cdot 4 - 1} = 0.071,$$
\[
S_{rep}^2 = \frac{(0.268 - 0.268)^2 + (0.268 - 0.268)^2 + (10.784 - 10.628)^2 + (10.472 - 10.628)^2 + (21.088 - 20.703)^2 + 
(20.318 - 20.703)^2 + (29.708 - 29.828)^2 + (29.948 - 29.828)^2}{2 \cdot 4 - 1} = 0.053.
\]

Then we have to calculate two dispersions of adequacy: 
\[
S_{ad1}^2 = \sum_{j=1}^{m} (\overline{W}_j - \overline{W}_{nominal})^2 / (N - (m + 1)).
\]
\[
S_{ad2}^2 = \frac{(0.000 - 0)^2 + (9.151 - 10)^2 + (19.393 - 20)^2 + (31.453 - 30)^2}{8 - (4 + 1)} = 1.067,
\]
\[
S_{ad2}^2 = \frac{(0.268 - 0)^2 + (10.628 - 10)^2 + (20.703 - 20)^2 + (29.828 - 30)^2}{8 - (4 + 1)} = 0.330.
\]

To compare dispersions of adequacy with dispersions of repeatability we traditionally use F-test:
\[
F = S_{ad1}^2 / S_{rep}^2, \quad F_1 = S_{ad1}^2 / S_{rep1} = 1.067/0.071 = 15.028, \quad F_2 = S_{ad2}^2 / S_{rep2} = 0.330/0.053 = 6.226.
\]

6. Conclusions

At first the workability of a static function, suggested in [7] with different moist substances was checked. Received graphs of static functions for the substances under research happened to be nonlinear, and calculated values of moisture content were significantly different from nominal in all points, except \( W = 0\% \).

To receive linear static function for the capacitive water cut meter method of Least Squares had been used. It was concluded that LS method is not effective. Next step of linearization was in calculating discrepancies between nominal points of moisture content and values, received after LS method application, and their approximation using general linear regression instruments.

Modified static function happened to be far more effective then initial static function, suggested in [2020-1] and static function, received from a first-order polynomial after LS method implementation. Value of absolute moisture measurement extended uncertainty is equal to \( U(W) = 0.301\% \), what is very good for a capacitive water cut meter.

Prototype product of the moisture content instrument measuring transducer had been developed with a purpose to fulfill multiple measurements with capacitive sensors \( C_1, C_2, C_3, C_4 \) and check the robustness of modified static function. Values of moisture content for initial and modified static functions, calculated for mean values of \( C_1, C_2, C_3 \) and \( C_4 \) capacitance, had been compared with a help of dispersion analysis. Modified static function of a water cut meter provides smaller dispersions of repeatability and adequacy and more than two times smaller value of F-test, what proves its' better robust properties.

References

Comparison of Energy Performance of Railway Rolling Stock on the Žilina – Rajec Railway Line

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Abstract

Energy performance is a current topic due to the ecological and financial environment in which it is anchored. The main goal of the article is to compare the energy performance of vehicles operated on the local railway line Žilina - Rajec. As this line is not electrified, only motive power units will be considered as they stand. Due to the potential of the line and its possible electrification, the consumption of the electric multi-system unit will also be compared in the future. This whole comparison will be made using the Open Track program. Such a comparison will also have a significant impact on the selection of the passenger carrier to emerge from the forthcoming competition.

KEY WORDS: energy, passenger transport, Open Track

1. Introduction

Today, transport is one of the components of the national economy. Stage of its development characterizes the level of development of the country. Despite many advantages, individual modes of transport have their disadvantages. One of them is energy performance. Energy intensity is expressed as the share of the total consumption of primary energy sources in a certain territory in the balance of the economy of a certain territory in Gross Domestic Product. Primary sources are the sum of domestic or foreign energy sources expressed in energy units. Energy consumption is growing worldwide, and transport is one of the largest contributors to this development. The intensity of road and air transport is growing the most, and therefore it is necessary to reduce energy dependence on conventional fuels, increase engine efficiency and thus reduce high energy consumption of transport and thus reduce its negative impact on the environment and thus back to the entire human population of today and future generations [1].

The second option is to use more environmentally friendly modes of transport, such as rail transport. This type of transport is intended primarily for the transport of large volumes of passengers and goods. However, such a movement of people and goods is preceded by a constant increase in competitiveness. In this conference paper, we will look at improving the competitiveness of rail passenger transport on the Žilina - Rajec railway line by reducing energy performance. These outputs will be divided into two parts. As the line is non-electrified, the first part will compare the current energy intensity using the current motive power unit and the new proposed motive power unit. In the second part, the electrification of the line by an alternating traction power supply system will be proposed, followed by a suitably selected electrical unit, on which its energy intensity will be demonstrated. As a result, the best current and future variant is selected.

The conference paper topicality lies primarily in the protection of the environment. The trend of this protection has extensive positive consequences, especially for future generations. In addition, there is the possibility of transferring passengers from car and bus transport to trains due to higher comfort and expected higher travel speed after a comprehensive reconstruction of the railway track.

2. Literature Review

Articles containing the issue in different angles can be divided into two groups. The first group presents studies and research focused on the use of the Open Track simulation tool in various areas of railway transport. The second part contains research focused on the energy performance of rail transport and its components.

The versatile usefulness of the Open Track simulation tool is discussed in a conference paper [2], which explores the possibilities of creating a timetable for freight transport which ensures the transport of coal to the local power plant. Carrying capacity is limited due to the number of trains, so with the help of this simulation tool, opportunities for improvement are being sought. When introducing and optimizing railway transport on a selected line, this procedure is considered to be the starting point, i.e., it is the first necessary to focus on the operation and then on the environmental impacts.

In order for the operation to work efficiently, constant investments are also needed in the railway infrastructure. Various components on the railway line, such as bridges, tunnels or pass filters, have a lifespan, and require regular maintenance and replacement. The conference paper [3] deals with the modelling of a bridge with wooden sleepers in a simulation tool on a double track. Here, too, the issue of buildings energy performance is very important.
In the open market for rail passenger transport, the carrier negotiates with the submitter of rail transport. The submitter (either the state represented by the Ministry of Transport or territorial units) assesses the individual offers of carriers and, above all, decides on the basis of the price per train-kilometer. However, there are also other indicators in the assignment for the operation of passenger transport, such as the number of barrier-free vehicles or the number of connections. And here we come to the energy performance of rail transport, which depends primarily on the type of rolling stock used. The bargaining strategy between the carrier and the customer is discussed in an article [4], which seeks to find a universal bargaining strategy.

Vibration is also closely related to the operation of rolling stock. Article [5] compares vibrations in tunnels and on open track. The magnitude of vibrations depends not only on the deployment of a particular vehicle but also on the condition of the track. Vibrations also adversely affect passengers and thus reduce the feeling of comfort and well-being.

Energy intensity is especially relevant for high-speed rail systems. Article [6] deals with the energy optimization system that has been tested on the Italian high-speed electric ETR 1000 unit of the Italian State Railways. Although we do not have high-speed railways in Slovakia, after the modification, according to the authors, this system could also be used for conventional railways.

A separate chapter is electricity substations, for which it is also important to assess energy performance. This is distinguished for different power supply systems and hybrid drives. It is Articles [7] that deals with the energy performance of such substations in an economic and environmental context. Based on multicriteria analysis, it tries to optimize energy intensity. In the article [8], such research focuses on the already developed prototype of a hybrid locomotive on the French Railways.

Energy intensity is calculated not only for specific railway track and lines in passenger transport but is also evaluated in freight transport and logistics. In the article [9], the authors compare the energy performance of ethanol transport in Brazil on four different routes between the inland and the port of Sao Sebastiao. In comparison, it uses road, rail, and air transport.

The case study presented in the conference papers [10] [11] focuses on the comparison of two light rail energy systems in order to determine their advantages and disadvantages, focusing on the braking and starting phase. Subsequently, a more suitable system should be chosen to drive these light trains. This study forms a good springboard not only for further research but also for better decision-making by public transport operators on the construction and operation of such trains with regard to their energy performance.

The new railway vehicles that are being manufactured are now riddled with electrical equipment. Despite high energy efficiency, energy efficiency needs to be constantly monitored. The individual methods are discussed in a part of a professional publication [12].

Energy intensity must also be monitored in the production process. The analysis of the flow of energy values is proposed for this monitoring in a conference paper [13]. This conference paper offers a broad context view of this issue. It is good to further develop this research from an energy point of view, as the production process in industry is closely linked to rail transport, for which it represents demand.

Energy performance is also monitored in metro systems. Specifically, on its braking and anti-slip systems. There is proposed a new anti-slip system of an automatically guided metro in the conference paper [14], which also monitors the energy side of this new system by means of an energetic macroscopic representation.

The last major area is testing new vehicles before putting them into service. Various safety and operational components are assessed here, including the energy performance in the individual phases of the test. Such research is also discussed in a conference paper [15].

3. Operating Characteristics of the Žilina – Rajec Railway Line

The Žilina - Rajec railway line has been put into operation on October 10, 1899. It is 20.9 kilometres long [16]. The characteristics of the line with basic data are given in Table 1.

<table>
<thead>
<tr>
<th>Basic operating data on the railway line [16] [17]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic information and track parameters</strong></td>
</tr>
<tr>
<td>Infrastructure manager</td>
</tr>
<tr>
<td>Track gauge</td>
</tr>
<tr>
<td>Number of main tracks</td>
</tr>
<tr>
<td>Railway line class</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Power supply system</td>
</tr>
<tr>
<td>Maximum grade</td>
</tr>
<tr>
<td>Maximum track speed</td>
</tr>
</tbody>
</table>

The railway line consists of four railway stations (Žilina, Bytčica, Lietavská Lúčka and Rajec) and eight railway stops (Žilina-Záriečie, Žilina-Solinky, Porúbka, Poluvsie, Rajec-Teplice, Konská pri Rajci, Zbyňka and Kľačač) [16]. The location of stations and stops is relatively close to each other. A passenger train that stops at each station and stop...
must therefore brake relatively often. At the entrance to each operating control point, the train must reduce the speed to 40 km*h⁻¹.


The level of energy performance is also affected by the occupancy of the vehicle and the related weight of the vehicle. The total occupancy of the unit on the Slovak railways is calculated according to Eq. 1.

\[ Total\ passenger\ weight = weight\ coefficient \times number\ of\ passengers. \]  

(1)

A weight coefficient of 0.8 is used on the Slovak railways network. As a result, we will model with a total passenger weight of 6 tons, which is an average of about 60% occupancy of the unit. Actual numbers vary depending on the phases of the day (traffic peak and traffic spring) and type of day (working day and weekend day). Based on the total average passenger occupancy of the unit, the total mass of the unit can be calculated according to Eq. 2.

\[ Total\ weight\ of\ the\ unit = weight\ of\ empty\ unit + weight\ of\ all\ passengers. \]  

(2)

Each unit being compared will have a different total weight and length. The parameters of the individual units are given in Table 2.

It is clear from the table that the longest and the heaviest is the electric unit of the 661 series. On the contrary, the lightest is the motive power unit of the 813/913 series. The passenger train 3506 in the direction Žilina - Rajec and the passenger train 3507 in the direction Rajec – Žilina were chosen for the calculations. Both trains cross at Lietavská Lúčka railway station.

4.1. Energy Performance of the Motive Power Unit 813/913 – Current Status

The engine unit 813/913 was manufactured by reconstruction from a driving car series 810 and a trail car series 011. Reconstruction took place in the years 2006 - 2010 in ŽOS Zvolen. A total of 44 pieces were produced [18].

Table 3 shows the course of energy consumption when driving in both directions. Energy consumption is expressed in kWh.

It is possible to see a marked difference in the energy intensity of the used vehicle in the even and odd direction in the table. The difference in the final stations is 65.723 kWh. Therefore it is clear that the railway line goes to the ascent in the direction of Rajec and descends in the direction of Žilina.
4.2. Energy Performance of the Motive Power Unit 840 – First Proposal

The 840 motive power unit was the first new engine unit purchased by the ZSSK carrier. It was produced by a consortium of Stadler, Bombardier and ŽOS Vrútky. This consortium produced a total of 6 pieces for the carrier in the year 2003. Its great advantage is fully barrier-free access [18].

Table 4 shows the course of energy consumption when driving in both directions. Energy consumption is expressed in kWh.

<table>
<thead>
<tr>
<th>Direction Žilina – Rajec</th>
<th>Values</th>
<th>Direction Rajec – Žilina</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Žilina</td>
<td>0.00</td>
<td>Rajec</td>
<td>0.00</td>
</tr>
<tr>
<td>Žilina-Zaričie</td>
<td>19.76</td>
<td>Kľačie</td>
<td>12.20</td>
</tr>
<tr>
<td>Žilina-Solinky</td>
<td>39.36</td>
<td>Zbyňov</td>
<td>18.44</td>
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<tr>
<td>Bytčica</td>
<td>53.98</td>
<td>Konská pri Rajci</td>
<td>27.83</td>
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<tr>
<td>Lietavská Lúčka</td>
<td>70.08</td>
<td>Rajec Teplice</td>
<td>30.79</td>
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<tr>
<td>Porúbka</td>
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<td>Poluvsie</td>
<td>38.89</td>
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<tr>
<td>Poluvsie</td>
<td>128.23</td>
<td>Porúbka</td>
<td>54.90</td>
</tr>
<tr>
<td>Rajec Teplice</td>
<td>149.51</td>
<td>Bytčica</td>
<td>75.72</td>
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<tr>
<td>Zbyňov</td>
<td>172.81</td>
<td>Žilina-Solinky</td>
<td>84.09</td>
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<tr>
<td>Kľačie</td>
<td>189.41</td>
<td>Žilina-Zaričie</td>
<td>92.55</td>
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<tr>
<td>Rajec</td>
<td>208.08</td>
<td>Žilina</td>
<td>103.91</td>
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Due to the greater weight and occupancy of the unit, the measured values are higher. In the arrival station Rajec from Žilina compared to the current state by 77.15 kWh. In the arrival station Žilina from Rajec compared to the current state by 38.71 kWh.

4.3. Energy Performance of the Motive Power Unit 861 – Second Proposal

The engine unit of the 861 series for the carrier ZSSK is a three-cell unit, the manufacturer of which is the company ŽOS Vrútky in the years 2011 - 2020. A total of 53 pieces were produced in nine years. The unit is wheelchair accessible and air conditioned. In the last two years, it has also been produced in a two-section version as the 861.1 series [18]. However, the simulation in the Open Track program counts on an original three-cell unit.

Table 5 shows the course of energy consumption of unit 861 when driving in both directions. Energy consumption is expressed in kWh.

<table>
<thead>
<tr>
<th>Direction Žilina – Rajec</th>
<th>Values</th>
<th>Direction Rajec – Žilina</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Žilina</td>
<td>0.00</td>
<td>Rajec</td>
<td>0.00</td>
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<td>Žilina-Zaričie</td>
<td>38.28</td>
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<td>Zbyňov</td>
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<td>Konská pri Rajci</td>
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<tr>
<td>Lietavská Lúčka</td>
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<td>60.15</td>
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<tr>
<td>Porúbka</td>
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<td>Poluvsie</td>
<td>76.48</td>
</tr>
<tr>
<td>Poluvsie</td>
<td>247.90</td>
<td>Porúbka</td>
<td>106.63</td>
</tr>
<tr>
<td>Rajec Teplice</td>
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<td>Konská pri Rajci</td>
<td>306.91</td>
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<tr>
<td>Zbyňov</td>
<td>336.08</td>
<td>Žilina-Solinky</td>
<td>161.99</td>
</tr>
<tr>
<td>Kľačie</td>
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<td>Žilina-Zaričie</td>
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<tr>
<td>Rajec</td>
<td>404.89</td>
<td>Žilina</td>
<td>200.73</td>
</tr>
</tbody>
</table>

The use of this type of motive power unit already has a much higher energy consumption. Compared to the currently used motive power unit, the consumption values are higher by 273.96 kWh in the Žilina - Rajec direction. In the opposite direction, the values are higher by 135.53 kWh. It is assumed that when using a two-cell motive power unit, the energy consumption values would be lower. However, there could be a problem with seating capacity during traffic peak.

4.4. Energy Performance after Starting Electrical Operation on the Track – Third Proposal

The latest proposal deals with the possible electrification of the railway line. In the variant, electrification to the
25kV / 50Hz system is calculated, i.e. an alternating current. The proposal also envisages the use of the 661 series electric motor train set. It is a three-cell multisystem electric motor train set, which was manufactured for the carrier ZSSK from 2019 to 2020 by Škoda Transportation. ZSSK purchased a total of 25 pieces of this electric motor train sets [18]. ZSSK also ordered a four-cell version of this electric motor train set, but due to the transport demands on the line, the capacity for passengers would be significantly oversized. Table 6 shows the course of energy consumption when driving in both directions. Energy consumption is expressed in kWh.

Table 6

<table>
<thead>
<tr>
<th>Direction Žilina – Rajec</th>
<th>Values</th>
<th>Direction Rajec – Žilina</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Žilina</td>
<td>0.00</td>
<td>Rajec</td>
<td>0.00</td>
</tr>
<tr>
<td>Žilina-Zariečie</td>
<td>41.97</td>
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<td>Žilina-Solinky</td>
<td>84.04</td>
<td>Zbyňov</td>
<td>42.89</td>
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<tr>
<td>Byčica</td>
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<td>Konská pri Rajci</td>
<td>65.67</td>
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<tr>
<td>Lietavská Lúčka</td>
<td>152.14</td>
<td>RajecTeplice</td>
<td>71.12</td>
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<tr>
<td>Porúbka</td>
<td>210.88</td>
<td>Poluvsie</td>
<td>89.73</td>
</tr>
<tr>
<td>Poluvsie</td>
<td>272.27</td>
<td>Porúbka</td>
<td>124.22</td>
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<tr>
<td>RajecTeplice</td>
<td>318.71</td>
<td>Lietavská Lúčka</td>
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<tr>
<td>Kľače</td>
<td>406.27</td>
<td>Žilina-Zariečie</td>
<td>202.20</td>
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<tr>
<td>Rajec</td>
<td>447.02</td>
<td>Žilina</td>
<td>225.68</td>
</tr>
</tbody>
</table>

It would be unnecessary to compare the energy performance between motive power units and electric motor train sets, given the different power transmissions. The benefit of an electric motor train set is its positive attitude towards the environment. It does not release harmful exhalates into the air, which adversely affect the environment. In addition, it has various accessories, such as electrical sockets, space for strollers, air conditioning, or an audio-visual system for messaging stations and stops for passengers.

Fig. 1 shows all four mentioned vehicles (units 813/913, 840, 861 and 661).

![Fig. 1 Slovak train units – from the left gradually 813/913, 840, 861 and 661 [18]](image)

![Fig. 2 Energetic performance on the railway line](image)

The final summary graph is shown in Fig. 2.

5. Conclusions

The aim of this paper was to compare the energy performance of individual railway rolling stock for passenger
transport on the Žilina – Rajec railway line. Energy performance is one of the basic indicators for evaluating the forthcoming competition for passenger transport on this railway track.

Among the motive power units, the 813/913 series, which currently runs there, has the lowest demands. On the contrary, the highest demands after the measurement were proved by the motive power unit of the 861 series. As part of the possible electrification of the track, the authors also made an experimental run of the electric unit of the 661 series.

However, this contribution represents only a fraction of the Ministry of Transport's claims on the carrier. In the conditions of the Slovak Republic, to successfully declare and select a tenderer, it is first necessary to re-evaluate other parameters and set up public tenders.

Acknowledgment

"This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund".

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18. Wikipedia contributors. Železničná spoľočnosť Slovensko [online cit: 2021-5-11]. Available from: https://sk.wikipedia.org/wiki%C5%BDelezni%C4%8Dn%C3%A1_spolo%C4%8Dnos%C5%A5_Slovensko#Vozidlov%C3%BD_park
Impact of the Pandemic Disease on the Railway Central Traffic Control Centers

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Abstract

Railway transport is an integral part of the transport system in Europe, and also in the Czech Republic it is a part of the national critical infrastructure. For the railway operation are necessary both inanimate parts like railway lines and personnel such as dispatchers. The train dispatcher, a human being as a part of the system which controls the movements of the trains is very sensitive to diseases, especially during pandemics. The paper briefly describes the current situation in the railway transport control of the Czech Republic, shortly deals with historical development which lead to the current situation and finally presents plans for the future. The paper shows weak points of operation control by the Central Traffic Control Centers and points out possible alternatives to eliminate these weaknesses and to prevent the impact of any severe diseases on the train operation.

KEY WORDS: Pandemic disease, Coronavirus, Central Traffic Control Center, Railway, Dispatchers

1. Introduction

The rail transport is one of the backbone transport means in the Czech Republic, which is being constantly improved not only at the level of reconstruction of existing railways and the construction of the new ones, but also at the level of securing safety of the movements of the trains. A relatively modern trend is a remote railway traffic management. The remote traffic control means that the train dispatchers are not physically present at all stations alongside the lines, but one train dispatcher controls remotely equipment at several train stations from one location. After introducing this mode of traffic management, the traffic on many railways was streamlined, consequently the cost of regional lines decreased changing their overall profitability and it was not necessary to terminate operation on these railways. The train dispatcher is responsible for managing track use, insuring that trains are routed safely and efficiently, and insuring the safety of personnel working on and around railroad track [1].

The latest trend of remote railway traffic control is to allocate the train dispatchers from several control stations to one central dispatching location. The dispatchers then control the train traffic on several long-distance routes from one building. This article builds on the dissertation papers of one of the authors and discusses the possible effects of unification of traffic management in one place or directly into one control room, especially from the point of view of hygiene, with an emphasis on current world development and the spread of diseases from one person to another [1-3].

2. Methods

In the context of the article, an analysis of the scheduling of the employees of the central dispatching office was carried out, as well as processes of the employees’ rotation at their workplace. Furthermore, the processes of traffic management on the railways and the functions of the security and protection devices were analyzed. The method of measurement and exploratory observation on the spot, i.e. the central dispatching station, was performed in order to analyze the work of dispatchers in a single work shift and monitoring of the work load of these dispatchers. During the measurement, the authors monitored the activities of the dispatchers and measured the duration of the execution of individual operations related to traffic management.

The results of this measurement accurately reflected the real work flow of dispatchers in one shift including activities that are not directly related to the traffic management, e.g. breaks, satisfying essential bodily needs and the like that cause deviations in work operations. The goal of this observation was to record these deviations and their causes, since other dispatchers behave similarly at random and therefore these records were desirable for acquisition of the net operating times unencumbered by these deviations. This was possible by observation only, since although other time measurement methods are able to record duration of activities more accurately, it is not possible to exclude deviation caused by the exclusive use of that method. To increase the objectivity of the output some other measurement methods were used by the security equipment. The outputs from the electronic remote control systems were also used where the system records, for example, the exact times of the assignment of commands for the position of the train routes by the dispatchers. This information source has greater accuracy of the measurements compared to field measurements. However, it is impossible to determine what deviations arise from dispatcher’s activities not related to traffic management. For this reason, the measurement outputs of both methods were compared, combined, and evaluated. This activity
provided the authors with the basis for the work of dispatchers, which is used to determine the possibilities of replacing the dispatchers of the central dispatching station with other possible methods of control, for example, alternative dispatching station [2, 4, 5].

2.1. Central Dispatching Department

The Central Dispatching Department (CDD) is a location from which traffic on specific railways is controlled. In the case of the Czech Republic, the operation is mainly controlled on the backbone railways, which are heavily used by both passenger and freight transport. More than half of all rail transport is carried out via railways controlled from two Central Dispatching Departments. The range of railroads controlled from the CDD is visible on the map of the railway network, which is in Fig. 1 [1, 6, 7].

![Fig. 1 Map of Railway network with remotely controlled routes](image)

The railways with traffic controlled from CDD in Prague are colored green on the map, they are blue if controlled from CDD in Přerov. The red railways are being remotely controlled from the selected stations in the relevant region. The traffic management that works in one location or in one building reduces the cost to train the employees and in the event of a telephone failure it allows for communication of individual dispatchers face to face. The disadvantage of this system is high cost of technologies to manage traffic from one place and thus the whole network is exceptionally vulnerable to external attack (war, terrorism) [1, 2, 7].

Last but not least, it is a disadvantage to have all traffic management in one place in the case of a possible epidemic or pandemic disease. In a case of having only one contagious person in the CDD leads to quarantine the entire shift of employees and the function of the alternative shift is going to be also significantly impaired. Together this creates a serious limitation of the operations. The deficiency of human resources, such as dispatchers will, consequently, create hindering limitation to the operations of the railway traffic which could cause a serious problem. This article proposes solutions that would minimize the risk of transmission of the spread of a disease between individual dispatchers in one shift [1, 2].

2.2 Distribution of Shifts and the Impact of the Disease

In the case of railway operator in the Czech Republic, the shifts schedules and rotation is based on the applicable legislation (Labour Code), which determines the duration of the shortest breaks between the shifts for individual dispatchers and the duration of the longest possible shift. In addition, these restrictions are regulated by the railway operator's applicable regulations. The 12 hours shifts are scheduled for the control dispatchers. The duration of the shift, however, must not exceed 13.5 hours. The maximum working hours per week cannot exceed 60 hours. Only with the consent of an employee can be his/her break shortened. Figure 2 shows the distribution of shifts of the employees, where each employee belongs to one workgroup under the condition that none of the employees is incapacitated or is on a leave of absence. The symbol "\(^{\text{\textdagger}}\)" stands for the day shift (usually 6:00 to 18:00) and "\((\)\" stands for the night shift (18:00 to
6:00 the following day [1, 2].

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Fig. 2 Distribution of employee shifts during normal operations

Fig. 2 shows that 4 shifts are needed to cover the rotating roster. The fifth shift can be used to bridge the gap between the shifts if necessary. However, for sufficient stability, it is advisable to include the fifth shift into a regular rotation. This roster is based directly on standards of the infrastructure manager in the Czech Republic [1, 2].

The option is not to create permanent groups of employees for one shift but to schedule each employee for a different shift. However, this solution is usually not applied because individual employees form a team and their activities in the dispatching center are mutually played. If you don't create permanent groups, the fact is that the performance of the team will not be as high as when one group will form a permanent team [1, 2].

Last but not least, it should be noted that with the regular interchange of employees from one team to another, there is a risk that the carrier of the disease will be a member of several groups, thus increasing the likelihood of interruption of operations due to the necessary quarantine of the employees working with the infected individual. To lower the risk of contagion among employees it is advisable to create a permanent staffing in each shift [1, 2].

At the time of composing this article, a COVID-19 pandemic is spreading in Europe. This fact may greatly influence the possible distribution of the shifts. In the event of an outbreak between dispatchers, the entire shift is automatically quarantined for 14 days. In this case, it would still be theoretically possible to ensure the operation of the rail transport in a particular region (if the composition of the employees in each shift was permanent and all the employees in the shift alternated in the same time exactly to a minute). However, if the employee’s rotation would not be permanent within each shift, it would be necessary to isolate all the employees working with the infected individual. In such a case, the rail traffic could be reduced or stopped completely in a region controlled from the affected dispatching point [1, 8].

2.3. Option to Prevent Disease Transmission

There are many ways to prevent the transmission of the disease between dispatchers. This article presents the authors' proposal and the measures taken against the spread of the disease in the Czech Republic. The first important rule to prevent the transmission of the disease is an increased emphasis on hygiene such as frequent hands washing, or using hand sanitizer, and using cloth face cover. This proposal complies with regulation issued by the Government of the Czech Republic. This is a way to limit the spread of the viruses. The disadvantage of this regulation is that employees have certain breathing discomfort and are not protected from the transmission of the disease by touching [1, 8].

The second effective course of action would be to divide certain activities of the central dispatching station in crisis situations. According to the authors, much more meaningful solution would be to divide the work of the control dispatchers. There is currently a system of locally situated dispatchers that serves as a support at train junctions. Regional traffic controllers are employees who, at heavy traffic railways, provide local support work at the selected stations (e.g. shunting, track maintenance work, etc.) but in the event of a failure of the central dispatching station, they are not able to fully take over its entire activity [1, 2].

This article proposes to transfer part of the scope of work of the dispatchers from the central dispatching department to the regional traffic controllers. The railways in red (Figure 1) are controlled by a dispatcher located at a regional dispatching station (stations alongside the relevant railway). The regional traffic controllers, who under normal circumstances manage traffic at the chosen railway would, if necessary, also manage traffic at the multiple railways of the backbone network. Regional traffic controllers at local stations would be primarily solving the issues connected to the local traffic (shunting, railway maintenance work) and the dispatcher would take over the activities of the central dispatcher. The scope of the controlled network and the conditions of operation would include the crisis preparedness plan. The crisis preparedness plan for the central dispatching station already exists. In this document it can be found how the CDD traffic will be managed in the event of crisis [1, 2].

As mentioned previously in the article, the crisis preparedness procedure should also include a situation where there is not a sufficient number of staff available. The authors of the article propose to address the lack of actively-working employees by handing over responsibility for controlled sections to the regional traffic controllers. This act may cause employees at regional dispatching sites to be overloaded and not to be able to effectively manage traffic on the railways that are under normal circumstances assigned to them. The solution to this problem should include a list of prioritized railways that have utmost importance for the rail traffic. These railways will be divided based on the importance with the highest priority assigned to the railways which are part of the state critical infrastructure, the so-called state designated railway network [1, 8].

If the dispatcher at the Regional Dispatching Office is not able to control the traffic in the areas newly assigned to him/her, the crisis preparedness plan determines which railways can possibly temporarily suspend operations. There is no doubt that the suspension of operations must be carried out in such a way as to ensure that the state's economy is the least
affected and that the trains currently moving can reach the nearest suitable transport hub, possibly with reduced quality of transport, but never with reduced level of safety. A sufficient level of safety is usually ensured by the very core of the security equipment. [1, 8].

3. Discussion

The rules for handing over some of the control from the CDD to the regional control areas will happen on both technical as well as personnel level. As to the regards of the technical rules, dispatcher’s workplaces in the Czech Republic operate according to the standards for the single control place of the Czech Infrastructure Manager (SŽCZ JOP). There are several remote control systems from different manufacturers, however all these systems and their parts must provide such a level of safety that would exclude human error and all logical operations would be solved based on the logical core of the electronic railway switch. Similarly, the security equipment of all manufacturers must be compatible with traffic control and information from this security device transferable to the CDD to the workplace of the regional traffic controllers (emergency dispatcher’s workplace) and vice versa. For this reason, it can be argued that technically, the transfer of part of the scope of work and powers can be transferred from central dispatching centers to the regional dispatching stations [9].

Personnel rules are, in this case, far more complex than technical side of the transfer. First, it is necessary to address the issue of a sufficient number of employees, which are needed to manage the operation in required quality. If the traffic controllers of the Central Dispatching Department are not able to control the operation on assigned railways, it is desirable that they transfer their powers to the regional control stations. The downside, however, is that even regional dispatching offices do not have enough actively serving employees. In this case, it is desirable to draw on the crisis preparedness plan, which will focus on the importance of the railways and train traffic operations. Next, it is necessary to mention the need to train dispatchers of regional dispatching stations for the eventual takeover of railway control on the main railway lines. The best way to prepare dispatchers for the takeover of traffic on the main lines is to train regularly to control traffic in the given sections. According to the authors, the best training is the actual management of traffic within the central dispatching station. This training can also be a whole shift in the control office at the central dispatching station. The methods of training of the employees should be laid down in the crisis preparedness plan described in the previous chapter.

4. Conclusion

The reason for choosing this topic was the need to address the issue of crisis management in railway industry in the Czech Republic. Unfortunately, the prevention is often underestimated until the crisis, consequently the relevant entities are not ready to address such an event. One of the authors has been drawing attention to this issue for a long time now in his dissertation work, but it was not until the first half of 2020 that the timeliness and the need to solve this problem proved to be up-to-date.

This article shows the need to address the issue of railway traffic management and proposes solutions. In the first half of 2020, the COVID-19 disease pandemic made it clear that the issue of the central dispatching department blackout is a topical issue even in countries with a low probability of terrorist attacks or a state of war.

According to the authors, one possible viable scheme could be as follows: there is a subsystem of regional dispatching offices, where employees are capable to manage and to control train traffic in the regions that are under normal conditions controlled from the Central Dispatching Department. However, it is necessary that the employees at regional dispatching offices have a firm grasp of the local conditions at the stations that will be handed over to them (e.g. electrified tracks, loading ramp location, etc.). Another rule should be followed, the so-called rotation of the work, i.e., the employees who can take control over a given territory, must be trained to manage the area (e.g. shifts at the central dispatching department). To implement this proposal is not organizationally easy, however by taking into account the cost of crisis preparedness and the level of security, and the possible consequences of failure, it is the optimal option for managing railway transport.

It should be noted that at the time of the submission of this article there had not been such a situation in the Czech Republic that the train operations had to be suspended due to illness of the employee working at the dispatcher’s office or due to the subsequent quarantine of the colleagues working with him/her in a team. The research was funded by the University of Pardubice, Faculty of Transport Engineering through the SGS project.

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HYPERNEX: Ignition of the European Hyperloop Ecosystem Project Within Horizon 2020

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Abstract

The article describes the most important issues related to the newest means of transport, which is to be the hyperloop technology. There are presented basic information about this disruptive technology, including the construction of capsules and pipe infrastructure. The article also addresses the concept of HYPERNEX project, which is undertaken within Shift2Rail Joint Undertaking of Horizon 2020. The HYPERNEX project aims to collect the most important information about hyperloop technology from R&D entities as well as industry players and to provide the appropriate basis to make this new transport mode sustainable and permanent in the coming years.

KEY WORDS: Hyperloop, vacuum railway, European transport network, disruptive innovation, Shift2Rail

1. Introduction

The transport of both passengers and freight has now become one of the strategic elements of the economy, which situation leads to other mobility problems, such as infrastructure congestion and pollution. These negative factors have led to the need to find a more efficient, cheaper and also more environmentally friendly transport system [1]. In addition, new solutions and transport models need to enable fast movement while respecting sustainability requirements. The hyperloop technology can be a complement to the existing medium-distance transport system. From the technical point of view, vacuum rail is based on the movement of a capsule (passenger/freight) in a depressurized environment (1% of atmospheric pressure) with the use of magnetic levitation. The significant reduction in air and rolling resistance makes it possible to reach a maximum speed of 1,200 km/h, i.e. the speed of light. This technology combines the advantages of rail (close proximity to city centers, short check-in times) and air (high speed) transport. Despite initial concepts and solutions, Hyperloop technology as a means of transport has all the potential to become an important part of the transport system [2].

2. Shift2Rail Joint Undertaking

The Hypernex project addresses the topic of Shift2Rail Joint Undertaking about innovation in guided transport. Shift2Rail JU (S2R JU) is formally established Public-Private Partnership supporting the research and innovation activities to enhance the level of rail services in Europe. The Shift2Rail was established in 2014 and operates within the eight Framework Programme for Research and Innovation 2014-2020 called Horizon 2020 [3, 4]. Shift2Rail JU enables to manage research and innovation activities in relation to passenger trains, freight transport, traffic management systems and railway infrastructure. It aims to deliver modern and innovative rail to drive the digital and green transition, while supporting the improvement of rail services in Europe [5]. S2R JU develops a more competitive and resource-efficient European transport system, through an unprecedented integrated rail system transformation to meet the evolving expectations of European citizens and shippers. The mission statement of S2R JU is: "Shift2Rail: moving European railway forward" [6].

The founding members of Shift2Rail JU are European Commission and nine key industry players who have committed to long term financial contribution to the Initiative: Alstom Transport from France, Ansaldo STS from Italy, Bombardier Transportation from Germany, CAF from Spain, Siemens from Germany, Thales from France, Network Rail from Great Britain and Trafikverket from Sweden. Furthermore, the members are also those entities that obtained the status of the Associate Member through an open, two-stage call launched in October, 2014. The status of Associated Member was given to consortiums of several companies: AERTITEC (Spain), EUROC (9 countries), SwiTracken (4 countries), SmartRaCon (4 countries), virtual Vehicle Austria (Austria), as well as to a single entities: Amadeus IT Group (Spain), AZD Praha s.r.o. (Czech Republic), CFW (Germany), DIGINEXT (France), FT (France), HaCon (Germany), Indra (Spain), Kontron (Austria), Knorr-Bremse (Germany), Mer Mec (Italy), Talgo (Spain) and SNCF (France) [7, 8].

The total budget of the Shift2Rail JU amounts to EUR 920 million [4]. This partnership is based on long-term commitment of their members. The European Union involvement in this Initiative amounts to EUR 450 million and it comes from the Horizon 2020 Framework Programme. The rest of the financial contribution is given by the Founding Members – EUR 270 million and the Associated Members – EUR 200 million. S2R JU is funded by the members contributing either in cash or in-kind to the administrative and operational costs of the joint undertaking. In particular,
the Members other than the Union deliver Research and Innovation activities to the S2R JU investing their own financial resources in the forms of staff, assets, technologies etc., that pave the way to major changes in the rail systems, which are matched by around up to 40% net by the Union funding [6].

The direct participation in the Initiative have only those entities which have declared the significant financial contribution towards implementation of the long-term objectives. Within S2R JU there is a formula of open calls dedicated to all entities except direct members. That yields to 412 participants of S2R JU from 29 countries, including 109 small and medium enterprises (SMEs) and 113 research centers and universities up to 2019 (Fig. 1).

Guided by its Strategic Master Plan [5], the Research & Innovation activities of Shift2Rail JU are structured around 5 key Innovation Programmes (IPs) and Cross-Cutting Activities (CCA) and Innovations in Guided Transport (IPX) encompassing the relevant railway technical and functional subsystems and actors, as well as interactions between them (Fig. 2).

- P1 Passenger trains
- IP2 Traffic management
- IP3 Optimised infrastructure
- IP4 Digital services
- IP5 Rail freight
- CCA Cross-cutting activities: long-term needs and socio-economic research, intelligent materials and processes, system integration, security and interoperability, human capital, energy and sustainable development
- IPX Disruptive innovation

The issues dedicated to exploring non-traditional and emerging track-bound transport systems are addressed in IPX. IPX work focuses on technologies that are disrupting the existing market or even creating new markets, and also looks at technologies that are not yet available, or have not been yet used in the railway sector. This work will create the opportunity to recognise that innovation is vital and economically relevant for the evolution of land transport and mobility concretely via engaging and responsibly generating new ideas, preserving technological neutrality with a due diligent and consistent programme approach.

The S2R R&I programme focuses on demonstration activities and dissemination of relevant results for market uptake, promoting the competitiveness of the European rail industry while creating a multiplier effect of EU funds.

3. Hyperloop Concept

Hyperloop technology, also known as vacuum rail, is a new mode of transport using special passenger and
freight capsules moving through a tunnel in which the pressure is reduced to about 100 Pa, or just 1% of atmospheric pressure. By using a solution like this, it is possible to significantly reduce air resistance [2, 9].

The capsule will be constructed with lightweight materials, which will enable it to maintain a low weight of around 300 kg. The latest design features include the expansion of the passenger space to a capacity of up to 50 persons, which will significantly increase the passenger capacity. During the journey, passengers will travel in a sitting or semi-recumbent position. An example of the capsule design is shown in Fig. 3.

The tunnels construction will be made of steel pipes with diameters ranging from 3 m to 5 m, depending on the destination of the transports. The joints between the pipes will act as expansion joints, which will guarantee the tightness of the system even in case the phenomenon of thermal expansion of the steel construction occurs [10].

The tunnel construction elements will be placed on concrete supports, fixed by means of hoops which will ensure that the entire structure is properly anchored, while at the same time allowing expansion and contraction of the steel elements. This solution will allow longitudinal slippage of the structure (due to temperature changes), while limiting movement in directions perpendicular to the tunnel axis. The average distance between concrete supports will be of about 30 m and their height up to 6 m, depending on terrain conditions [10, 11]. An example of the tunnel constructions is shown in Fig. 4.

The basic layout of the vacuum rail system will consist of two steel tunnels placed paralelly. In case more capacity is required, it is envisaged that more tubes (four) may be constructed. Entrances and exits to passenger stations, unloading areas and service yards will be operated via a system of sluices to maintain depressurised environments throughout the vacuum rail system. The reduced pressure will be provided by vacuum pumps located throughout the route length [2, 12].

The specificity of the hyperloop system lies in the magnetic way of moving the capsules. Both the propulsion and the lift of the vehicle are achieved by magnetic interactions. The levitation used in the hyperloop system is passive. This means that the lifting force is generated only when the vehicle is moving at a minimum speed of about 14 m/s. At that very moment the capsule, analogically to the aeroplane, pulls away from the surface on which it moves with the help of wheels at low speeds.

During the movement on wheels and in the state of non-contact with the ground, the propelling and braking power is obtained by the capsule through an electromagnetic linear motor.

Thanks to the applied solutions and limiting the air resistance, it will be possible to accelerate the capsule to speeds of about 1200 km/h [13, 14]. The most recent assumptions, for ecological reasons, among others, assume limiting the speed to about 500-600 km/h. According to assumptions [10, 15], capsules are to run even every 30-60 seconds. Taking into account not only the possible time of the sequence, but also the time of passenger check-in (getting
on/off), it seems that the real time of the sequence will be of about 4-5 minutes [11].

According to [16], the entire vacuum rail technology on the section between San Francisco and Los Angeles is to be based on electricity coming from solar panels located along the entire tubular artery. It is assumed that the entire hyperloop system will consume an average of 21MW, providing an average annual power at the level of 57MW [16].

4. The HYPERNEX Project

The Hypernex project addresses the topic of Horizon 2020 Shift2Rail Call for proposals for the Joint Undertaking open calls S2R-OC-IPX-01-2020: Innovation in guided transport. The HYPERNEX project is related to IPX – disruptive technologies.

The project started on 1st December 2020 and will run for one year under the coordination of Universidad Politecnica de Madrid (UPM) from Spain. The consortium consists of thirteen participants (Table 1) among them the IK Railway Research Institute from Poland. The total budget of the project yields to EURO 250 000.

<table>
<thead>
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<th>No.</th>
<th>Participant organisation name</th>
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<td>1</td>
<td>Universidad Politécnica de Madrid (UPM)</td>
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<td>5</td>
<td>IFS-RWTH Aachen University (RWTH)</td>
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<td>6</td>
<td>Instytut Kolejnictwa (IKOLEJ)</td>
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<td>9</td>
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<td>10</td>
<td>TU Berlin (Hermann-Föttinger Institut (TUB))</td>
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<td>11</td>
<td>Union Internationale des Chemins de Fer (UIIC)</td>
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<tr>
<td>12</td>
<td>Sapienza Università di Roma DICEA (DICEA)</td>
<td>UNI</td>
<td>IT</td>
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<tr>
<td>13</td>
<td>Zeleros Global, S.L. (ZEL)</td>
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To ensure the success of the project, HYPERNEX must cover a wide range of research and a critical mass of technical expertise in Hyperloop such as magnetism, electric propulsion, aerodynamics, electronics, sensors, industrial integration, transport economics and design among others to enable innovation across multiple application sectors. Therefore, the consortium consists of thirteen entities: both enterprises and research centers, whose expertise is not limited to technology products but also encompasses innovation and business development. A key factor of success in HYPERNEX is to have a broad geographic coverage in Europe both at the partners and their networks level (Table 1 and Table 2).

<table>
<thead>
<tr>
<th>Project Supporters</th>
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<td>Actisa</td>
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¹ former Hyper Poland
HYPERNEX consortium is organised to devote its complementary expertise to coordinate and execute a set of actions (hyperloop technology land value chain mapping, market and stakeholder analysis, etc.) with the objective to produce an asset in a report. This report will serve as the backbone for a set of complementary actions that will maximize the impact of the work. The analysis and conclusions reached will be accompanied by the definition of a set of guidelines supporting its end-users on “how to interpret it”, based on each stakeholder type (industry, academia, regulatory body, etc.). The relation model and concept methodology are depicted in Fig. 5.

Fig. 5 Hypernex framework description

5. Role of IK in the Project

The aim of the Hypernex project is to start the common examination and cooperation between the research-development institutions, scientific centers as well businessmen, aiming to enable a sustainable development of new technologies. Within the project a report will be created, which will take into account and analyze the most important aspects that may have an impact on the development of the hyperloop technology. The Railway Institute will act as leader of the task entitled „Transferability and roadmap beyond HYPERNEX” (WP 4), in which also the following entities will take part:

- SINTEF;
- UPM;
- ZELEROS;
- TransPod France;
- HARDT BV;
- Nevomo (former Hyper Poland);
- RWTH AACHEN.

Acting as the work package leader, the Railway Institute will be responsible for both substantial and administrative supervision of the task. Additionally, the Railway Institute will take responsibility for development of content input for the point 3, i.e. Standardization and regulation.

WP4 will cover 3 separate tasks:

- **T4.1- Transferability under S2R roadmap**
  
  The aim of this task is to identify synergies that occur between the research and areas where investigation activities can be beneficial for both parties and enhancing them.

- **T4.2-Transferability and cross fertilization to non-guided modes**
  
  This task will concentrate on description of synergies with other areas and programs, including Climate, FCH, non-guided modes of transportation, etc., as well as reciprocal exchange of knowledge between different transport modes.

- **T4.3- Standardization and regulation**
  
  The applicability of current regulatory practices in Europe to Hyperloop certification scheme including roles for AsBo and NoBo will be covered within this task. Moreover possibilities of use of current technical railway standards for the hyperloop technology components will be analysed.

The Hypernex projects will make it possible to significantly accelerate the development of the hyperloop system in Europe and to strengthen the position of European entities implementing the vacuum rail system. The exchange of experience and knowledge will enable the creation of a complementary and compatible means of transport in Europe.
6. Conclusions

Transport is a rapidly developing and changing sector with many radical and constant developments in both its technological and business aspects. The increasing global demand for the fastest and cheapest mode of transportation, less expensive and easier-to-build infrastructure, transportation type with less land area requirement, and technology that is not vulnerable to earthquakes and other natural calamities are some of the significant drivers for the growth of the hyperloop technology market.

HYPERNEX project will bring a new common ground of understanding related to hyperloop in Europe. The complementarity of diverse profiles such as universities, R&D centres, Hyperloop developers, and industry players will grant the output of the project a great value for the acceleration of the hyperloop ecosystem. The aim is that the combination of deliverables and dissemination activities (including workshops) brought by HYPERNEX partners will set a starting point for the industry. Increasing the awareness of close industries such as Railway, Aerospace and others will bring synergies where all parties can benefit. The impact brought by HYPERNEX is aimed to be measurable and effective.

HYPERNEX aims to accelerate the development of hyperloop, an energy efficient solution based on direct zero emission. According to the statement made by the European Commission in the white book [18], the development of new technologies for vehicles will be key to lower transport emissions in the EU as in the rest of the world. HYPERNEX brings the opportunity of developing a solution capable of achieving aviation speeds, on demand and propelled by renewable-power sources. Therefore, hyperloop is a key tool for transport segment decarbonization in Europe.

Acknowledgment

The HYPERNEX project has received funding from Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101015145.

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7. Shift2Rail website available on: www.shift2rail.org
Prediction of Safe Maneuvers in Restricted Waters as Problem of Navigation and Ship Hydrodynamics

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Abstract

As is known, state-of-the-art integrated systems for assistance in navigation (e.g., ECDIS) use real-time data of various sensors (radars, log, echo-sounder, etc.) which can be also used by appropriate mathematical models of ship maneuverability. Even more ambitious systems for autonomous ships are created now, so algorithms of processing navigational data are more than ever of interest. An original method for calculation and visualization of suggested maneuvers is described in this paper. It particularly aims to prompt aid in restricted waters. However, in the restricted waters a complex of hydrodynamic phenomena (shallow water, currents, etc.) significantly affects parameters of controlled movement. Effects of those phenomena can be simulated based on dynamic models of maneuverability which are able to trace realistic trajectories of a ship in advance. Some initial data, e.g., water depth, can be provided by electronic charts. But the dynamic models need numerous hydrodynamic parameters, and it’s hard to prepare full data set for a particular ship. More affordable CFD simulations can be used for this purpose now. In this way, a combination of approaches provided by the navigation and ship hydrodynamics can be recommended for further improvement of the software algorithms for preventing collisions and prediction of safe maneuvers.

KEY WORDS: problems of navigation; ship maneuverability, electronic charts, CFD simulation

1. Introduction

Application of mathematical models to analysis of ship maneuvers was established as an important part of navigation science a long time ago. In particular, it was used for analysis of the accidents and drawing up recommendations to navigators on how to avoid them. From the very beginning approaches of navigation were closely intertwined with approaches of ship design. Maybe the most famous example is the enquiry of RMS Titanic disaster. Among the other things, the ship’s maneuverability was investigated with the help of sea tests of the sister-ship RMS Olympic to establish how quickly the ship could turn two points at various speeds, to approximate how long it would have taken Titanic to turn after the iceberg was sighted. Despite a criticism of Titanic’s maneuver immediately before the collision, it was shown that the ship could not avoid collision at her actual speed, because of inadequate steering equipment. Thus, there were important conclusions both for navigators and ship designers. The former ones concerned too high speed and ignore of iceberg warnings. The latter ones concerned ship design and equipment and eventually have become part of the International Convention for the Safety of Life at Sea (SOLAS).

From the standpoint of navigation, the main problem is to provide efficient and trouble-free sea shipping. The problem redoubles in the regions of intensive marine traffic: approaches to large ports and anchorages; natural or artificial estuaries. As the name suggests, the most intensive traffic is peculiar to restricted waters. Now mathematical modeling can be used not only for aftermath analysis, but as means of prompt aid to navigator in form of software elements of computer systems for preventing collisions. As is known, such systems (e.g., ECDIS) use real-time data of various sensors (radars, hydrodynamic log, echo-sounder, etc.) and electronic charts, which can be used for prompt prediction of collision risks and suggestion of safe further maneuvers. Therefore, it is quite natural to develop corresponding software especially in view of the restricted waters. Much more ambitious computer systems for autonomous ships are created now, so advanced algorithms for processing navigational data are more than ever of interest. Usual approach to formulation of such algorithms implies use of certain kinematical characteristics of the ship.

From the standpoint of ship design and ship hydrodynamics, the restricted waters are even more dangerous due to lack of maneuverability many ships face there. On the one hand, those ships, especially of high-capacity, often have insufficient maneuverability at low speed due to decrease of steering gear efficiency. But they are forced to use low speed due to requirements of traffic or other aspects of safe navigation. On the other hand, there is also a complex of hydrodynamic phenomena that significantly affect parameters of controlled movement of every ship in real conditions of the restricted waters (shallow water, proximity of shores or other ships, currents, etc.). In principle, the mentioned phenomena are studied within scientific projects or some selected designs of inland ships. However, though the equations of controlled movement are well-known, and can be efficiently solved, it’s still a problem to provide full set of data needed for a particular ship. Nor typical set of design documentation, nor typical sea trials usually doesn’t provide all necessary information. In the current situation, design studies and sea trials mainly concern parameters of maneuverability in still deep water. Nevertheless, the additional data can be effectively used now, whereas so expensive studies were not
justified before. Especially since the more affordable CFD simulations can be used now for obtaining the needed hydrodynamic parameters.

2. Method Prompting Safe Maneuvers for Collision Avoidance in Restricted Waters

2.1. Method Formulation

When a ship runs in the restricted waters and dangerous convergence with some object occurs, maneuver of avoidance should take into account both navigational dangers and other ships. Due to ECDIS true position and movement of all objects can be synchronously shown in electronic charts. Since electronic charts contain information on navigational dangers as well, necessary initial data for calculation of safe or unsafe maneuvers is theoretically available.

If current trajectory of the ship is unsafe, a maneuver of avoidance should be applied. It should follow some standard strategy or emergency strategy. A strategy describes full process of avoidance, starting with leave of initial course and finishing with return to it after missing. Since maneuver of avoidance interferes with normal movement, an optimal maneuver can be based on minimal distance of convergence, which is still considered as acceptable.

The starting moment of the maneuver $t_y$ can be expressed as follows:

$$
t_y = t_y' - \frac{A \left( \Delta \xi \cos \vec{K}_{xy} - \Delta \eta \sin \vec{K}_{xy} \right)}{V_{ito} \sin(\vec{K}_{ito} - \vec{K}_{xy})} ; \quad (1)
$$

$$
t_y' = \frac{A \Delta D \sin(\vec{K}_{ito} - \vec{K}_{xy}) - D_y}{A V_{ito} \sin(\vec{K}_{ito} - \vec{K}_{xy})} \quad (2)
$$

where $\tau_y$ – period of turning; $\Delta \xi$, $\Delta \eta$ – decrements of coordinates for the period $\tau_y$; $V_{ito}$, $K_{ito}$ – initial relative velocity and heading; $\vec{K}_{xy}$ – relative heading of avoidance; $V_c$, $K_c$ – velocity and heading of avoided object; $\alpha$, $D$ – bearing and distance to avoided object; $D_d$ – minimum acceptable distance.

Period of turning $\tau_y$ and decrements of coordinates $\Delta \xi_y$, $\Delta \eta_y$ are determined by kinematic model of the ship’s rotational movement with known angular velocity.

The starting moment for the next turn, leading to the initial general course, $t_b$, can be expressed as follows:

$$
t_b = t_{yo} - \Delta t_b ; \quad (3)
$$

$$
\Delta t_b = \Delta \left( \frac{\Delta \eta_{yo} \sin K_{yo} - \Delta \xi_{yo} \cos K_{yo}}{V_{yo} \sin(\vec{K}_{yo} - \vec{K}_{yo})} \right) \quad (4)
$$

In Eq. (3) $\Delta t_b$ is correction for inertia of the ship’s movement, which is expressed by Eq. (4). The terms of Eq. (4) with subscript “b” are analogous to those of the Eq. (1) and Eq. (2) with subscript “y”. Crucial parameters of the first phase of the suggested maneuver are illustrated in Fig. 1 (avoided object is denoted as point C).

Finally, the starting moment of turn to general course is expressed in the following way:

$$
I_{ko} = t_y + \frac{L_p}{V_o \sin(K_c - K_y)} - \Delta t_k ; \quad (5)
$$

$$
L_p = \delta V_c (t_y - t_{yo}) \sin(K_c - K_y) ; \quad (6)
$$

$$
\Delta t_k = \frac{I_k}{V_o \sin(K_c - K_y)} ; \quad (7)
$$

$$
I_k = \frac{\delta \left[ \Delta \xi (\tau_y) + \Delta \eta (\tau_y) \right]^{1/2} \sin \epsilon}{\pi \arctan \left[ \Delta \eta (\tau_y) / \Delta \xi (\tau_y) \right] - K_y} \quad (8)
$$

$$
\epsilon = \arctan \left[ \Delta \eta (\tau_y) / \Delta \xi (\tau_y) \right] - K_y \quad (9)
$$

According to different input parameters of Eq. 1 – Eq. 9, first of all, to the ratio between velocity of the ship $V_o$ and velocity of the object $V_c$, there can be various trajectories of avoidance.
For an arbitrary moment in time \( t_y \) relative headings of avoidance to the right \( K_{sys} \) and to the right \( K_{syp} \) can be expressed through distance to avoided object \( D_y \) and corresponding bearing \( \alpha_y \):

\[
K_{sys} = \alpha_y + \frac{D_y}{D_y};
\]

\[
K_{syp} = \alpha_y - \frac{D_y}{D_y};
\]

\[
D_y = \sqrt{V_c^2 t_y^2 + D^2 - 2DV_c t_y \cos (K_{ot} - \alpha)};
\]

\[
\alpha_y = K_{ot} + \arcsin \frac{D_y}{D_y}.
\]

The relative headings \( K_{sys} \), \( K_{syp} \) can be eventually converted into absolute headings:

\[
K_{ys} = K_{sys} + \arcsin \left[ p^{-1} \sin \left( K_y - K_{sys} \right) \right];
\]

\[
K_{yp} = K_{syp} + \arcsin \left[ p^{-1} \sin \left( K_y - K_{syp} \right) \right].
\]

Headings of avoidance \( K_{ys} \), \( K_{yp} \) as functions of time \( t_y \) form the borders between two regions on the flat of possible headings (coordinate system \( K_y, t_y \)). The first region contains safe combinations, which lead to \( D_{\min} > D_d \), while the second region contains unsafe ones, which lead to \( D_{\min} < D_d \). It should be noted that the time moment \( t_y \) has zero minimum value which means current time. Similar approach can also be applied to further phase of avoidance maneuver, for the time moment \( t_b \). The regions of unsafe combinations \( K_y, t \) are used as ranges of the forbidden maneuvers.

At first sight, the method described is correct for unrestricted conditions of high seas. In restricted waters there is a possibility that optimal trajectory of avoidance would lead to a navigational danger. However, the method allows individual analysis of many avoided objects. They can be other ships or navigational dangers. Navigational dangers are considered as snapped to electronic charts, and can be analyzed as they approach.

2.2. Example of the Method Application

The submitted method has been implemented as Windows application that can be used for practical, scientific or
training purposes. An example of avoidance maneuver for the case of dangerous convergence of two moving ships near a navigational danger has been simulated with the help of the said software.

The ships are moving towards each other with velocities of 17 and 20 knots in the vicinity of navigational danger – Fig. 2. In Fig. 2 the left ship performs avoidance, the right is circled by minimum safe distance \( d_D \). The navigational danger is shown as small blue circle on starboard of the avoiding ship.

At the initial moment of time (shown in Fig. 2) analysis of the forbidden maneuvers is made (Fig. 3), and the safe turning points are selected. Optimal time moment for the turn can be selected in the borderline between regions of safe and unsafe maneuvers. Subsequent phases of the avoidance maneuver are visualized in Fig. 4.

![Fig. 2 Simulated maneuver of avoidance – initial position](image1)

![Fig. 3 Analysis of safe turning points](image2)

![Fig. 4 Further phases of the avoidance: a – moment of turning to general course; b – moment of setting general course](image3)

### 3. Use of More Advanced Hydrodynamic Models

#### 3.1. Features of Kinematic and Dynamic Models

The method described in the previous section, as well as many others in navigation [1-4], uses a simple kinematic model of ship movement. Accordingly, the period of turning \( \tau \) and the decrements of coordinates \( \Delta \xi, \Delta \eta \) in Eq. (1) and Eq. (4) are expressed through angular velocity \( a_\omega \) which is supposed to be known. This is a rational approach to analysis of instantaneous parameters of movement which can be detected by sensors in real time. Since other ships move permanently with incomprehensible further trajectories, it’s reasonable to analyze their current positions and velocities to assess tendencies. And in intricate situations good timing often is more important than accuracy of calculations, especially considering that there is always a time gap between navigator’s decision and starting moment of a maneuver.

However, a kinematic model hardly can predict realistic trajectory of a ship. Trajectory of a ship significantly depends on inertial and damping forces. A ship can try following some preset course strictly, but it may be impossible or may cause big loss of time. It seems more efficient to select one of realistically simulated trajectories which is safe and causes minimal time loss due to keeping higher speed. It’s especially reasonable for avoiding navigational dangers or other motionless obstacles. In fact, motion of a ship obeys dynamic model that involves, in the simplest case,
hydrodynamic and inertial forces of hull; thrust of propellers and steering forces of rudders.

Frequently used dynamic models of ship motion describe the horizontal motion of a ship with three degrees of freedom (DOF) [5]: surge, sway and yaw. These models imply that the roll, pitch and heave motions are small, and can be neglected. Common 3 DOF model is based on three equations for the total hydrodynamic forces \( X, Y \) and the moment \( N \) about vertical axis \( z \) (yaw moment). Full equations are rather complex, but \( X, Y \) and \( N \) can be eventually expressed through the motion states and the rudder angle:

\[
\begin{align*}
X & \rightarrow f (u, v, r, u, v, r, \delta_r) \\
Y & \rightarrow f (u, v, r, u, v, r, \delta_r) \\
N & \rightarrow f (u, v, r, u, v, r, \delta_r)
\end{align*}
\]

where \( u, v \) – velocities of the center of gravity (CG) of the ship in horizontal plane, in ship-fixed reference frame; \( r \) – angular velocity (yaw rate); \( \delta_r \) – rudder angle.

Initially the dynamic models corresponding to the Eq. 16 (or similar ones) were considered as too complex for operational purposes. But now they can be resolved nearly in real time.

3.2. Effects of the Restricted Waters

The dynamic models of manoeuvrability are actively in use in special fields of ship design, including simulation of various maneuvers. Evidently, they can be a useful tool of navigators under normal conditions. But we would like to emphasize importance of some effects of the restricted waters on maneuverability. In principle, dynamic effects are well-known, and a navigator has to take them into account anyway, with the help of calculation or just “ship feeling”. However, behavior of any ship significantly changes in the restricted waters due to certain hydrodynamic phenomena. In many cases this change may be unexpected or underestimated by navigator accustomed to the conditions of the high seas. Previously made simulation is able to show the need of bigger rudder angles or impossibility of the maneuver at a preset speed.

Hydrodynamic effects of the restricted waters can be subdivided into several groups. The first group may include effects of interaction between the ship and other ships, shores or walls of channels. The effects are quite complex and dangerous, but all of them can be avoided by keeping some minimum distance. The second group is the effects of shallow water on maneuverability and propulsion. They are of critical importance, and can be soundly estimated due to, on the one hand, well-developed mathematical models and, on the other hand, detailed depth maps. The effects caused by weather and currents may constitute the third group. The latter ones are close to the conditions of the high seas, but still have some peculiarities. For example, the waves formed in confined water areas may have unusual parameters.

Presently, there are a good many of well-developed dynamic models of maneuverability which are able to take into account the described hydrodynamic phenomena. In Fig. 5 the influence of water depth on circulation maneuver of a containership is submitted based on the research [6]. These results, as well as many others, indicate drastic decrease of turning ability pro rata with decrease of depth (ratio of draught to depth \( d/h \) is used). In shallow water majority of ships suffer significant shift of the designed balance between turning ability and course routing in favor of the latter one.

3.3. Problem of Necessary Hydrodynamic Data

An important practical problem of more widespread use of the dynamic maneuverability models is the necessity of numerous data on hydrodynamic properties of ship hulls, thrusters, rudders and other equipment for drawing up the equations of motion. The most reliable method of obtaining the necessary data is special model tests in which a ship model moves curvilinearly, e.g., with the help of the Planar-Motion-Mechanism for towing tank. Unfortunately, such tests are rather long-term and expensive, so they are performed in some individual cases (scientific purposes, designs of specialized ships with high requirements to maneuverability, etc.). Multiplicity of different hydrodynamic coefficients makes difficult development of simplified methods of estimation based on the accumulated experimental data.

Since disadvantages of the experimental approach were long known, several ways to avoid them were suggested, e.g., different decompositions of hydrodynamic forces which allowed extracting the necessary data from propulsion tests for reducing experimental works [6]; mathematical post-processing of the sea trials [7]. Although these ways didn’t give great results, and, in our opinion, hardly can help to introduce the dynamic models to navigation systems, the latter approach becomes more prospective now. Modern sensors and recording systems can provide detailed data on the parameters of motion together with navigation and weather conditions as well as position of rudder and main engine mode. There is no need in special sea trials for a so equipped ship – the sea trials last permanently. However, the results contain too much data with certain outliers caused by inaccuracy of sensors, unaccounted effects and other reasons. Their processing is the separate problem which need special methods up to self-learning algorithms.

Probably the most suitable alternative to the model tests is CFD methods which are much more affordable. Lower costs are often explained by flexible adjustment of works due to avoiding production of models. Available experience in the field of propulsion [8-10] shows that the CFD methods help to significantly expand data volume all else being equal. Since data needed for the dynamic models of maneuverability may be not so accurate as needed for propulsion, advantages of the CFD methods can be assessed even better. In Fig. 6 an example of CFD simulation of a trawler’s hull flow with constant drift angle is shown as the distribution of elementary yaw moment \( N \) over the hull surface.
4. Conclusions

The method prompting safe maneuvers for collision avoidance in the restricted waters has been suggested. Formulation of the method is regular to contemporary methods of navigation using ship sensors and electronic charts. It’s shown that the suggested method can be used for avoiding both other ships and navigational dangers.

Application of the more advanced dynamic models of manoeuvrability within the suggested method is considered. Especial importance of the dynamic models for accounting hydrodynamic effects of the restricted waters on ship manoeuvrability has been noticed.

The necessity of numerous data on hydrodynamic properties of ship hulls, thrusters, rudders and other equipment for drawing up the equations of the dynamic models has been stated. Possible ways to provide the needed data have been analysed. Application of the CFD simulations is concluded to be a reasonable compromise in the considered situation.

References

Fuel Saving Methods in an Airline

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Abstract

The subject of the paper „Fuel Saving Methods in Airline” is to introduce economical operational measures applicable to a predefined airline, to quantify potential savings resulting from the implementation of these measures based on actual flight data analysis and to design a set of processes to achieve real financial savings.

KEY WORDS: Air traffic; aircraft; airline; costs; fuel consumption; fuel management; savings

1. Introduction

In a sensitive and a highly competitive sector as commercial aviation, costs are a key aspect for airlines’ operations. The pressure to optimize costs has recently further increased with the arrival of low-cost airlines on the market. Fuel costs represent a significant part of the total flight costs for an airline, an average of 21 percent for European airlines last year [1]. The price of fuel is also highly volatile and, moreover, it may vary depending on the airport of the fuel uplift. Between May 2017 and 2018, jet fuel prices had risen by as much as 47% [2]. These sudden and unexpected fluctuations in price of jet fuel can significantly threaten the financial health of airlines. Another important factor that has for airlines operating in Europe emerged only recently is the obligation to monitor their carbon dioxide footprint. The European Union's ongoing project, the Emission Trading System, is based on the purchase and exchange of emission allowances, which air carriers flying into or out of the EU must pay for their carbon dioxide emissions. Currently (December 2019), airlines pay approximately €75 for each ton of jet fuel burned, based on the current emission allowance price. However, the nature of the project, which aims to reduce the amount of carbon dioxide emitted into the atmosphere, suggests that the price of emission allowances, or each ton of CO2 produced, is likely to increase in the future [3]. ICAO is preparing a similar project called CORSIA that will cover the entire world of commercial aviation and its implementation is likely to take place sometime after 2020.

Moreover, the European society seems to be increasingly committed to reducing environmental burdens. Clear example can be seen in the Scandinavian countries, particularly Sweden, where the air traffic share is currently on decline and what is probably a result of the local environmental movement. All the factors above force airlines to actively address fuel management issues and try to reduce fuel costs. There is a number of measures the airlines can use to reduce fuel consumption which, when used regularly, will result in significant financial savings while still maintaining a high safety standard. These include for example a better flight route calculation, more economical climb profile, the use of lower flaps or idle reverse during landing or taxiing from the runway to the parking stand with one engine turned off. All of these procedures generally reduce fuel consumption by a few tens of kilograms per flight, but if used daily, larger airlines can save hundreds of tons of fuel and hundreds of thousands of dollars a year, respectively.

The article Fuel Saving Methods in An Airline therefore focuses on fuel management in a predefined airline, which purposely corresponds to the largest Czech airline – both charter and scheduled air carrier based at Prague airport operating a fleet of approximately 50 aircraft Boeing 737-800. Its aim is to analyze selected fuel consumption reducing operating procedures and to further determine – with the help of a real flight data sample – the potential of implementing these methods into the company daily operations, while taking into account the nature of these operations, aircraft used and destination airports. The output of this paper is a set of measures, to be implemented mainly at the Prague airport, which will reduce the total airline fuel costs. Gross amount of the fuel and financial and savings is also calculated. The paper also proposes internal measures, which, according to the author, are necessary for a functional fuel efficiency project and for achieving real financial savings.

2. Fuel Saving Methods

There are several fuel-efficient procedures that airlines all over the world are implementing or are in the process of developing them into a future fuel project. Some of the most popular procedures that also could be well used in the predefined airline are listed below.
3. On the Ground

The decision to use a fuel consumption reducing method is either to be made in the cockpit by the flight crew, or in the office on the ground. Common fuel efficiency methods to consider on the ground before the actual flight takes place are:

- Optimizing Flight Trajectory;
- Cost of Weight;
- Pilot Extra Fuel.

Despite the quality and precision of today’s flight planning systems, actual flight trajectories often differ from what was planned beforehand. These deviations may cause the aircraft to burn significantly more fuel compared to the flight plan. To ensure safe operations when traffic is dense, ATS puts aircraft on hold or vectors them, throwing them off the optimal route. According to IATA, vectoring costs the airline an average of $50 for each lost minute of flight. Flying at an altitude different than the optimal also means higher fuel consumption. Boeing 737NG flying 4,000ft under optimum burns 5 percent more jet fuel [4]. The airline’s job here is to analyze if their aircraft are flying at the optimal flight level and how precise are the flight planning systems. Airline navigators need to monitor how often actual flight routes deviate from the planned ones and how often and where are flight crews granted directs. Direct routes often generate substantial savings in terms of time and fuel. However, the benefits and the likelihood to obtain a direct depend on each route, time of day, and flight conditions (wind, ATC).

One of the most important factors in fuel consumption is the weight of the aircraft - the higher it is, the more fuel is needed to fly it. Cost of weight is the amount of fuel that is needed to transport one kilogram or one pound of payload, and the value varies historically from 3 to 5% per flight hour – this means that an additional ton of mass onboard the plane will require another 30 to 50 kg more fuel per hour [5]. The goal: Keep the aircraft weight to a minimum. Unused fuel, in-flight magazines, old seats or unsold catering are all things that make the fuel consumption rise.

Before each flight, the captain gets to decide whether he wants to add fuel onboard on top of the amount that was calculated by flight dispatch using historical data. The captain is responsible for the safety onboard and he has to consider several factors before making a decision to get extra fuel, like weather at arrival airport or an ATC strike. However, as written above, every kilogram of additional weight means more fuel burned. That is why the pilots should be very careful with the amount of extra fuel added onboard, as lack of it may put the flight safety at risk, but on the other hand, carrying too much of fuel will result in excessive fuel consumption. The airline’s task is to educate pilots and show them relevant fuel statistics, so they can make a better decision and save their airline a bunch of money.

4. In-Flight

These in-flight fuel efficiency procedures are always at the pilots’ discretion, because usage at an inappropriate time may put the flight safety at risk. That is also why using these can never be mandatory – safety always remains the highest priority. Rather, the airline should cooperate with the pilots and let them know that using these methods often means generating big savings in the long term.

- Reduced Acceleration Altitude;
- Continuous Descent Approach;
- Idle Reverse Thrust;
- Engine Out Taxi.

Usually, there are two different climb profiles to use when departing from an airport. In Reduced Acceleration Altitude, the value to look for is the ACC ALT (Acceleration Altitude). This specifies the height at which the aircraft may level off, bring the flaps up and continue the climb with less drag. The lower the ACC ALT and the lower the wing configuration is clean the less fuel is burned during the climb phase. Lowest legally applicable Acceleration Altitude is 800ft, but always depends on the corresponding airport and authorities – they are the ones certifying a lower ACC ALT for commercial usage.

Continuous Descent Approach is a very intuitive way how to push down the fuel burn during descent to destination. Instead of descending gradually from e.g. TOD to FL290, from FL290 to FL200, FL200 to FL100 and so on, the flight crew may opt to descend continuously from TOD all the way to the final approach altitude, saving considerate amount of fuel in the process by using only idle engine power while descending. It is not that simple however, as the procedure must be granted by ATC. At very busy airports or during rush hours, CDA procedure may be hard to achieve due to dense traffic.

A fuel-efficient procedure that is not hard to achieve and can be used very often is called Idle Reverse Thrust. When landing on a long runway, the use of engine thrust reversers may not be necessary to safely stop the aircraft and using the thrust reversers only on idle may be fully sufficient. Running the engines on full reverse burns a lot of fuel, so when landing regularly on major airports in good weather conditions, this procedure can save a not only a whole lot of money, but also the engine wear and tear.

Last procedure analyzed is the Engine Out Taxi. Modern major international hubs are extremely big airports in terms of area. Average taxing times at Amsterdam Schiphol Airport or Paris CDG are among the longest and may reach 20 minutes and even more. Because there is a huge amount of fuel burned while taxiing, some airlines came
forward with a procedure to turn off one engine after landing and taxi to the gate with only one engine running. There are restrictions though – the aircraft usually cannot make right angle turns due to asymmetric thrust or go uphill. Also, the engine must only be turned off after a cooldown time defined by the manufacturer, to prevent damage to the engine. When done properly though, this procedure saves a lot of fuel, especially at airports with long taxi times.

5. Flight Data Analysis

Real flight data samples were provided by Smartwings, a Czech airline, through a software application SkyBreathe by OpenAirlines. This software gathers flight data from the flight recorder, flight plans, ACARS or load sheets and comes in handy when estimating the potential of implementing the fuel-efficient procedures.

Five sets of data were analyzed to better understand the current state of fuel saving operations in the company and to come up with the potential savings. Because the predefined airline has a main hub in Prague, Czech Republic and two thirds of the airline operations take place there, the author focused mainly on that particular airport for implementing efficient techniques. Three of the five analyzed procedures that showed most promising results are presented below.

Starting with Reduced Acceleration Altitude, the analysis compared two airports with different standard Acceleration Altitudes in terms of fuel burned (or saved) in the immediate climb phase following a take off. While at PRG the airline uses 1,500 ft, AMS has a certified ACC ALT of 800 ft. The difference in actual ACC ALT is however less than 700 ft, presumably because the pilots are more familiar taking off from PRG and so they get closer accelerating at the desired altitude. The average difference in the Acceleration Altitude at PRG and AMS showed out to be mere 227 ft, instead of expected 700 ft, but is still not by any means negligible. How does ACC ALT relate with the amount of Fuel Burned during take off is shown in Fig. 1 below.

![Graphical representation of the relation between actual Acceleration Altitude (ACC ALT) and amount of Fuel Saved](Author)

Departures from AMS at an average ACC ALT of 1,922 ft and from PRG at 2,149 ft may seem almost identical, but in fact, the former burns 22 kg less fuel. At 10,000 departures from PRG per year, using 32 800 ft could save the airline 220 t of fuel or almost $150,000 financially [2]. It came out clear that every hundred feet count and can bring substantial savings.

Moving on to a procedure the analyzed airline had not really used to their profit yet – Engine Out Taxi. Even though the predefined airline operates a lot of charter flights to smaller leisure airports, it also has plenty of frequent scheduled flights to big international airports in Europe and Asia and thus the pilots should be well aware of the savings they can achieve by turning one engine off during a long taxi. But it turned out they are probably not, as the airline share of EOT operations at the most suitable airports in the network (AMS, CDG, MAD) turned out to be less than 20%. The potential savings are not small. Average time of taxi at these three airports is almost nine minutes so there is plenty of time for the engine to cool down after landing and be turned off. Madrid even averages at more than 10 minutes per taxi (see Table 1). The amount of fuel to be potentially saved by taxiing to the stand with only engine running can be seen below – with the cooldown time taken into regard.
Table 1

Average times of taxi for the analyzed airline at three major European airports and respective saved fuel potentials, with regard to the engine cooldown time [Author]

<table>
<thead>
<tr>
<th>Airport</th>
<th>Average Taxi Time</th>
<th>Saved Fuel Potential [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS</td>
<td>7m 14s</td>
<td>28</td>
</tr>
<tr>
<td>CDG</td>
<td>9m 30s</td>
<td>39</td>
</tr>
<tr>
<td>MAD</td>
<td>10m 24s</td>
<td>57</td>
</tr>
<tr>
<td>Average</td>
<td>8m 53s</td>
<td>38</td>
</tr>
</tbody>
</table>

With two scheduled daily flights to AMS, four to CDG and six weekly to MAD, the airline could save tons of fuel annually just at these three airports. However, the engine cannot be turned off every time due to traffic or weather conditions, so the author used a conservative estimate of a 50% application – even though other similar airlines reached 90%. Also, it is not always possible for the flight crew to turn off the engine immediately after the cooldown time, so the author calculated with a delay. With the engine turned off after half of the landings at these airports under these conditions, the annually saved fuel potentials were the following: AMS 5.9 t, CDG 15.6 t, MAD 5.6 t.

At Prague Airport, the situation is even worse with only 12% of landings being followed by an EOT operation. PRG is not nearly as big as the previous airports but still, with an average taxi time of 4:43, it does offer room for savings. The average time of a taxi exceeds 5 minutes after landing on the busiest RWY24, so the greatest potential lies within the most frequent runway. The average calculated savings per taxi is 9.8 kg. With 10,000 annual landings at PRG, 50% application and the engine switch-off delay, the calculated savings potential reached 49 t. See Table 2 below for EOT operations potential.

Table 2

Four airports analyzed for the purpose of Engine Out Taxi operations with calculated average annual fuel savings [Author]

<table>
<thead>
<tr>
<th>Airport</th>
<th>Landings (Taxis) per year</th>
<th>Saving per taxi [kg]</th>
<th>Annual Savings [ton]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRG</td>
<td>10,000</td>
<td>9,8</td>
<td>49</td>
</tr>
<tr>
<td>AMS</td>
<td>750</td>
<td>15,8</td>
<td>5,9</td>
</tr>
<tr>
<td>CDG</td>
<td>1,500</td>
<td>20,8</td>
<td>15,6</td>
</tr>
<tr>
<td>MAD</td>
<td>300</td>
<td>37,3</td>
<td>5,6</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>76,1</td>
</tr>
</tbody>
</table>

Last presented analyzed procedure is the Continuous Descent Approach. The idea of this procedure is very straightforward: the fewer steps the aircraft performs during a descent towards destination, the less amount of fuel is burned. In Table 3, STARs into Prague Airport RWY24 are listed by the number of steps performed while descending. It is clear to see that fewer steps really do lead to a smaller fuel consumption. While a precise continuous descent burned 397 kg on average, each additional step made the fuel burn rise by about another 100 kg.

Table 3

STARs onto Prague airport RWY24 shown with the number of steps taken during descend, together with the corresponding average amount of fuel burned in kg [Author]

<table>
<thead>
<tr>
<th>STAR at PRG</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOLO2S 24</td>
<td>380</td>
<td>411</td>
<td>488</td>
<td>574</td>
<td>654</td>
<td>657</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>421</td>
</tr>
<tr>
<td>GOLO3S 24</td>
<td>360</td>
<td>421</td>
<td>502</td>
<td>601</td>
<td>815</td>
<td>775</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>439</td>
</tr>
<tr>
<td>GOSE3S 24</td>
<td>575</td>
<td>556</td>
<td>663</td>
<td>780</td>
<td>921</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>623</td>
</tr>
<tr>
<td>GOSE4S 24</td>
<td>505</td>
<td>576</td>
<td>643</td>
<td>684</td>
<td>742</td>
<td>750</td>
<td>1291</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>610</td>
</tr>
<tr>
<td>LOMK6S 24</td>
<td>458</td>
<td>565</td>
<td>588</td>
<td>663</td>
<td>657</td>
<td>835</td>
<td>1229</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>585</td>
</tr>
<tr>
<td>LOMK7S 24</td>
<td>495</td>
<td>560</td>
<td>577</td>
<td>627</td>
<td>600</td>
<td>772</td>
<td>962</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>576</td>
</tr>
<tr>
<td>VLM2S 24</td>
<td>360</td>
<td>561</td>
<td>662</td>
<td>774</td>
<td>737</td>
<td>1151</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3262</td>
<td>573</td>
</tr>
<tr>
<td>VLM3S 24</td>
<td>368</td>
<td>612</td>
<td>692</td>
<td>808</td>
<td>858</td>
<td>996</td>
<td>1032</td>
<td>1222</td>
<td>1120</td>
<td></td>
<td></td>
<td>630</td>
</tr>
<tr>
<td>Grand Average</td>
<td>397</td>
<td>541</td>
<td>628</td>
<td>720</td>
<td>799</td>
<td>905</td>
<td>992</td>
<td>1124</td>
<td>1020</td>
<td>3262</td>
<td></td>
<td>563</td>
</tr>
</tbody>
</table>

What needs to be done to start achieving lower fuel burns during descent and approach by taking fewer steps is requesting CDA authorization actively by the flight crew. SkyBreathe data show that the company culture and the pilots’ habits can make all the difference [6]. The calculation of the savings potential from CDA application at Prague
airport was made by deducting 20kg off the average fuel burn during descent, which, according to the author, should be perfectly achievable, in case the proposed fuel project is implemented.

The total amount of fuel and finances saved at Prague airport by the implementation of the proposed fuel efficiency project can be seen in Table 4. Total saved fuel runs up to 492 metric tons and the annual financial savings projected are $344,700, based on a market price of jet fuel in December 2019. Add that to the price of the allowances for 492 tons of jet fuel and the total financial savings amount to $386,100.

<table>
<thead>
<tr>
<th>Saving at PRG</th>
<th>Average Fuel Saved per flight [kg]</th>
<th>Annual Fuel Savings [Ton]</th>
<th>Annual Financial Savings [$]</th>
<th>ETS price [$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Out Taxi</td>
<td>9,8</td>
<td>49,3</td>
<td>34,500</td>
<td>4,150</td>
</tr>
<tr>
<td>Extra Fuel</td>
<td>6,5</td>
<td>22,1</td>
<td>15,500</td>
<td>1,850</td>
</tr>
<tr>
<td>Reduced Acceleration Altitude</td>
<td>22,1</td>
<td>221</td>
<td>154,700</td>
<td>18,600</td>
</tr>
<tr>
<td>CDA</td>
<td>20</td>
<td>200</td>
<td>140,000</td>
<td>16,800</td>
</tr>
<tr>
<td>Total</td>
<td>58,4</td>
<td>492,4</td>
<td>344,700</td>
<td>41,400</td>
</tr>
</tbody>
</table>

### 6. Fuel Efficiency Project

How to turn this savings potential into real financial savings is another issue though and requires development of a complex fuel efficiency project by a fuel team, established from across all interested departments of the airline. The paper thus continues with a proposition of processes, which should be set in place in order to actually optimize the fuel costs.

Pilots’ cooperation is absolutely essential for achieving real savings as they are the ones controlling the aircraft and making the difference. Their confidence in these fuel-efficient procedures is very important— they need to be sure these techniques do not put flight safety at risk and that they are in fact saving fuel and finances for the airline. That is why two-way communication and interaction must be established and many training courses must take place before the actual implementation of the fuel-efficient procedures. Three communication channels are proposed to better engage the pilots:

- Mobile App;
- Newsletter;
- Training Courses.

The smart application should be installed on every pilot’s tablet or smartphone and it should contain all sorts of data concerning that particular pilot’s past and future flights and fuel efficiency techniques and policies. This way, the pilot could look into the app before each flight and see its historical data, what to look out for and where could be time or fuel saved on that route at that moment. Also, after the flight, the pilot could benefit from looking into the app again and seeing what could have been done better, what was done correctly and how much fuel did he indeed save by his piloting. Another important thing is to also gather feedback from the pilots and a mobile application is a very effective way to do that. It can be used to feed the fuel team with feedback on ATC constraints, last minute changes or reasons to add extra fuel.

The newsletter comes in handy to remind the pilots every now and then about their fuel savings accomplishments, to inform them about new challenges or to get an important message across. Periodicity is key for this type of communication. Training courses are important so the pilots can get more familiar with the procedures and give instant feedback to the fuel team.

### 7. Conclusions

In the extremely competitive field of commercial aviation in Europe, after eight European airlines went bankrupt in 2019, it seems very important that the airlines monitor their fuel costs and try to reduce them by using fuel-efficient procedures, since they represent a significant part of the total cost of the flight. Add to the fact that the price of jet fuel is highly volatile and for each ton of carbon dioxide produced, European and soon all other airlines have to pay an emission allowance, bringing down the fuel costs is surely a thing a European should do to better compete on the market and stay afloat during financial trouble. The aim of the paper was to analyze the possibilities of reducing fuel consumption for the purpose of a predefined airline operating a fleet of Boeing 737-800 aircraft and also identify places with possible savings potential.

The highest potential from the five analyzed operational measures was identified in reducing the acceleration altitude of the NADP2 procedure at Prague airport from the current 1500ft to the lowest possible 800ft and in the higher utilization of the CDA approach. The savings calculated from the extra fuel amount reduction came out to be only of little significance. The total financial savings identified at Prague airport was $344,700, based on a jet fuel price in December 2019. Since the quantification of the potential savings is only the first part of an economical fuel project, the
work continues with a set of processes that the author recommends in the airline to be established for the actual achievement of the projected financial savings. Great emphasis is put on a well-prepared fuel efficiency project, communication with pilots, their feedback and engagement through smart applications, training and regular newsletters, to support mutual confidence and thrust.

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5. How to use the cost of weight to be more fuel efficient? [online] Open Airlines, ©2019 Available at: https://blog.openairlines.com/how-to-use-the-cost-of-weight-to-be-more-fuel-efficient
Operating Characteristics of Electric Buses and Their Analysis

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Abstract

This article deals with the operating characteristics of electric buses in the conditions of the Slovak Republic. At present, only about fifty electric buses are in operation in Slovakia. Therefore, the first part of the article forecast the future numbers of such vehicles in operation. The research part includes the statistical analysis of obtained data from actual operation for several winter and summer months. The main idea of the article is to verify several hypotheses about the electricity consumption of these vehicles. We have focused on different seasons because the consumption of electric cars is significantly affected by the environment. The article answers few research questions about the efficiency of electric buses in our conditions.

KEY WORDS: electromobility, operation, bus, fue, electricity, consumption

1. Introduction

Nowadays, we can feel the pressure on reducing greenhouse gas emissions and improving air quality in cities. Therefore, there is a need to introduce new types of vehicle propulsion. Especially in transport, there is a need to look for alternatives to traditional fossil fuels. The transport sector in the EU Member States consumes around 30% of the total energy consumed in the 27 European countries [1; 2]. For the field of road transport is necessary to find an alternative to conventional internal combustion engines [3]. If we look to passenger cars, not only hybrid vehicles (HEVs) are available today, which combine conventional internal combustion and electric engine, but also pure electric vehicles (BEVs). In addition to battery-powered vehicles, another alternative is fuel cell vehicles - fuel cell hybrid electric vehicles (FC-HEV) [4].

Despite these battery technologies, oil-based mobility still holds the largest share of the transport market. The market penetration of alternative technologies is still low [5; 6; 7]. It has several reasons, most notably economic aspects. In a market economy, carriers and private users make decisions according to the efficiency of their investments. Whether electric cars are economically efficient is addressed by several foreign studies, e.g. [8; 9; 10] through the so-called total cost of ownership of the electric or hybrid vehicle. There are also other aspects that slow the alternative propulsion systems in road transport. The problem is energy storage - technologies are currently not allowing a higher range of electric cars. Energy logistics and related infrastructure can also be problematic. Insufficient infrastructure initially has all kinds of fuels. In the recent past, at the turn of the millennium, different fuel had a similar problem with infrastructure. We are talking about nowadays well-known liquefied petroleum gas (LPG) [11]. Today, there is no problem with pumping this fuel. It has become a common commodity and a full-fledged competitor to petrol or diesel. Of course, we cannot consider LPG, CNG, or LNG as a long-term strategic solution to oil dependence.

According to [12], the introduction of new progressive drives is faster in public passenger transport. It is mainly due to fixed routes and lines, a centralized depot for vehicles, and the possibility of using existing infrastructure [13]. In the environment of public passenger transport, it is possible to test, optimize, operate new types of vehicles. At the same time, these activities reduce emissions in the city [14; 15]. In addition, transport services are financed from public funds. The main goal may not be financial profit [16; 17].

In addition, transport services are financed from public funds. Therefore, profit-making aspects may not be paramount. There is a possibility to introduce greener vehicles at the expense of their return on investment and efficiency. At present, there is progress in the market of electric buses. Of course, these are mainly city buses, or buses usable for short suburban lines. The choice of a suitable bus depends on various factors such as price, network structure, energy source, and driving conditions. A compromise between different functions is required for optimal use of each technology [18].

Foreign studies in the field of electric buses mainly examine the technical, economic, and environmental impacts. Therefore, they focus on the three most important aspects of the operation - environmental, energy, and economic efficiency. Environmental models mentioned in [19] examine the potential reduction of greenhouse gas emissions from electric buses. Energy consumption models consider the energy efficiency of electric buses [20; 21]. Economic studies focus on analysing the costs and economic benefits of operating electric buses [22; 23]. After all, we should not forget about user-oriented investigations, e.g. or [24; 25], which examine the opinion of the passengers - user of electric buses. There are also few safety studies, for example [26].

This article provides practical knowledge in the field of electric bus operation in Central Europe. The following...
chapter describes the development of the introduction of electric buses into service in the Slovak Republic and its comparison with selected European countries. Based on the literature, the authors will try to roughly predict the future numbers of buses with zero emissions in service.

The research part of this article focuses on the detailed statistical processing of the obtained data on the operation of two electric buses. We have received these data from the Transport enterprise of the city of Žilina, Ltd. This company also operates hybrid buses, trolleybuses, partial trolleybuses, and buses with a conventional diesel engine.

In this study, we will focus primarily on energy use. It means, we have analysed available data obtained from the practice. We will test several hypotheses and answer several research questions, which are described in the third chapter.

2. Electric Buses in Slovakia

According to the Ministry of Economy of the Slovak Republic, the number of battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV) is increasing. If we look only at passenger cars, in 2015 only 86 plug-in hybrids and 224 electric cars drove on Slovak roads. As of June 30, 2020, their number increased eightfold to 1,021 PHEV and 1,582 BEV. As of this date, there is also the exact number of electric cars in each category of these vehicles (BEV only):

- category L (motorcycles): 606 vehicles;
- category L7e (quads): 139 vehicles;
- category M1 (passenger cars up to 3.5 t gross weight): 1,582 vehicles;
- category N1 (lorries up to 3.5 t gross weight): 124 vehicles;
- category M3 (buses): 47 vehicles;
- and 15 working machines.

Due to the low number of electric buses in the Slovak Republic, it is easy to identify their operating transport company. We have processed the list of their registration numbers and specify the exact type of electric bus for all numbers. We managed to accurately locate 46 of the 47 registered vehicles:

- 23 electric buses - Transport enterprise of the city of Košice;
- 18 electric buses - Transport enterprise of the city of Bratislava;
- 2 electric buses - Transport enterprise of the city of Žilina;
- 2 electric buses - Public transport Prešov;
- 1 electric bus - Arriva Nové Zámky.

Up to 41 vehicles are from manufacturer SOR Libchavy, three electric buses are Škoda, two were made by the Slovak manufacturer Troligabus. The process of introducing electric buses into operation is shown in Fig. 1. It also shows all prototypes and demonstration vehicles used but not registered in the Slovak Republic.

![Electric buses used in Slovakia](image)

The past number of registered electric buses is growing slowly. In the following lines, we will also focus on future development. The study [28] described the conditions of the European public passenger transport market. It aims is to forecast the future numbers of zero emissions buses (ZEB). It predicts the numbers of registered vehicles in few member states of the European Union. However, the study did not focus on Slovakia and the Czech Republic. However, we can estimate the development based on other surrounding countries as Austria, Poland, and Hungary. One of the research questions of the study was: "In which year the member state will reach the level of 95% of the share of zero-emission buses?" The method used was the Bass model. It showed that only 4 EU Member States probably achieve a 95% share without emission buses before 2050 (Belgium, Spain, Norway, and Romania).

If we look at the algorithm for calculating the expected number of ZEBs in future periods, we will find that it counted with four types of powertrains. Total numbers of ZEB include electric, hybrid, plug-in hybrid and hydrogen vehicles. In the above text, we mention that the future number of zero-emission buses could roughly copy Poland or Hungary. We are convinced about that because the present number of buses with zero emissions, on which the calculation was based, is approximately the same as in Slovakia.
In Slovakia 46 electric buses, 16 hybrid buses and approximately 250 trolleybuses operated in 2020 (131 in Bratislava, 31 in Banská Bystrica, 46 in Žilina and 42 in Prešov) [29]. In total, there are up to about 300 vehicles with zero emissions. Nevertheless, meeting the 95% share of emission-free buses before 2050 is very unlikely.

Analyses have shown that by 2050, only four EU members will be able to reach a 95% share of clean buses in urban bus fleets. Likely, other countries may not achieve this by 2050.

The technical parameters of electric buses operated in Slovakia are relatively similar. These are solo buses with a length of 8 to 12 meters with an output of up to 160 kW. All parameters with the number of vehicles in service are in the following Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Brand</th>
<th>Type</th>
<th>Length [m]</th>
<th>Capacity [pax]*</th>
<th>Weight [kg]</th>
<th>Engine power [kW]</th>
<th>Max. speed [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>18x</td>
<td>SOR</td>
<td>EBN 11</td>
<td>11,10</td>
<td>29+63</td>
<td>10 000</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>5x</td>
<td>SOR</td>
<td>EBN 10.5</td>
<td>10,37</td>
<td>19+54</td>
<td>10 200</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>2x</td>
<td>SOR</td>
<td>EBN 8</td>
<td>8,00</td>
<td>16+38</td>
<td>9 020</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>16x</td>
<td>SOR</td>
<td>ENS 12</td>
<td>12,00</td>
<td>33+72</td>
<td>12 350</td>
<td>160</td>
<td>80</td>
</tr>
<tr>
<td>2x</td>
<td>Škoda</td>
<td>Perun 26SH01</td>
<td>12,00</td>
<td>28+42</td>
<td>12 835</td>
<td>160</td>
<td>80</td>
</tr>
<tr>
<td>1x</td>
<td>Škoda</td>
<td>Perun 26BB HE</td>
<td>12,00</td>
<td>28+42</td>
<td>12 835</td>
<td>160</td>
<td>80</td>
</tr>
<tr>
<td>2x</td>
<td>Troliga-bus</td>
<td>Leonis EV</td>
<td>12,00</td>
<td>30+64</td>
<td>13 000</td>
<td>113</td>
<td>90</td>
</tr>
</tbody>
</table>

*Capacity in passengers: sitting + standing

In this study, we focused on two Škoda Perun 26SH01 vehicles. According to [30], these are low-floor 12-meter battery-electric buses, which have been manufactured by the Czech company Škoda Electric since 2013 with the bodies of the third-generation Solaris Urbino 12 bus. Since 2016, they have been produced with the new Urbino 12 fourth-generation bodies. In 2017, the Škoda Electric won a public tender for two low-floor 12-meter electric buses for the Transport enterprise of the city of Žilina. Both Škoda Perun vehicles with the Solaris Urbino 12 IV body have been in operation since November 2018.

### 3. Data Analysis and Research

In this chapter, we focused on the statistical analysis of the obtained data. We wanted to describe the relationship between the temperature of the environment and electricity consumption. Therefore, we have chosen two summer and three winter months, during which the examined electric bus was in daily operation.

Hypothesis H1, which we verified, reads: There is a strong dependence between the ambient temperature and the total electricity consumption of the electric bus. We express the dependence by Pearson's correlation coefficient, while its interpretation will be as follows in the sense of [31]: values of the coefficient from 0.0 to 0.4 (or -0.4 to 0.0) will be considered as weak, values from 0.4 to 0.8 (or -0.4 to -0.8) will be moderately strong, values of 0.8 to 1 (or -0.8 to -1.0) will be considered particularly strong. It means a very strong interdependence between the variables.

The research questions we verified were as follows: O1 - What is the exact value of the correlation coefficient between total electricity consumption and temperature? O2 - What is the exact value of the correlation coefficient between the electricity consumption of the traction motor drive itself and the temperature? O3 - What linear or exponential function is it possible to express this dependence?

### 3.1. Input Data

For our research, we were able to obtain a large dataset from two operated Perun 26SH01 trolleybuses. We processed data from a data log that contained the following information:

- Identification data (bus number, VIN - vehicle identification number) and time range of data entry.
- Total travelled distance in kilometres.
- Total electric energy in kWh:
  - charged via pantograph;
  - charged via the power cable.
- Total consumption divided into:
  - internal consumption with energy redistribution: clean traction, auxiliary drives, heating, air conditioning, energy for 24V appliances;
  - external consumption.
- The data log also contains daily data of charged energy, mileage, consumption, and number of battery balances.

In addition to these operational data, we also used publicly available temperature records from the given days - used from a source [32]. The total graph of energy consumption data for traction motors, heating, and air conditioning for one of the electric buses is in Fig. 2.

![Fig. 2 Absolute electricity consumption and total travelled distance per month. Source: Processed by authors](image)

### 3.2. Data Analysis

First, it was necessary to clean the absolute values of consumed electricity from the travelled distance. In the same way, we recalculated kWh of energy consumed for heating and air conditioning. As can be seen from the previous picture, heating was used in each of the months, and air conditioning was used in the two summer months. The impact of air conditioning on consumption is negligible overall.

Based on the input data, we found that the Pearson correlation coefficient between the total consumption of the electric bus and the ambient temperature is at the level of -0.880 at the significance level of 0.01 (two-tailed test). We took 105 values in the calculation. We can assume that this dependence is due to the need for passenger cabin heating at low temperatures. For this reason, we also focused on the energy consumed by the traction motors. In this case, the resulting correlation coefficient was -0.496 at the significance level of 0.01 (two-tailed test). The dependence in both cases was indirect. Indirect dependence means that the temperature decreases and the amount of consumed electricity increases. The average total electricity consumption in kWh per kilometre is in Fig. 3.

![Fig. 3 Mean of overall electricity consumption per km in selected months. Source: Processed by authors](image)

We performed regression analysis separately for the relationship total consumption - temperature, consumption of traction motors - temperature. The suitability of the chosen regression equation was assessed through the so-called coefficient of determination, which expresses the degree of causal dependence of two variables and is defined as the square of the correlation coefficient R. In linear regression, approximately 77.4% of the values ($R^2 = 0.774$) were explained by the line $y = 3.71 + -0.08x$. In the case of translating the measured values by the exponential function, it was possible to explain more than 80% of the values ($R^2 = 0.819$). This curve can be seen in Fig. 4, in which the consumption...
values in the summer and winter months are colour coded.

![Graph showing consumption vs temperature with regression analysis](image)

Fig. 4 Distribution of values and regression analysis. Source: Processed by authors

The second part of the mathematical-statistical analysis was focused on the relationship between electricity consumption for the electric bus electromotor and the ambient temperature. Due to the relatively low correlation coefficient ($R = -0.496$), only about a quarter of the consumption values were explained by regression analysis. We calculated the coefficient of determination $R^2 = 0.246$ in linear regression. With the exponential function, the coefficient of determination was $R^2 = 0.268$.

4. Conclusions

In our research, we tested the hypothesis: "There is a strong dependence between the ambient temperature and the total electricity consumption of the electric bus." As we showed, this consumption also includes the energy consumed for heating or air-conditioning the electric bus. Therefore, there is a strong dependence. We can confirm the hypothesis. Furthermore, we will answer the following research questions.

Q1: What is the exact value of the correlation coefficient between total electricity consumption and temperature? The value of the correlation coefficient is -0.880. It is a strong and indirect dependence.

Q2: What is the exact value of the correlation coefficient between the electricity consumption of the traction motor drive alone and the temperature? The value of the correlation coefficient is at -0.496. This value represents medium-strong indirect dependence.

Q3: What linear or exponential function is appropriate to express this dependence? With regression analysis, it is possible to estimate relatively accurately the development of the values of the total consumption of the electric bus in kWh per km depending on the ambient temperature. The exponential curve and its mathematical function are in Fig. 4.

The results of this research can be used in practice when planning daily driving distances in transport companies operating electric buses. Nowadays, the capacity of batteries for electric vehicles is still insufficient. Therefore, there is necessary to predict the electricity consumption in advance. As proved by a mathematical analysis of the obtained data, the ambient temperature has a significant effect on the consumption of the electric bus. We are sure that the monitoring of the ambient temperature will be necessary for the optimal use of electric buses. In future studies, we will focus on the other types of operated electric buses in Slovakia to prove that our assumptions are correct.

Acknowledgement

This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

References

Estimation of Environmental Footprint Caused by Freight Vehicles Using WIM Data in a Local Scale

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Abstract

Road transport has high share in freight shipments in Poland and is performed mainly by heavy duty vehicles with gross vehicle mass above 30 Mg. Unfortunately, speeding and overloading are also common. In these conditions environmental cost of road transport is rather high. In local scale, estimation of direct impact of road freight transport on environment needs more data than traffic volume. In this paper an environmental footprint for a road section on motorway S11 is estimated. Necessary set of data on load and speed of vehicles was obtained from four Weigh In Motion station. Vehicle categories according to emission standards are designed based on Eurostat data. Finally, energy demand, exhaust emissions of nitrogen oxides and particulate matter are calculated using COPERT model.

KEY WORDS: HDV, exhaust emission, WIM, freight

1. Introduction

Sustainable development of road transport requires an appropriate level of road safety and ensuring that the environmental impact is minimised. In Poland, transport emissions of greenhouse gas and air pollutants remain above the EU average. At the same time, road safety is poor and is one of the lowest in the EU [1]. In the case of a high share of road transport in freight shipments, there is a need for widespread application of solutions from the intelligent transport systems group for control speed, vehicle weight Gross Vehicle Mass and correctness of loading. It is well known, that speeding and overloading have a negative impact on road safety. The results presented in [2] shows that speed limit violation by heavy-duty vehicles in Poland is commonplace. Moreover, vehicles with excessive gross weight are also a larger source of environmental pollution. This regards both the increased emissions of harmful products of fuel combustion in engines and particulates resulting from the wear of breaks, wear of tires and increased noise [3]. The vehicle is overloaded when gross weight or the load on at least one of the axles is greater than permissible. Limit values of those parameters are set out in Council Directive [4]. More than 100 preselection high speed Weigh in Motion (HS-WIM) stations have been installed to control weight on national roads in Poland. However, the practice effectiveness of HS-WIM station in eliminating overloaded vehicles is limited and the share of overloaded vehicles in traffic is still high [5]. In this work, we tackle the issue of environmental cost footprint estimation due to the freight vehicles movement at the selected section of the expressway in Poland.

2. Methods

2.1. Study Locations

The study was carried out for an approx. 30-km section of the S-11 expressway. It also partially serves as the western bypass of the Poznań city – the fifth most populous (533,830 inhabitants in June 2020) and sixth in terms of area (262 km²) city in Poland. There are two road nodes of national importance in the section – the A2 motorway (with the status of the European route E30) and the national road No. 92 parallel to it. Therefore, in the studied section S-11 road takes over the transit traffic and provides fast access to A2 motorway – Fig. 1.

The section under consideration comprises two carriageways with two lanes each, the design speed is 100 km/h, the gradient does not exceed 3.5% and the permissible vehicle axle load is 115 kN/axle. The traffic in the section is characterised as very heavy (traffic category KR 6). The averaged share of heavy-duty vehicles on the section was 21.5% in 2015.
2.2. Data Collection

The study used data on traffic volume, speeds and weights of vehicles recorded by 4 pre-selective weighing stations managed by General Directorate for National Roads and Motorways. Stations are located on the analysed section of the S11 road, two in each traffic direction (Fig. 1). The distance between the stations was 26.1 km in the south direction and 24.5 km in the opposite direction, respectively. The analysis period covers 29 days from 01.03.2021 to 29.03.2021.

WIM stations detect vehicles passing through the measuring station and record the following data [6]:
- the individual wheel and axle loads of the vehicle;
- total vehicle side loads;
- the distance between the various axles of the vehicle;
- the total mass of the vehicle;
- vehicle length;
- information about the exceedance of: maximum axle load, a group of axles load, the total weight of the vehicle or vehicle combination, together with the value of the excess;
- the maximum permissible weight of the vehicle, according to the recognised vehicle class and the data stored in the system;
- vehicle speed.

Each WIM station shall provide appropriate measurement accuracy according to the specifications shown in Table 1.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Accuracy class - δ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total weight (&gt; 3,5t)</td>
<td>B+(7)</td>
</tr>
<tr>
<td>Individual axle weight</td>
<td>7</td>
</tr>
<tr>
<td>Axle weight in a group</td>
<td>11</td>
</tr>
<tr>
<td>Group axle weight</td>
<td>14</td>
</tr>
<tr>
<td>Axle specing</td>
<td>10</td>
</tr>
<tr>
<td>Speed</td>
<td>3</td>
</tr>
</tbody>
</table>

In 2018, 85.4% of EU road freight transport was done by vehicles with a Gross Vehicle Mass over 30 Mg. In Poland, the shares of vehicles with GVM 30–40 Mg and over 40 Mg in road freight transport are equal to 91.5% and 2.2% respectively [7]. Therefore in this work, we consider two main classes of freight vehicles, the GVM 34–40 Mg class and the GVM 40–50 Mg class.
2.3. Calculation of Energy Consumption and Exhaust Emission of NOx and PM

The environmental footprint of freight vehicles can be defined in terms of individual negative impacts of road vehicle operation, in particular emissions of toxic exhaust gases, emission of CO₂, noise and fuel consumption. In this work energy demand and exhaust emission of nitrogen oxides and particle matter are calculated based on data given for method Tier 3 in COPERT model [8]. In this method, energy consumption factor (ECF) and road emission factors (EF) for a given category of heavy-duty vehicles is calculated using values of average speed, load factor and road slope. Due to lack of detailed data, all calculations were carried out ignoring local road slope values corrections. However, the omission of this factor is compensated to some extent by a combined analysis of both traffic directions. The calculations used factors for articulated trucks with semi-trailer, belonged to a class with GVM 34–40 Mg \((k = 1)\), and class with GVM 40–50 Mg \((k = 2)\). Each of the main categories includes subcategories with reference to the emission standard (EURO). Then averaged ECF \([\text{MJ/km}]\), \(\text{EF}_{\text{NOx}} [\text{g/km}]\) and \(\text{EF}_{\text{PM}} [\text{g/km}]\) for given GVM class were calculated as:

\[
E_{\text{x,k}} = \sum_{i=1}^{m} \alpha_{i,j} \sum_{j=1}^{n} E_{\text{speed}, \text{load factor}} \cdot \beta_{i,j},
\]

(1)

where \(x\) – ECF or EF; \(m\) – given emission subcategories; \(n\) – given load factor subcategories; \(\alpha_{i,j}\) and \(\beta_{i,j}\) – share of given subcategory in the set of vehicles of GVM class \(k\) in relation to \(i\)-th emission standard and \(j\)-th load factor respectively.

Factors \(E_{\text{x,k}}\) in COPERT model can be calculated for a wide range of average speed but only for three discrete load factors (empty, half load, full load vehicle). Carrying out the calculation for overloaded vehicles according to Eq. (1) requires the estimation of the value of an appropriate coefficient. To the authors’ knowledge, no databases are available that define ECF or EF when vehicle load is over 100%. Therefore factors \(E_{\text{x,k}}\) for overload vehicles were calculated by using linear extrapolation of known values for three discrete load factors at a given average speed. Total energy demand and exhaust emission of NOx and PM are calculated simply as:

\[
E = \sum_{i=1}^{k} N_k \cdot L \cdot \bar{E}_{\text{x,k}},
\]

(2)

where \(E\) – total energy demand when \(\bar{E}_{\text{x,k}}\) is averaged ECF for a given traffic composition, or total emission when \(\bar{E}_{\text{x,k}}\) is averaged EF; \(N_k\) – number of vehicles in the category \(k\); \(L\) – length of the discussed section.

3. Results and Discussion

The freight vehicle classes included in the study belong to the 5th category of vehicles according to the COST 323 [9]. In the analysed period, a total of 730,760 vehicles passed through the section in both directions, including almost 60,000 articulated trucks with semi-trailers belonging to the considered GVM categories, of which more than 15% were marked as overloaded. Vehicles within both classes were assigned to one of four sub-categories based on their load level. Statistics for data recorded by WIM stations are presented in Table 2.

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>GVM 34–40 Mg</th>
<th>GVM 40–50 Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcategory</td>
<td>Number</td>
<td>Share %</td>
</tr>
<tr>
<td>Empty</td>
<td>1775</td>
<td>3.03</td>
</tr>
<tr>
<td>Half load</td>
<td>22,575</td>
<td>38.49</td>
</tr>
<tr>
<td>Full Load</td>
<td>25,418</td>
<td>43.34</td>
</tr>
<tr>
<td>Overload</td>
<td>8881</td>
<td>15.14</td>
</tr>
</tbody>
</table>

Data presented in Table 2 show that 98% of articulated trucks with semi-trailer belonged to a class with GVM 34–40 Mg and 2% to class with GVM 40–50 Mg. Histograms of vehicle weight distribution are shown in Fig. 2.
Average vehicle speeds were determined for each subcategory by loading level. The average speeds of the vehicles are shown in Fig. 3.

In carried out calculations, a simplified structure of vehicles due to emission standard was assumed based on data about road freight transport performed by HDV’s in Poland [7]. The adopted breakdown based on Eurostat data is shown in Table 3.

<table>
<thead>
<tr>
<th>Emission standard</th>
<th>Percentage share in fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>EURO VI</td>
<td>45%</td>
</tr>
<tr>
<td>EURO V</td>
<td>20%</td>
</tr>
<tr>
<td>EURO IV</td>
<td>23%</td>
</tr>
<tr>
<td>EURO III and older</td>
<td>12%</td>
</tr>
</tbody>
</table>

The averaged factors $E_{x,k,i}$ were calculated taking into account the percentage share of given emission categories and traffic statistics data using Eq. (1). The results are presented in Table 4.

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>$E_{x,k,i}$ ECF [MJ/km]</th>
<th>$E_{x,k,i}$ EFNOx [g/km]</th>
<th>$E_{x,k,i}$ EFPM [g/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVM 34–40 Mg</td>
<td>10.82</td>
<td>2.27</td>
<td>35.8·10^{-3}</td>
</tr>
<tr>
<td>GVM 40–50 Mg</td>
<td>11.99</td>
<td>2.39</td>
<td>38.4·10^{-3}</td>
</tr>
</tbody>
</table>
Then calculate the total energy demand and exhaust emission of NO\textsubscript{x} and PM according to Eq. (2), the values shown in Table 5 are obtained.

### Table 5

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Energy demand [TJ]</th>
<th>NO\textsubscript{x} emission [Mg]</th>
<th>PM emission [Mg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total value</td>
<td>32.8</td>
<td>6.87</td>
<td>0.108</td>
</tr>
</tbody>
</table>

The external cost of exhaust emission for the analysed period and road section can be calculated using the data given by Research and Statistical Education Centre [10]. The cost of NO\textsubscript{x} and PM exhaust emission at motorways in 2015 was 16,813 Euro/Mg and 65,647 Euro/Mg respectively. Thus, per day the cost of exhaust emission on the analysed section is approximately 4,200 Euro.

### 4. Conclusions

Weigh-in-motion stations can be an excellent data source for statistical purposes as well as for transport environmental footprint estimation. Based on the analyses, the authors indicate that the percentage of overloaded articulated trucks with a semi-trailer on the selected road was significant and reached over 15%. As a consequence, it has to be noted that estimations of pollutant emission for a local scale should also consider overloaded vehicles. In the study, the authors use data recorded by WIM stations and COPERT model for the calculation of energy demand and exhaust emissions of nitrogen oxides and particulate matter. The averaged energy consumption factor and road emission factors of NO\textsubscript{x} and PM calculated for freight vehicle class with GVM 40–50 Mg are approximately 10%, 5% and 7% higher than for vehicle class with GVM 34–40.

### Acknowledgement

The authors would like to thank the General Directorate for National Roads and Motorways for providing access to their measurement data.

### References

Market Liberalisation of Railway Freight Transport in Croatia

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Abstract

Railway freight transport was liberalised on 1st July 2013 with Croatia's entry into the European Union. In the Croatian Railway Act was predicted that from the date of Croatia's accession to the European Union licenses issued to railway undertakings by other member states competent authorities would be accepted. First new railway freight undertakings were founded in the same year. New rail freight undertakings today cover half of the freight market. Today on the railway freight market are present ten companies. Effects on the liberalisation of the railway market services are being researched. Data for impact analyses of railway freight transport liberalisation was used from the following sources: (1) Eurostat, (2) Infrastructure Manager, (3) Regulatory Bodies, (4) Independent Regulators' Group – Rail and (5) Croatian Bureau of Statistics. The analysis will show the actual situation and the impact of rail freight transport liberalisation through railway infrastructure usage according to (1) train kilometres, (2) number of railway undertakings, and (3) transported goods. The research results show the effect of liberalisation in the rail freight market in a relatively small market such as Croatian.

KEYWORDS: railway freight transport, liberalisation, regulation, railway undertakings

1. Introduction

In literature [1], we have many definitions of the term "Liberalisation" some of the authors define Liberalisation in the most acceptable in below.

Liberalisation is a technical concept describing processes of market restructuring and change. Liberalisation has a markedly normative dimension, reflecting views on the optimal operation of markets and society beyond. Contemporary discourse is complicated by the fact that it is often unclear which dimension is invoked; or, where potentially both, the extent to which views on one colour approaches to the other. Moreover, although liberalisation is not a settled legal term of art, it has a significant presence within both substantive law and law-making procedures. Both processes and underlying policy objectives thus need to be cognisable in legal terms. [1].

Liberalisation was often a watered-down version of privatisation schemes that had been compromised in the political process. The thesis develops an alternative privatisation model centred on a concept of market-based integration and a competitive market [2].

Liberalisation, the loosening of government controls. Although sometimes associated with the relaxation of laws relating to social matters such as abortion and divorce, liberalisation is most often used as an economic term. In particular, it refers to reductions in restrictions on international trade and capital. Liberalisation is often treated as synonymous with deregulation - that is, removing state restrictions on business. In principle, the two are distinct (in that liberalised markets can still be subject to government regulations—for example, to protect consumers). Still, in practice, both terms are generally used to refer to the freeing of markets from state intervention [3].

It can be concluded that liberalisation is the withdrawal of the state from the provision of certain public services, privatisation of service providers or services, and the creation of prerequisites for the emergence of competition in monopolistic markets.

The liberalisation of the railway market was feasible by the establishment of the legal framework that created the preconditions for free and non-discriminatory access to railway infrastructure.

In this process, it was necessary to separate and define the activities of railway infrastructure management and transport, define special requirements for the transport operation, and provide various services enabling the operation of railway transport.

The fulfilment of the aforementioned preconditions enabled the transition of the monopolistically structured railway market towards a market in which there is competition among service providers. This paper elaborates on present the adoption of railway regulations at the level of the European Union and Croatia, which were a prerequisite for creating a legal basis for the opening of the railway market.

The research has shown the development of the railway freight transport market of the European Union and Croatia since the liberalisation, i.e. Croatia's accession to the European Union (since 2013) and the emergence of new railway freight undertakings in the until then monopolistic railway market. The results are presented in the form of tables and graphs through the number of undertakings and various traffic indicators showing the development of the railway freight
2. Railway Liberalisations in European Union

The liberalisation of the railway market understood as the opening of the railway sector to several operators, including non-state-owned companies - is one of the most important tendencies in the contemporary transport development in the European Union. It is seen as an instrument that should contribute to making railway transport more efficient and competitive. This policy of creating a common railway market which is formulated in several EU directives as "railway packages" - aims to revitalise railway transport in order to make it more attractive and to try to reverse the negative trend of its modal market. In fact, liberalisation (or deregulation) started at the national level (e.g. Sweden) as early as in the 1960s as a response to individual modes of transport requirements. The separation of infrastructure from railway transport is the crucial element that enables competition in rail transport. Competition in the rail market may have a different character, for example:

1. Vertically integrated rail companies.
2. Train operating companies with regulated access to track infrastructure); and,
3. Market between rail companies, which is connected with competitive tendering [4].

The liberalisation of the European Railway sector is based on the splitting of infrastructure and train operation. The overall goal of this process is defined clearly, in several documents and directives (European Community (1991), European Commission (2001), European Commission (2011), European Parliament and Council (2012)) [5].

Regarding the liberalisation process of the rail market at the European Union level, it is necessary to harmonise community and national rules. Still, both of them need to be non-discriminatory and enable control of that rules between all railways operators. At the level of the European Union, there were several legislative measures to create fair conditions for the liberalisation of rail transport to ensure a common European railway area. And must important all that measures were set to enable competition between existing and new railway undertakings. In 1991, implementing Council Directive 440/1997 EEC on the development of the Community was set a milestone for liberalisation of the rail freight market at the level European Union. The main goal of the Directive was to facilitate railway undertakings new rules and send a clear signal that the rail freight market is open and ready for newcomers. In the meantime, there were three so-called railway packages. Thus, an effort was to enforce common standards for different measures for opening the rail freight market. At one point, there were too many different decisions by different states members, so a decision was maybe to establish a supranational regulatory body. Regulation No. 881/2004 establishing a European Railway Agency (ERA). The Directive 2012/34/EU of the European Parliament and the Council define the issue of competitiveness of rail transport, establishing a single European railway area. This Directive basic requirements include creating appropriate procedures for allocating railway infrastructure capacity to achieve a better balance between others modes of transport. Train access charges need to be calculated at the level of direct cost that is the result of train movement, and also the level of train access charges need to be set to fulfil the transport demand. This action requires the necessity of using public funds. Spending public funds must also enable social benefits of the matter. Allocation and railway infrastructure capacity charging must directly connect to quality of service of infrastructure and trains [6]. By the deadline for the full implementation of the First Package had not been realised in 22 EU states. There there have been failures with the regulatory body, which has not been set up in every country and/or, is not independent. Another problem was that the infrastructure manager and their charging system were dependent of the railway's incumbents. However, the charge for a minimum access package should be the basis of competition and open markets [7].

Also, an important aspect of the European policy is to intensify the role of railway services. It is necessary to increase the competitiveness of railway transport compared with road. This can be achieved if rail provides efficient and attractive services. If we eliminate regulatory and market failures, barriers to entry and burdensome administrative procedures hamper efficiency and competitiveness. Liberalisation is one of the economic means to increase the competitiveness of railway transport in the transport market [8]. The entry of new railway companies into the transport market can increase the quality of rail services, technological modernisation, and competitiveness. Also, it allows the customer to choose between railway undertakings and hence stimulates the relationship between quality and price. [9-10].

EU railway transport liberalisation started with Directive 91/440/EEC, requiring railway companies to separate railway infrastructure from transport services. This was to be achieved initially by accountancy to ensure non-discriminative usage and the charging of rail infrastructure. Thus, it allowed new entries into the rail market and therefore induced competition. In the first instance, the Directive aimed to increase efficiency and transparency, especially in the case of subsidies. However, it has not been applied extensively and has had significant results only in the United Kingdom and Germany [10, 11].

In accordance with the development of the legislative framework of the European Union, each one of the member states shall adjust its national regulations and the liberalisation of the railway services market. Through the implementation of railway packages in the Member States, market liberalisation appears first as legal or so-called legislative liberalisation. The creation of legislative frameworks enables the operation of new railway freight undertakings on the so far, monopolistic market. After that, as shown in Fig. 1, there comes a practical liberalisation marked by the starting of operation of new freight undertakings in liberalised circumstances. According to Fig. 1, only in 26% of the 23 Member States shown, the practical liberalisation took place within a year from the legislative liberalisation. New freight railway undertakings in 22% of the Member States started transport activities within two years, and in the other 52% of
the Member States new freight railway undertakings only started their first transport activities after two or more years.

The development of the rail freight transport market of the Member States of the Union through the realised train kilometres, net tonne-kilometres and the total number of freight railway undertakings is shown in Fig. 2. In the analysed market development indicators, different trends were identified for the observed Member States. Thus, the total number of freight train kilometres until 2016 was following the increase or decrease in the number of freight railway undertakings, while the amount of net tonne-kilometres regardless of the number of undertakings and train kilometers from 2013 to 2018 was constantly growing. In the observed Member States, the liberalisation of the rail freight transport market positively impacted the total number of freight railway undertakings and the performance of undertakings through the number of the realised net tonne-kilometres net tonne-kilometres.

The share of the realised train kilometres of new freight railway undertakings in relation to historical freight railway undertakings of the observed Member States in the total number of realised train kilometres is shown in Fig. 3. The share of the new freight railway undertakings in train kilometres since 2013 was gradually increasing. New freight railway undertakings their share from 29% since enlarged their share of 29% in 2013 to 39% by 2019. The share increase of 10% of new freight railway undertakings is a trend that individually follows all countries in which the freight railway market has been liberalised and is an indicator of a positive shift in the market development and healthy competition in freight rail transport.
Fig. 3 Share of domestic incumbent and non-incumbent in EU. Source: authors using EUROSTAT and IRG-RAIL [17,18]

3. Railway Liberalisations in Croatian

Liberalisation of rail freight transport in the European Union began in the early '90s. The first countries that liberalise rail freight transport were the United Kingdom and Germany. European Commission with Railway packages establishes a single railway market. Market development is monitored through the emergence of new railway undertakings, the use of railway infrastructure and the amount of transport realised. In addition to infrastructure managers, operational service facilities are also appearing on the market, which also provide railway-related services and are part of the railway services market. Liberalisation of the railway services market seeks to raise the quality of railway services and reduce the costs of maintenance, regulation, and management of railway traffic. The provision of infrastructure capacity and the collection of fees increase the financial benefit to infrastructure managers and reduce financial assistance to the Member States.

The entire European rail freight market was fully opened in 2004 with a second rail package. Member States have gradually implemented European legislation, allowing access to domestic and international rail freight. According to the Croatian Railways Act (OJ No 53/94, 139/97 and 162/98), railway activities in the Republic of Croatia could be performed just by the only public company HŽ - Hrvatske željeznice d.o.o. Amendments to the Railways Act (OJ No 123/03, 30/04, 153/05, 79/07, 120/08 and 75/09) and the accession of the Republic of Croatia to the European Union on 1st July 2013, railway licenses issued to railway undertakings by other Members States were also recognised. New railway undertakings which enabled the arrival of new carriers on the liberalised railway infrastructure of the Republic of Croatia. In addition to opening up the railway market, European legislation also required the regulation of the railway services market. The first measures relate to the implementation of accounting separation for the purpose of transparent management of infrastructure and transport. This required additional amendment to the Railway Act, and in order for the Republic of Croatia to harmonise with the EU legislation, the implementation of Directive 34/2012 is in Croatian legislation in the Railway Act (OG 94/13). After the legal liberalisation in the Republic of Croatia in March 2014, there was a practical liberalisation when the first new railway undertakings met all the conditions for performing the activity of railway freight transport. However, competition rights in rail freight began in 2015 when new freight carriers began to operate more serious services. The Railway Act defined railway market which consists of services and operators. On the market, an infrastructure manager and operators of service facilities supply services. Those services are grouped as appropriate use in several groups:

1. Minimum access package;
2. Access to service facilities and to the services provided in these facilities, including track access to service facilities;
3. Additional and
4. Ancillary services. [13]

In Europe and Croatia, railway infrastructure is defined as a public good in general use, which under equal and transparent conditions should be available to all applicants [14]. The liberalisation of the railway market increase to the quality of railway services for the applicants, and at the same time reduce costs of railway infrastructure for the amount of charges which is collected from the applicants [15, 16].

Railway freight market development is reflected in the increasing number of railways incumbent, but also in the number of Railway Undertakings and the amount of services used, which will be presented through traffic indicators of the market in the part of this research.

Legislative liberalisation of rail freight transport in Croatia took place before the accession to the European Union, as can be seen in Fig. 1, because in 2009 a legislative framework was created to liberalise the railway transport market, and only in 2014 did practical liberalisation take place. With the accession of Croatia to the European Union in 2013, the first freight railway undertakings appeared that have been doing more intensive transports since 2015, which is shown in Fig. 4. A larger number of active railway freight undertakings results in greater number of activities in the transport market and has a positive impact on transport indicators and especially on net tonne-kilometres, which is also shown in Fig. 4.
A larger number of new freight railway undertakings affects a larger share of them in the realised train kilometers, which can be seen in Fig. 5. Greater transport activities were carried out by new undertakings as early as 2016 when they held 15% of the total market share in realised train kilometers. The share of realised train kilometers of all the new freight railway undertakings since 2013 quickly reached the European level and in 2019 it was already 38%. In just 4 years, the new rail freight undertakings have managed to achieve significant business results and hold 38% of the market share which is an indicator of healthy competition and great progress in the development of the rail freight market in Croatia. In just 4 years, new freight railway undertakings in Croatia have reached the average of the European Union countries in which the freight railway market had been liberalised much earlier than it was in Croatia.

4. Conclusions

The liberalisation of the European Union's freight rail transport market is a complex legally demanding and practically long-term process that began in the 1990s. With the adoption of the first legislative recommendations by the European Commission for the definition and implementation of regulations of the European Union, began a new era of rail transport. By adopting a legislative framework, Member States created a precondition for legislative liberalisation that was followed by practical liberalisation. Freight railway undertakings participated in the creation of the railway transport market by their transport activities, but prior to those activities they had to meet all legal prerequisites for obtaining the licenses to do railway freight transport activities. The first legislative liberalisations in the two European countries, the United Kingdom and Germany, occurred in 1994, but practical liberalisation did not still occur. In the countries of the European Union, in as many as 52% of them, it took over two years for the new freight railway undertakings to start doing transport activities in liberalised circumstances. The same case occurred in Croatia, where the new freight railway undertakings started doing their activities five years after the legislative liberalisation was established. New rail freight undertakings started their first transport activities in the liberalised freight transport market, until then, there was only a freight railway undertaking which had 99% of the market share from 2015 to 2019 participating with a 62% market share, when looking at the total realised train kilometers. The development of the overall European railway market observed through the number of railway freight undertakings, net tonne-kilometres and train-kilometres cannot be connected as rect dependence determinedly their until 2019. Their activities five years after the legislative liberalisation and it is impossible to identify their direct dependence as the number of train kilometers and the number of freight railway undertakings varies while the net tonne-kilometres indicator recorded a steady growth from 2013 to 2018. It was only at the end of 2015 that new freight railway undertakings started operating in Croatia with a share of 15% in train kilometers, while in the same year the European share was already at 34% that continued until 2019 when the European average was reached on the Croatian freight transport market.

A significant positive growth trend and rapid takeover of the freight railway transport market by new freight
railway undertakings in Croatia was a consequence of market liberalisation and the creation of positive market opportunities that undertakings recognised and reached the European average in just 4 years. The market liberalisation has created the preconditions for new services and new players in open markets, which ultimately leads to the emergence of healthy competition and increased quality in the provision of all services in the railway services market. The number of new freight railway undertakings is gradually growing, the market is expanding through new services, and the amount of work done is growing, which is a positive shift in a small transport market such as Croatia and a significant indicator of the positive impact of liberalisation on the market development.

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AIS AtoN Network Simulation on the Dangerous Section of the Dnieper River

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Abstract

Every year, vessels run aground due to the fact that the navigation mark and notices were not recognized in time, especially in narrow areas with poor visibility, which causes great losses for both shipowners and government organizations. The design principles of a monitoring system for ships should be used to provide auto-configuration capabilities. The presented method is based on the development of a program, the logic of which will ensure the automatic placement of virtual buoys in places of increased danger. The work also developed and tested the requirements for finding the optimal location for the placement of V-AtoNs, taking into account the navigation conditions and the maneuvering elements of vessels.

KEY WORDS: monitoring system, auto-configuration, V-AtoNs

1. Introduction

In maritime and inland navigation, AIS or IAIS networks assume to enhance the characteristics of classic AtoNs (Aids to Navigation) for instance, equipment, such as radar, SNS (Satellite Navigation System), ECDIS, etc. For example, by means of special messages, it is possible to send position information and significance of the AtoN, as well as information concerning deviation of the buoy from the required position on the value exceeding permissible one. Such message can be transmitted by a specific AIS AtoN station located on a buoy, wind power plant, beacon or directly on the AIS shore station.

The main purpose of the AIS AtoN station is to assist and increase the safety level and efficiency of navigation in one or more of the following ways:

- maintaining of reliable means of identification in any weather conditions;
- transmission of messages concerning the accurate location of AtoN;
- indication of AtoN deviation from the required position on a distance greater than the permissible value which displayed on ECDIS charts through alarm signal;
- using virtual AIS AtoNs provide additional capabilities in a case when the installation of real buoy is difficult or impossible due to technical or functional reasons;
- maintaining of operational/temporary designation of new factors of navigational hazard (static or dynamic) using virtual AIS AtoNs.

There are two options for synthetic AIS AtoN: monitored and predicted. Predictable synthetic AIS AtoN does not imply tracking to confirm the position or condition of the buoy. It is acceptable to use such a message for fixed aids to navigation, as their location remains unchangeable, but its status cannot be verified.

Monitored synthetic AIS AtoN is equipped with a position sensor and a communication line between the AIS station and AIS AtoN, which confirms the position and condition of the buoy.

A synthetic buoy can be equipped with an additional sensor that records deviations in water level, wave height, wind force, current speed, as well as clearance value when passing under the bridge. These options enable to calculate the risks connected with possible changes in the fairway.

The transmission of a virtual AIS AtoN message provides all vessels equipped with AIS and an ECDIS with the ability to receive, under any visibility conditions, accurate information regarding the type, name, and location of the AtoN status. A prerequisite for using the AIS AtoN system is the unconditional availability of Inland AIS and ECDIS on all vessels.

In some cases, three different locations of the AIS AtoNs can be observed by the navigators: radar marker, electronic chart and AIS location. The harmonization of standards will help to reduce this problem to a minimum [1].
To improve the safety of navigation, the location of AIS AtoN should be determined most reliably and optimally adopted in navigation. For determining the location of synthetic and virtual aids to navigation, the following factors were taken into account: navigation, hydrographic and hydrometeorological conditions in the navigation area, established routes of movement of vessels (fairway), types of vessels operating in this area, the nature and characteristics of navigation hazards, as well as analysis of the accident rate of vessels.

2. Research

As an example, it was considered a sea-river «Slavutich» type vessel. It is one of the most typical vessels operating on the Dnieper River with standard dimensions: length overall - 109 meters, breadth - 16 meters, draft - 3.2 meters.

For ensuring safe maneuver it is necessary to determine the turning radius of the vessel by the formula [2]:

$$R_T = 0.95 \frac{V}{W_T},$$

(1)

where \(V\) – vessel velocity, m/s; \(W_T\) – angular velocity, rad/s.

Further, the distance on the route was calculated between the wheel over point (WOP) and the previous waypoint (WP). The \(AC\) segment is calculated in each specific case according to the formula [3]:

$$\overline{AC} = R_T \tan \left( \frac{Q}{2} \right),$$

(2)

where \(R_T\) – turning radius, m; \(Q\) – vertex of the angles of the turn, rad.

Fig. 1 shows a schema of a safe turn of the vessel, where \(WOP_1\) is the preparation point for the start of the turn, \(A\) – the starting point of the turn, \(WP_1\) – the vertex of the turning angle on the first point, \(WOP_2\) – the finishing point of the turn, \(WP_2\) – the vertex of the angle of the turn on the second point, \(Q_1\)and \(Q_2\) – the vertex of the angles of the turn to the corresponding rotation arcs.

![Fig. 1 Schema of a safe turn of the vessel](image)

To determine a safe maneuver, the distance to the next turn must be taken into account, i.e. the length of the segment \(WOP_2 - WP_2\) should allow the vessel safely complete the first maneuver before the second. Thus, the following inequality must be maintained:

$$\overline{WOP_1 - WP_1} > \overline{WOP_1 - WP_2} + \overline{WOP_2 - WP_2}.$$  

(3)

Determination accuracy of the AtoN position depends on the applying method such as the differential, radar, or satellite correction. The accuracy assessment depends on the using detector, the transmission time from the detector to the receiver, and what type of receiver is installed on the satellite or radar. The DIF correction depends on the distance to the correcting station. For V-AtoN, the position of the buoy is determined relative to the inaccuracy of the fairway change, which is an error in determining the coordinates of the virtual buoy. Under conditions of fairway changing, the resulting error is predictable and calculated by extrapolation.
It is proposed to install a synthetic AIS AtoN on a selected dangerous section of the river for ensuring the transmission of the virtual buoys. Synthetic AIS AtoN was installed on the lateral buoy which is placed not at the turning point, in order to prevent the risk of crushing of expensive equipment by the vessel.

For convenience and simplicity of the solution, as an example, it was decided to use three points for installing virtual buoys on the passage during turning of the vessel, as shown in Fig. 3. The first and third buoys are installed along the tangent of the circle and the plotting route, the second at the intersection of the line drawn from the center of the circle to WP.

Fig. 3 shows the symbol of the virtual buoy on the ECDIS which indicates safe water.

Fig. 4 shows symbols of synthetic and virtual AIS AtoNs and how navigators observe it in real conditions [4].

<table>
<thead>
<tr>
<th>Green Lateral Buoy</th>
<th>Red Lateral Buoy</th>
<th>Safe Water Mark</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIS</td>
<td>AIS</td>
<td>AIS</td>
<td>Real / Synthetic AIS AtoN</td>
</tr>
<tr>
<td>V-AIS</td>
<td>V-AIS</td>
<td>V-AIS</td>
<td>Virtual AIS AtoN</td>
</tr>
</tbody>
</table>

Obtained results are summarized in Table.
Table

Coordinates of synthetic and virtual AIS AtoNs on dangerous sections of the Dnieper River

<table>
<thead>
<tr>
<th>Section</th>
<th>№ 1</th>
<th>№ 2</th>
<th>№ 2a</th>
<th>№ 3</th>
<th>№ 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_1, ^\circ$</td>
<td>31°</td>
<td>39°</td>
<td>35°</td>
<td>42°</td>
<td>34°</td>
</tr>
<tr>
<td>$AC, m$</td>
<td>388</td>
<td>485</td>
<td>438</td>
<td>525</td>
<td>425</td>
</tr>
<tr>
<td>$R_T, m$</td>
<td>1147</td>
<td>1443</td>
<td>1295</td>
<td>1554</td>
<td>1258</td>
</tr>
<tr>
<td>WPWP</td>
<td>correct</td>
<td>correct</td>
<td>correct</td>
<td>correct</td>
<td>correct</td>
</tr>
<tr>
<td>&gt;WOPWP &lt;WOPWP</td>
<td>correct</td>
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</tr>
<tr>
<td>Synthetic AIS AtoN ($\varphi_s, \lambda_s$)</td>
<td>47°46′11″N 35°09′27″E</td>
<td>48°05′08″N 35°02′21″E</td>
<td>48°05′08″N 35°02′21″E</td>
<td>48°10′23″N 35°11′44″E</td>
<td>48°27′18″N 35°05′27″E</td>
</tr>
<tr>
<td>V-AIS №1 ($\varphi_1, \lambda_1$)</td>
<td>47°46′16″N 35°09′12″E</td>
<td>48°05′18″N 35°02′39″E</td>
<td>48°05′57″N 35°02′49″E</td>
<td>48°08′17″N 35°11′12″E</td>
<td>48°27′31″N 35°05′27″E</td>
</tr>
<tr>
<td>V-AIS №2 ($\varphi_2, \lambda_2$)</td>
<td>47°46′27″N 35°09′08″E</td>
<td>48°05′21″N 35°02′41″E</td>
<td>48°06′18″N 35°02′53″E</td>
<td>48°08′51″N 35°11′36″E</td>
<td>48°27′53″N 35°05′09″E</td>
</tr>
<tr>
<td>V-AIS №3 ($\varphi_3, \lambda_3$)</td>
<td>47°46′34″N 35°09′14″E</td>
<td>48°05′25″N 35°02′43″E</td>
<td>48°06′24″N 35°03′11″E</td>
<td>48°09′08″N 35°11′26″E</td>
<td>48°28′08″N 35°04′44″E</td>
</tr>
</tbody>
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Fig. 5 shows virtual and synthetic AIS AtoNs which are auxiliary marks for vessels.

For implementing the chosen method, it is necessary to solve the problem of possible deviations between the image on the radar and on the electronic chart. It can occur due to the fact that the virtual AIS AtoNs are dependent to the coordinates used in ECDIS, however, during navigation, the location of the virtual buoy on the ECDIS and the radar image may not coincide. Under good maritime practice, the navigator should give priority to radar information when choosing a safe route.

Virtual AtoNs are not related to the radar bandwidth (S-band, X-band). The display of the same target on AIS
and RADAR can be different. The AIS operation is based on the reception and transmission of messages in the VHF range. The AIS transmitter operates at longer wavelengths than radars, which makes it possible to exchange information not only at distances of direct visibility area but also with obstacles in the form of not very large objects, as well as in bad weather conditions.

The deviation between the virtual AIS AtoN on the radar and on the electronic chart is due to the fact that the image on the ECDIS is attached to coordinates, and on the radar to reference marks (points) on the ground. Even if AIS AtoN will be arranged according to the coordinates, the image on the radar may not correspond to the required (selected/determined) position of the buoy. To avoid this situation, assess of the risks must be assumed, such as changing the fairway during a flood, accelerating of a current, large flow of sand, silt, etc. It is necessary to determine with what probability the described situations are possible.

Thus, it is essential for navigators have clear understanding what means synthetic and virtual AtoNs. There is a possibility of missing important information in case if navigators would not be properly trained [5].

Information in the VHF range is transmitted through the AIS system, which limits its effect. Using satellite systems is quite expensive. For increasing the level and expanding the area of signal reception, a satellite system can be used, however, it is practically inaccessible for transport vessels due to its high cost.

In some sections of the river can be observed fairway position changes and sometimes very intense. Therefore, it is necessary to make recommendations for Sounding Party to take measurements not at the same time intervals, but attached to the situation. In this case, automatic level posts must be used as indicators, which are included in the AIS AtoN system. They can be installed both on shore and on synthetic buoys and record the speed and sequence of changes in the water level.

It should also be taken into account, that the transfer of information related to safety, exclusively by AIS means, is connected with risk, and also each additional virtual AIS AtoN increases traffic on the VHF AIS communication line.

In our article, we would like to warn against the thoughtless use of V-AtoNs, as well as the necessity to make assess the reasons of the deviations between the radar and the electronic chart in order to make the right decisions.

3. Conclusions

The study of the feasibility and practical applicability of the method must be considered on a case-by-case basis, taking into account the navigational conditions. It is necessary to calculate the risk assessment regarding safety as well as the reliability of the entire system. At the same time, individual solutions which concern using virtual aids to navigation equipment can be implemented in areas where accidents have been observed. It should be taken into account that each additional virtual AIS AtoN increases the traffic on VHF (very high-frequency bands) AIS communication line, therefore, it is necessary to install virtual buoys only in case of necessity.

Virtual aids to navigation can be resort to transfer specific information intended for a specific group, for example, vessels with a deep draft or special transport, etc. Modeling of the AIS AtoN network was carried out in dangerous sections of the Dnieper River, considering that the deployment of such a system is necessary only in the area of practical use with the highest probability of a navigational accident.

Using the AIS AtoN messages, in particular, the information received via the AIS network concerning virtual and real buoys makes it possible to increase the level of navigation safety in the area of their operation. However, it must be taken into account that not all vessels are still equipped with AIS AtoN message display systems, but this process is under development stage.

The risks connected with the installation of V-AtoNs are determined by the possibility of communication loss between the AIS base station, synthetic buoy and virtual buoys. As well as the risks associated with insufficient interference immunity of VHF communications in determine areas. It is necessary to have alternative energy sources for synthetic AIS AtoN and also maintain it in a constant abundance of electricity with a redundant power supply system.

It should be noted that the risk zone also includes the emergence of vandalism process by the private sector, therefore, the buoy should be provided with a security system.

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Prospects of Intermodal Transportation and Logistics Channels Development for Georgia

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Abstract

The paper discusses the importance of intermodal transportation and key elements in the geopolitical reality of Georgia, and provides relevant recommendations. Georgia's strategic geopolitical location determines the interest of neighboring countries, as well as European and East Asian countries, to use Georgia as a transit region. Globalization and growing economic ties with the EU provide a unique opportunity for Georgia to fully integrate into international trade. The transport and logistics sector should play one of the crucial roles in this process. In this regard, Georgia's integration into the EU transport system has a special importance, which implies the implementation of European standards and the improvement of transport links. The article also emphasizes that through the developed infrastructure and quality services, Georgia will become part of the global supply chain, which will have a positive impact on the development of manufacturing and export activities in the country.

KEY WORDS: logistics, maritime transport, Caucasus Transit Corridor, intermodal operations.

1. Introduction

The existence and development of society are impossible without transport. In modern conditions, transport is an integral part of economic activity and is a means of transportation for both people and cargo (goods). Almost all types of transport are developed in Georgia: rail, road and air, as well as seaports, oil and gas pipelines, which facilitates Georgia's integration into the international transport network. This, in turn, is a guarantee of security and economic development of the country.

Georgia has the potential to become a regional transit hub and increase its share of transit cargo. Georgia's oil and gas pipelines, Black Sea ports, East-West Highway, and airports play an increasingly important role in connecting East and West. At the same time, Georgia is a vertical (north-south) transport link between Russia and Turkey and, via Armenia, Iran. The government approved a 10-point action plan to make the country a regional center ("hub") and persistently began to improve border management [1]. Moreover, it has made it possible for the private sector to participate in the port sector, in parallel with the strengthening road infrastructure along the East-West Highway. Railway reform was implemented and rail transportation services were moved to a commercial basis. Also, the commercial civil aviation sector operates in a completely liberal mode.

Positioning Georgia as a transport and logistics hub is one of the most ambitious and interesting projects of modern Georgia. Part of this project has already been implemented. Reviewing the map of the region is enough to understand the strategic location of Georgia in relation to the transport arteries in the region. Some of these transport corridors date back to antiquity, including sections of the Silk Road.

Georgia is an active participant of TRACECA (Transport corridor for Europe-Caucasus-Asia), the Middle Transport Corridor and other international transport corridors. Talks are underway on the GUAM transport corridor from Poland to Baku (Organization for Democracy and Economic Development - GUAM is an international regional organization which includes: Georgia, Ukraine, Azerbaijan and Moldova.). Georgia also has expressed interest in participating in the New Silk Road Initiative. A new platform, the Three Seas Initiative, has emerged, linking the Baltic, Adriatic and Black Seas. Georgia should also express interest in participating in this initiative (Fig. 1).

Some of these initiatives are multidimensional and sometimes even act in favor of various economic and geopolitical interests. This creates favorable conditions for action in line with the state interests of Georgia and the strategic vector of economic and political development. The crisis caused by Covid-19 has expanded the opportunities available for Georgia in this regard: instead of price, credibility and flexibility have become crucial in organizing industrial and supply chains [2].

As a result of economic and infrastructural reforms carried out in recent years, the transport and logistics sector has developed significantly in Georgia. As a consequence of infrastructure modernization, simplification of customs procedures and liberalization of services in key sectors of the economy, the country's transit and logistics potential has been enhanced, ensuring better international connectivity with global markets. Georgia is currently upgrading and expanding its transport infrastructure, which includes a growing national expressway system, new rail routes, international airports, and expanded seaports / terminals. At the same time, continues legislative rapprochement with the EU in the field of transport, which is a priority issue in the process of Georgia's European integration.
The development of the country's infrastructure, transport, logistics, communication, energy, technological, educational and financial hub systems is important for the realization of Georgia's potential as a regional hub for the long-term economic development of the country [3, 14, 15].

Despite the successes achieved, a number of challenges remain to transform Georgia into a regional transit and logistics hub. Low quality of service, outdated logistics infrastructure and equipment, inefficient supply chain management, as well as lack of workforce organization and qualified staff – all of these are an incomplete list of problems in the field of transport and logistics. This will require continued efforts to improve transport infrastructure and services until the existing limiting factors are fully addressed.

It should be noted that the ongoing infrastructure projects in the country and the region, economic development, visa liberalization, significant progress in the tourism sector before the global spread of the Covid-19 pandemic, led to a significant increase in the movement of individuals, cargo and traffic through customs checkpoints. Therefore, in order to ensure further growth of the throughput rate, the issue of modernization / expansion of the existing checkpoint infrastructure is on the agenda. In this context, the importance of modern standards of existing customs checkpoints (land, sea, air, rail), international trade-oriented, risk-based, effective and fast customs control, as well as the construction of new checkpoints is becoming more important [3, 15].

2. Object of Research

Efficient transport and logistics systems create opportunities and benefits for economic and social development that lead to positive cartooning effects such as increased access to markets, education, employment, and additional investment. Transportation and logistics in developed countries account for 6% to 25% of GDP (as of 2019, transport and warehousing in Georgia accounted for 6.5% of GDP, which is an important part of the country's economy). In addition to this, the increased cost and employment effects of transportation and logistics services usually outweigh the benefits generated by passenger and freight transportation and have a significant and indirect positive effect [3].

Cargo transport vehicles are characterized by constantly evolving dynamics, which primarily implies faster and more reliable services. In the global transport industry, intermodal operations are increasingly used to transport cargo, which underscores the importance of infrastructure connecting different modes of transport, especially at seaports and logistics centers (rail, road and air connection). Consequently, in order to ensure a continuous transport system, it is
important not only to create an efficient transport system for each type of transport, but also how different modes of transport interact. This tendency was conditioned by the possibility of containerization of cargo.

Georgian logistics field is going through a transformation process. The appearance of new international players in the Georgian market and the expansion of existing players are observed. Companies can develop types of logistics services through internal resources and outsourcing. However, the reasons for making this decision are important. The development of strategically designed internal logistics helps the company to maintain a high level of control over logistics processes and, accordingly, in maintaining quality. Procurement of strategically planned external services has a positive effect on the focus of the company. Most companies operating in Georgia prefer internal logistics, however, this is due to lack of knowledge about the benefits of using external service procurement, limited knowledge and skills in managing external service procurement projects in companies, lack of supply chain and logistics processes for monitoring external procurement effectiveness and etc. As a result, the cost of logistics services is high, which reduces the competitiveness of local companies.

Located at the crossroads of Europe and Central Asia, Georgia is a transit country that connects several important economic regions with a total population of 700 million. These include the European Union (448 million), the Commonwealth of Independent States (CIS) (240 million), Turkey (85 million) and the Caucasus region (17 million) [5]. The Caucasus Transit Corridor (CTC) is a major transit route between Western Europe and Central Asia for the transportation of oil and gas, as well as dry cargo. CTC is part of the TRACECA International and Regional Corridor; It is an alternative to the Northern Corridor leading to the Russian Federation and Belarus in the north and the corridor leading to Turkey and Iran in the south, as Iran cannot accept cargo sent from Europe and the United States [6, 14]. Transit by type of transport accounts for about 60% of the total weight of cargo transported by land, 75% of Georgian rail transport and almost 80% of the volume of cargo handled by Georgian ports [7, 10].

The development of trade and transit potential is crucial to Georgia's future. With a population of up to 4 million, Georgia's local market is much smaller than that of its geographical neighbors. Turkey, Azerbaijan, Kazakhstan and Turkmenistan together are about thirty times larger in terms of population, with an average purchasing parity three times higher than the Georgian market. In such a case, it is not difficult to understand why trade and transit are essential elements of Georgia's development plan. By using its central geographical location, the country can take advantage of some of the trade flows from west to east and, conversely, expand its participation in the international value chain by providing logistics services. This may include transportation, warehousing, forwarding services, and even value-added services related to the supply chain.

3. Results and Discussion

The need to develop the logistics sector in Georgia is also indicated by the World Bank Logistics Index (LPI), where according to the latest data, Georgia ranks 124th out of 160 countries. The LPI is an international ranking with six evaluation criteria, which covers the most important issues of countries' logistics efficiency. These criteria are:

- **Customs** – efficiency of border crossing procedures and customs clearance;
- **Infrastructure** - efficiency of logistics and transport infrastructure;
- **International Shipments** - Ease of organizing competitive international shipping with competitive prices;
- **Logistics Competence** - quality and competence of logistics services;
- **Tracking and Tracing** - Possibility of tracking and tracking shipments along the supply chain;
- **Timeliness** - the rate of timely delivery of cargo at the scheduled time.

The Logistics Index reflects the vision of international service providers and business operators on how countries are integrated into the global logistics network through their core trading gateways. Therefore, it reflects not only changes across the country, but also problems with access outside the country. For example, border crossing issues at border checkpoints in neighboring countries [8].

It should be noted that in the 2018 ranking, Georgia has improved its position by several steps compared to 2016. Despite the progress, the current situation is far from the desired indicators. According to 2018 data, a small improvement is observed in almost all components: Customs (2.38 points), Infrastructure (2.36 points), International Shipments (2.38 points), Logistics Competence (2.27 points), Timeliness (2.92 points). Only Tracking and Tracking rate deteriorated (2.37) (Table) [3].

The main reasons why the rate of tracking and tracing has decreased is the lack of integration of information and communication technologies and electronic data exchange systems and the low level of automation of logistics processes. GPS systems are rarely used in tracking and tracing operations, and more sophisticated radio frequency-based cargo/goods identification (RFID) systems are almost non-existent in Georgia at this stage. However, despite the fact that Georgia has invested heavily in road infrastructure development over the past decade, the logistics and intermodal infrastructure remains to be improved compared to developed countries, which leads to low efficiency, high cost and relatively low reliability of the logistics system operation. High costs negatively affect international shipping [3, 11].

In addition, the current level of knowledge and education in transport and logistics management in Georgia does not meet market requirements. Existing qualification standards for higher and vocational education need to be updated. Demand for skilled labor in the field of logistics and supply chain management is growing dramatically. Planned logistics centers, as well as the development of existing and new port infrastructure will increase this demand and deepen the shortage of logistics specialists. The shortage of experienced personnel in logistics is one of the serious obstacles to the inflow of foreign investment in this sector.
In Poti [7].

Inconvenient land access was one of the main challenges facing the ports of Batumi and Poti, however, work has begun in recent years to eliminate this challenge. In order to ease traffic jams in the vicinity of the Batumi port, the construction of a four-lane one-kilometer overpass at the entrance to the city was completed in July 2018. The overpass separated the Batumi container terminal and the entrances to the city, therefore, traffic jams were eased. Investments have been made to increase the capacity of container handling in the port of Batumi, ferry and container spaces were separated, which does not need the help of a pilot and tugboat, which makes ferry transportation more expensive to Georgia and from Georgia.

Most of the cargo flow in Georgian ports are transit. Dry, bulk and liquid cargoes are negatively impacted by declining economic activity in neighboring countries. Another challenge is the fact that Georgian ports do not have the terminal for ferry only, which does not need the help of a pilot and tugboat, which makes ferry transportation more expensive to Georgia and from Georgia.

In Poti, road transport is mobilized to berths, from where containers are unloaded from ships and transported to container terminals away from the berth. However, most trucks that transport containers in both directions are outdated and unreliable. Also unfavorable is the quality of access roads and terminal equipment to terminals away from the port, which hinders the processing of containers and significantly increases the duration of ferry operations, which has a very negative impact on the port's competitiveness. Accordingly, the port system needs to be improved in order to increase the productivity of the port [9].

Supply chain management in Georgia is at an early stage of development. Although third-party logistics service providers are present in Georgia, they do not offer a full range of services to customers, as in countries with relatively more developed economies, and are mainly transit-oriented. A small number of well-developed companies are vertically integrated into the market to fill gaps in service delivery. In particular, direct and indirect support for training and upgrading in logistics and supply chain management will be important. Another priority is to explore alternative regulatory models for forwarding services that will help to improve service quality and to reduce costs, especially for small exporters.

Georgia's task is to transform the country into a regional logistics center and upgrade a variety of (different types of) infrastructure. The analysis of the transit potential and the functioning of the corridor indicates the urgent need for international cooperation and the need to address regulatory, institutional and infrastructural shortcomings. Thus, proper coordination mechanisms are essential, especially to facilitate many types of transport planning. In this regard, a state transport strategy is being developed, which should significantly contribute to the effective planning and coordination of these issues.
4. Conclusions

According to the researches results, the potential of the Caucasus Transit Corridor in terms of additional transit shipments needs to be explored in order to compare it with alternative transit routes. In recent years, high growth rates of shipments highlight the following positive trends in the development of Georgia's transport corridor:

- The international freight market is recognized as a transit country for Georgia;
- New cargo will be transported by rail, which would not be transported by any other means of transport through the corridor to Georgia;
- The prospect of attracting additional cargo flows ensures the interest of sea lines to carry out regular shipments between Georgian seaports and other European ports.

It is clearly necessary to establish a unified transport network, where the relationship between the client and the freight forwarder is regulated by a single tariff policy and the cargo is transported by a single transport document / bill of lading (two or more modes of transport in two or more countries). This is one of the main ways in which it will be possible to effectively reduce and eliminate the real problems in the transport space of Georgia today [10]. The creation of a multimodal (mixed) type of transport operator and a unified transport system in general is of economic, political and social interest for each of the countries of the Caucasus transport corridor, as well as for the region as a whole.

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Improvement of Customs and Logistics Services in Ukraine

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Abstract

Ukraine has a significant transit potential, which is not fully realized. To increase the cargo transit volume, it is necessary to attract carriers by simplifying customs clearance formalities and offering additional logistics services.

The paper considers the possibility of using a logistics chain providing customs and logistics services to the customer at cargo customs complexes in order to consolidate all necessary operations related to the export of goods in the country of origin to the maximum extent. Besides, it is also compared with existing logistics chain variations that are already operated.

KEYWORDS: cargo transportation, logistics chain, cargo customs complex, customs infrastructure, improvement

1. Introduction

The development of transport and customs infrastructure in the world involves the use of advanced product shipment methods, strict compliance with customs legislation by all transportation process participants and the promotion of the country’s positive image in the international trade and service market by public authorities.

In terms of development programs for customs infrastructure and enterprises constructing transport and logistics hubs, it is expedient to study cargo customs complexes (CCC’s) performance indicators in Ukraine as well as the main criteria for assessing customs infrastructure facilities’ operation \[1, 2\].

The existing CCC’s significantly differ in their operation due to their technical, technological and organizational support, the peculiarities of demand generation for customs and logistics services depending on their topological location and capacity, the cost of services, service time as well as the available range of services provided to entities engaged in foreign economic activities.

Among the CCC’s performance indicators, we should single out the following: the degree of accessibility, the customs infrastructure facility’s reputation, reliability, employee competence, the level of technical support, and the characteristics of the technological process of service provision \[3, 4\]. The main CCC’s operation assessment criteria are the following \[5\]: location; a range of provided services; service tariffs; service time; quality of service and methods of working with clients; an operating mode.

2. Improving the Logistics Servicing of Vehicles

Ukraine has broad foreign economic ties. Trade value between Ukraine, the EU and CIS states and other countries in 2020 in million dollars is shown in Fig. 1.

The cumulative effect of the transport and logistics support of foreign trade operations at cargo customs complexes consists of the results yielded from interaction among government agencies, transport market entities and the owner of a cargo customs complex. The state is concerned with forming the country’s positive image as a trading partner as well as with the maximum return of duties on export-import operations.

The World Bank’s study on the logistics performance index (LPI) of Ukraine showed that in 2018 the country ranked only 66th. This index consisted of six components, each of which was evaluated on a five-point scale determining the rank. Let us consider the value of each of them for Ukraine in 2018 (among 160 countries participating in the ranking):

- efficiency of customs clearance procedures: score – 2.49 (89\textsuperscript{th} position);
- quality of trade and transport infrastructure – 2.22 (119\textsuperscript{th} position);
- ease of arranging international shipments – 2.83 (68\textsuperscript{th} position);
- competence and quality of logistics services – 2.84 (61\textsuperscript{th} position);
- tracking of consignments – 3.11 (52\textsuperscript{nd} position);
- timeliness of shipments– 3.42 (56\textsuperscript{th} position).
For example, let us consider the dynamics of change in LPI indicators over the course of 2012-2018 years according to the ease of arranging international shipments (Fig. 2). We made a comparison of the dynamics of change in indicators for 5 countries.

The analysis of this relationship indicated that Germany was a leader throughout the analyzed period. Poland occupied the second position, gradually improving its indicators, which in 2018 were almost equal to the ones of Germany. Hungary and Belarus were gradually losing traction. As for Ukraine, there was a fluctuant dynamics of change. It was indicative of the fact that the country, in its search for the best conditions for international shipments, had not always made the right decisions.

The obtained results require the initiation of some measures that would help improve Ukraine's rating in the international trade market. One of such measures may be the maximum CCC involvement in the provision of comprehensive customs and logistics services.

This decision results in a number of positive fallouts, among which we should emphasize the following:

- consolidation of a wide range of services in activities carried out by one legal entity, which will significantly reduce the waiting time in queues for service;
- possibility of clients’ interaction with one organization providing comprehensive customs and logistics services; it will greatly simplify financial arrangements as well as the exchange of information between all the participants in the shipment process;
- opportunity to complete customs clearance formalities in any customs mode on the territory of a cargo customs complex;
- increase in demand for the services performed by a cargo customs complex will attract additional financial resources that can be used to improve the technical, technological and organizational support of this infrastructure facility.

As, according to world experts, in Ukraine, it is necessary to increase the efficiency of the completion of customs formalities and the quality of the country's infrastructure, the involvement of cargo customs complexes in customs and
logistics servicing will bring it closer to global requirements and standards [6].

Nowadays, in Ukraine, there are different approaches to the organization of customs and logistics services for foreign trade operations. They are mostly related to the customer's requirements guided by the following criteria for evaluating this process effectiveness: cost, time, quality and reliability of service. These services are provided by entities in the transport service market, which are the following: freight forwarding companies, shipping carriers, customs brokerage companies, storage facilities, cargo customs complexes and some other organizations involved in the transport process in specific conditions of its realization.

In addition, in foreign economic activity organization, there are several options to complete customs clearance formalities: internal customs offices providing customs clearance only and not performing any additional logistics services; customs offices located on the territory of cargo customs complexes providing a full range of customs and logistics services on a commercial basis (except for customs formalities which are within the competence of public authorities); customs offices located at border checkpoints. Accordingly, these actions take place only on a country of origin’s territory; in turn, in a consignment country, customs agencies do customs clearance paperwork (performing functions similar to those of domestic customs brokers), and then the completion of customs clearance formalities and loading off cargo delivered by motor vehicles are performed on the territory of logistics centers. As seen, there are many possible combinations of logistics service provision by involving various actors in the market for transport services and ways to complete customs formalities in cooperation with customs authorities.

To study the interaction among all the transportation process participants, let us consider the current trends in logistics chain formation in the international transportation market. The links of a logistics chain in international road transportation are a consigner (C-R), a forwarder (F), a carrier (C), freight forwarding companies (FFCs), customs brokerage companies (CBCs), storage facilities (SFs), cargo customs complexes (CCCs), checkpoints (CPs), customs agencies (CAs), a logistics center (LC), a consignee (C-E) and a number of other actors in the transport services market involved in the transport process in specific conditions of its realization. There are several types of the most common logistics chains used in international road transportation.

A logistics chain of the first type is the longest according to the number of links (Fig. 3). Its advantages are a clear division of responsibilities between all organizations; it ensures a qualified approach to service. However, there are some drawbacks associated with considerable time expenditures on information and financial flows as well as the increased cost of services due to a big number of involved entities.

The second type of logistics chain involves the implementation of freight forwarding services by one company ensuring the maximum consistency of actions in transport process organization (Fig. 4).

According to the operation conditions of the third logistics chain type, in the structure of a freight forwarding company, there is a customs brokerage department providing the most efficient freight forwarding and customs brokerage servicing of customers (Fig. 5).

Accordingly, the fourth logistics chain type provides customs and logistics services to the customer at cargo customs complexes in order to maximize the integration of all the necessary operations related to the export of goods in the country of origin (Fig. 6).

In order to reduce the load at border checkpoints, it is recommended to complete customs clearance formalities at internal customs offices at the consigner's location, as there is a risk of customs clearance delay due to a limited number of checkpoints and their service areas where representatives of state control bodies, customs brokers, etc. can perform their duties. This logistics chain type provides comprehensive customs and logistics services to foreign economic entities.

Given the specifics of the CCC’s operation, let us consider its functions as a part of a logistics chain (Fig. 7).
The need to perform certain functions in the organization of foreign economic operations is determined by the type of cargo, the shipment size, transportation distance, materials handling time, etc. Developed countries of the world acknowledge comprehensive customs and logistics servicing feasibility as it ensures high quality and reliability of the international shipment organization and reduces its cost and time. Its implementation also contributes to enhancing the level of confidence in Ukraine as a reliable business partner for foreign countries. In fact, an increase in the volume of outbound and inbound cargo entering a CCC will increase cash inflow into the state budget in the form of customs duties.

A CCC’s operating efficiency lies in optimizing the management of material, information and financial flows to ensure minimal total costs, high-quality service and the integrated interaction of all the parts of a logistics chain; complex use of integrated customs and logistics functions; prompt analysis of customs and logistics activity results; reasonable formation and timely correction of logistic tactics and strategy in the conditions of demand fluctuation for services; integrated use of modern information technologies in customs and logistics activities [7].

The advantages of a CCC’s operation as a link in the logistics chain are the following: integration of the links in a logistics chain into a single service system providing effective cargo flow management; ensuring the interaction of customs authorities with business entities; comprehensive servicing of foreign trade cargo; transport and logistics service cost minimization; reducing the number of logistics intermediaries; reduction in time for the attendance of customs formalities. A significant shortcoming of domestic CCCs’ operation is the inconsistency of their technical facilities with the level of European standards.

To study the CCC’s operation as a link in the logistics chain, we analyzed the characteristics of one of customs and logistics infrastructure facilities under different operating conditions:
- completion of customs formalities for exported and imported cargo only given that paperwork provided to the customs authorities for verification is correct or that some paperwork errors have been detected by customs officers;
- provision of complex customs and logistic service for foreign trade operations;
- placing goods at the customs warehouse and temporary storage warehouse.

In the current research, we used the model described in [8]. The proposed queuing model was implemented in the GPSS World simulation automation package. We conducted the research during one calendar year at the CCC opened 5 days a week from 9 a.m. to 6 p.m. Simulation model limitations were related to the conditions imposed on the incoming flow of vehicles going into service - it was assumed that it was the simplest, i.e. there were no re-applications and no phenomena changing the patterns of vehicle service time at the CCC (equipment failures and errors, etc.).

An example of the modeling results of the mean cargo customs complex dwell time for vehicles to get customs and logistics servicing is shown in Table 1.

<table>
<thead>
<tr>
<th>Customs and logistics service operations</th>
<th>Mean service time value, min (MEAN)</th>
<th>Standard deviation, min (STD.DEV.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Export Customs Clearance, $t_1$</td>
<td>254.8</td>
<td>152.3</td>
</tr>
<tr>
<td>– correct paperwork</td>
<td>216.2</td>
<td>91.0</td>
</tr>
<tr>
<td>– in case of paperwork errors</td>
<td>566.3</td>
<td>185.1</td>
</tr>
<tr>
<td>Export Customs Clearance, $t_2$</td>
<td>253.8</td>
<td>148.7</td>
</tr>
<tr>
<td>– correct paperwork</td>
<td>217.0</td>
<td>91.4</td>
</tr>
<tr>
<td>– in case of paperwork errors</td>
<td>558.1</td>
<td>179.0</td>
</tr>
<tr>
<td>Comprehensive customs and logistics services, $t_3$</td>
<td>500.2</td>
<td>84.9</td>
</tr>
<tr>
<td>Placement of goods at the customs warehouse, $t_4$</td>
<td>352.4</td>
<td>28.4</td>
</tr>
<tr>
<td>Placement of goods at the temporary storage warehouse, $t_5$</td>
<td>426.6</td>
<td>91.6</td>
</tr>
</tbody>
</table>
When comparing the results of service time for different types of procedures, we can conclude that the mean time required for comprehensive customs and logistics servicing at the CCC is quite optimal given that this process includes many components to support foreign trade operations. The distribution of the annual duration of comprehensive customs and logistics services for vehicles is shown in Fig. 8.

![Fig. 8 Distribution of the annual duration of comprehensive customs and logistics services](image)

As a result of modeling, some Evaluation of comprehensive customs and logistic service operation characteristics were also obtained, which are shown in Table 2.

### Table 2

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematical expectation for the provision of complex customs and logistics services, min</td>
<td>500.2</td>
</tr>
<tr>
<td>Standard deviation for the provision of comprehensive customs and logistics services, min.</td>
<td>84.9</td>
</tr>
<tr>
<td>Probability of timely provision of complex customs and logistics service (the norm is 650 minutes)</td>
<td>0.80</td>
</tr>
<tr>
<td>570 min.</td>
<td></td>
</tr>
<tr>
<td>610 min.</td>
<td>0.93</td>
</tr>
<tr>
<td>650 min.</td>
<td>0.97</td>
</tr>
<tr>
<td>690 min.</td>
<td>0.98</td>
</tr>
<tr>
<td>730 min.</td>
<td>0.99</td>
</tr>
</tbody>
</table>

The reliability $p$ of the logistics supply chain and its links, defined as the estimated probability of a timely execution of individual operations and the process as a whole, is the following:

- type 1 logistics chain: $p_1 = 0.77$;
- type 2 logistics chain: $p_2 = 0.81$;
- type 3 logistics chain: $p_3 = 0.90$;
- type 4 logistics chain: $p_4 = 0.93$.

### 3. Conclusions

The analysis of the research results allows us to conclude that type 4 logistics chain implying customs and logistics services at the CCC is the most efficient, as it provides the highest reliability of compliance with the comprehensive vehicle service time. In this case, as compared to type 3 chain characterized by almost the same reliability, it is shorter. This reduces operating costs and the risk of corruption in the completion of customs formalities.

The reliability of logistics chains of type 1 and type 2 is low due to unsatisfactory reliability indicators of its individual links. To ensure a sufficiently high reliability level of the logistics chain as a whole, it is necessary to ensure a high reliability level of each of its links, which is problematic given their number.

### References


Mathematical Modeling and Computational Study of a Passenger Car Dynamics During Acceleration

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Abstract

A mathematical model of a passenger car dynamics during acceleration is proposed. The model takes into account the parameters of the car and engine, gear shift mode, external conditions (parameters of the road surface, road slope, gear shift time). As a result of the calculation for the ZAZ-Sens car, the loads that arise in the drive of the car were analyzed. The time for which the car accelerates from 0 to 100 km/h has been determined. The influence of vehicle mass, engine nominal power, gear shift mode, wheel radius, vehicle height, aerodynamic drag coefficient on the dynamics of vehicle acceleration has been analyzed. It is shown that the mass of the vehicle, the rated power of the engine and shifting gear time affect the acceleration dynamics to the greatest extent. The influence of other parameters is not so significant. The explanation of the obtained results is given.

KEY WORDS: vehicle dynamics; mathematical modelling; drive unit; car parameters

1. Introduction

One of the important parameters characterizing a vehicle dynamics is the acceleration time from 0 to 100 km/h. The comfort of driving a car, its commercial qualities depend on this parameter, therefore, improving the dynamic properties is one of the key tasks when designing a car.

The dynamics of a car depends on many parameters - the maximum power of the internal combustion engine, the weight of the car, the parameters of the gearbox, the frontal area of the car and others. The experimental study of the dynamics is complicated by the high labor intensity and cost of testing. It is rational to conduct a computational study using adequate mathematical models.

Currently, a number of detailed mathematical models describing vehicle dynamics have been proposed, for example [1-4]. In these models, the car is presented as an oscillating system. The rolling of the wheel on uneven and smooth surfaces is described in detail, the inertial and elastic characteristics of the moving parts of the engine, transmission and wheels are taken into account. These models are characterized by the complexity of validation and require setting a number of empirical coefficients based on the results of experimental studies. In addition, there is very little information in the literature on the use of such models in tasks of car parameters optimization.

In some cases, for example, when creating a draft design of a car, preliminary study of the powertrain design, it is rational to use simple but at the same time sufficiently reliable mathematical models [5-7]. A fairly popular model in Eastern Europe countries is the model of Chudakov and Yakovlev, detailed in [5]. This model allows determining acceleration and path of the car and based on the dynamic factor calculation. In turn, the dynamic factor depends on the forces acting on the car during its movement. However, this model doesn’t take into account the influence of the gear shift time on the dynamics of car acceleration. Existing methods of modeling the process of shifting gears take into account the processes of interaction of leading and led friction elements of the transmission. However, their use at the initial stage of design, when kinematic and mass parameters of the transmission parts are unknown is problematic.

The purpose of the work is to create a simple mathematical model of the car acceleration dynamics and to perform a computational research of car parameters influence on the acceleration process.

2. Vehicle Parameters and Driving Conditions

The ZAZ-Sens car with the MeMZ-307 engine was selected as the object of the research (Table).
### 3. Calculation Method

The developed mathematical model is based on the method of Chudakov and Yakovlev. The speed interval of a car from 0 to 100 km/h was divided into small sections with duration of 1 km/h. It is considered that at each section the car is moved with constant acceleration. Thus, knowing the speed at the beginning of the section and the average acceleration in the calculated interval, one can determine the speed at the end of the section.

The main parameter that determines the current value of vehicle acceleration is the dynamic factor (sometimes it is called ‘performance’ factor) $D$, which depends on the traction force, air resistance force and vehicle weight. Thus, the task of the study was to calculate parameters determining the dynamic factor and acceleration of the vehicle.

It is shown that the basic method doesn’t take into account the influence of gear shifting time on the car acceleration dynamics. The authors proposed to determine the acceleration time $\Delta t$ from speed $v_1$ to speed $v_2$ when shifting gears by the following method. Time $\Delta t$ is divided into two intervals (Fig. 1):

\[ \Delta t = \Delta t_1 + \Delta t_2, \]

where $\Delta t_1$ – gear shifting time; $\Delta t_2$ – acceleration time from speed $v_1$ to speed $v_2$.

![Fig. 1 Scheme for determining the acceleration time of a car when shifting gears](image)

The time $\Delta t_1$ depends on the driver’s qualification and can vary from 0.2 to 3 s. During the time $\Delta t_1$ the speed of the car decreases by the value of $\Delta v$ and at the end of the first interval reaches the value $v'_1 = v_1 - \Delta v$.

When shifting gears, the car moves by inertia, and the traction force $F_{t1} = 0$. Accordingly, the dynamic factor during the interval $\Delta t_1$:

\[ D_1 = -\frac{F_v}{G}, \]

where $F_v$ – aerodynamic drag; $G$ – vehicle weight.

The dynamic factor $D_1$ determines the acceleration of the car $j_1$ in the interval $\Delta t_1$.

To simplify the calculations, it is assumed that aerodynamic drag $F_v$ when changing gears is considered constant and corresponds to the speed of the previous gear. In this case, the acceleration $j_1$ is considered to be constant and the

### Table: ZAZ-Sens car parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter value</th>
<th>Parameter</th>
<th>Parameter value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle mass $m$, kg</td>
<td>1100</td>
<td>Piston stroke $S$, m</td>
<td>0.0735</td>
</tr>
<tr>
<td>Static radius of the tyre $r_{st}$, m</td>
<td>0.285</td>
<td>Compression ratio $e$</td>
<td>9.8</td>
</tr>
<tr>
<td>Vehicle height $B_r$, m</td>
<td>1.432</td>
<td>Engine nominal power $N_e$, kW</td>
<td>50</td>
</tr>
<tr>
<td>Vehicle width $H_r$, m</td>
<td>1.678</td>
<td>Engine nominal speed $n_{nm}$, rpm</td>
<td>5400</td>
</tr>
<tr>
<td>Frontal area filling factor $\alpha_d$</td>
<td>0.78</td>
<td>Transmission efficiency $\eta_T$</td>
<td>0.92</td>
</tr>
<tr>
<td>Engine displacement, $V_h$, l</td>
<td>1.3</td>
<td>Gear ratios: $u_{k1}$; $u_{k2}$; $u_{k3}$; $u_{k4}$; $u_{k5}$</td>
<td>3.454; 2.056; 1.333; 0.969; 0.828</td>
</tr>
<tr>
<td>Cylinder diameter $D$, m</td>
<td>0.075</td>
<td>Final drive ratio $u_0$</td>
<td>4.13</td>
</tr>
</tbody>
</table>

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where $F_v$ – aerodynamic drag; $G$ – vehicle weight.

The dynamic factor $D_1$ determines the acceleration of the car $j_1$ in the interval $\Delta t_1$.

To simplify the calculations, it is assumed that aerodynamic drag $F_v$ when changing gears is considered constant and corresponds to the speed of the previous gear. In this case, the acceleration $j_1$ is considered to be constant and the
reduction in speed when shifting gears will be $\Delta v = j_1 \cdot \Delta t_1$.

During the second interval, after clutching the crankshaft with the engine transmission traction force $F_{t2}$, dynamic factor $D_2$, acceleration $j_2$ and acceleration time $\Delta t_2$ from speed $v_1$ to speed $v_2$ are calculated by the formulas of the basic method for a car movement with a certain gear ratio.

The average dynamic factor in the calculated interval:

$$D_{av} = \frac{D_1 \cdot \Delta t_1 + D_2 \cdot \Delta t_2}{\Delta t_1 + \Delta t_2}.$$  \hfill (2)

The average speed in the calculated interval

$$v_{av} = \frac{(v_1 + v_1) \cdot \Delta t_1 + (v_2 + v_1) \cdot \Delta t_2}{2}. \hfill (3)$$

The traction force depends on the engine power. When the car accelerates in order to achieve maximum speed, the accelerator pedal is pressed all the way, therefore, the engine operates with maximum power according to the external speed characteristic. The operating engine power can be determined by the empirical Leiderman’s formula:

$$P = P_n \left[ A_1 \cdot \frac{n}{n_n} + A_2 \cdot \left( \frac{n}{n_n} \right)^2 - \left( \frac{n}{n_n} \right)^3 \right], \hfill (4)$$

where $P_n$ – nominal power; $A_1, A_2$ – empirical coefficients. For the MeMZ-307 engine we can take $A_1 = A_2 = 1$; $n, n_n$ – operating and nominal engine speed.

Operating engine speed is determined by the vehicle speed, wheel sizes and transmission parameters

$$n = \frac{v \cdot u_k \cdot u_{pb} \cdot u_0}{0.377 \cdot r_s^p}, \hfill (5)$$

where $v$ – vehicle speed; $u_k$ – operating value of the gear ratio; $u_{pb}$ – transfer case ratio; $u_0$ – final drive ratio; $r_s$ – static tyre radius.

The calculations were performed in the MATLAB program.

4. Analysis of Calculation Results

4.1. Loads in the Vehicle Drive During Acceleration

The results of calculating the forces in the car drive during acceleration are given in Fig. 2, engine parameters – in Fig. 3.

![Fig. 2 Forces in the car drive during acceleration](image1)

![Fig. 3 Engine parameters](image2)

When calculating the gear shift time was set to 0.5 s. Switching from first to second gear was carried out when reaching a speed of 30 km/h, from second to third – when reaching a speed of 55 km/h, from third to fourth - when reaching a speed of 90 km/h, from fourth to fifth – when reaching speed of 120 km/h.
Fig. 3 shows that with the basic settings in each gear, the crankshaft speed during acceleration increases to values close to 4000 rpm. This provides a sufficiently large power, engine torque and traction on the wheels. This traction is spent mainly on overcoming the inertia force, which at the beginning of the car moving exceeds the rolling resistance and aerodynamic drag more than 50 times. As the speed of the car increases, the inertia force decreases and at a speed of 100 km/h it is only twice that of the other components of the load.

From Fig. 2 we can see that the aerodynamic drag grows in proportion to the square of the vehicle speed and at a speed of 100 km/h makes a significant contribution to the overall driving resistance. This force limits the maximum speed for the car, the calculated value of which is 155 km/h. The increase in speed can be achieved mainly by increasing the engine power.

The speed of 100 km/h is reached in 18.6 s (Fig. 4), which corresponds to the passport data of the ZAZ-Sens car and indicates the adequacy of the calculation method.

Thus, the developed mathematical model allows to research the performance of an engine and a vehicle during acceleration, determine the influence of car parameters on these processes and to carry out optimization studies.

4.2. Influence of Car Parameters on the Acceleration Dynamics

Using the mathematical model, the influence of the vehicle mass, static tyre radius, vehicle height, engine nominal power, drag coefficient, gear shift mode on the vehicle acceleration has been studied.

Basic set of parameters: vehicle weight – 1100 kg, static tyre radius – 0.285 m, vehicle height – 1.432 m, nominal engine power – 50 kW, drag coefficient – 0.3. Gear shift mode: the first gear is engaged when driving from 0 to 30 km/h, the second gear – from 30 to 55 km/h, the third gear – from 55 to 90 km/h, the fourth gear – from 90 to 120 km/h, the fifth gear – more than 120 km/h.

The nominal power of the engine was set in the range from 40 to 80 kW. Engines of such power can be installed without significant problems in the engine compartment of a ZAZ Sens car.

The car mass varied from 900 to 1400 kg. It was considered that the minimum mass according to the passport characteristics of 1100 kg can be reduced to 900 kg by using a plastic or aluminum lining of the body, replacing the cast-iron engine block with an aluminum alloy block. Maximum vehicle mass with full load - 1400 kg. It was left unchanged.

The static tyre radius varied from 0.24 to 0.33 m. Such tyres can be used without significant alterations to the car body.

According to [5] shifting gear speed varied from 0.5 to 3 s.

Drag coefficient was set in the range from 0.2 to 0.35. Such parameters have existing cars; therefore, they can be implemented on an experimental car.

When shifting gears, three variants were considered, which differ in the speed ranges of the vehicle when shifting. In addition to the basic one (called ‘Variant 2’), a Variant 1 was proposed when the first gear was engaged when driving from 0 to 20 km/h, the second - from 20 to 45 km/h, the third - from 45 to 70 km/h, the fourth - from 70 up to 100 km/h, the fifth - more than 100 km/h and the Variant 3 when the first gear is engaged when driving from 0 to 40 km/h, the second - from 40 to 65 km/h, the third - from 65 to 110 km/h, the fourth - from 110 to 140 km/h, the fifth - more than 140 km/h.

Influence of the ZAZ-Sens car parameters on the acceleration time from 0 to 100 km/h is shown in Fig. 5.

Analysis of the calculation results showed that the most significant influence on the acceleration time have the engine power, car mass and shifting gear speed. The effect of the vehicle weight and shifting gear speed on the acceleration time is linear. With a decrease in vehicle weight for every 100 kg, the acceleration time from 0 to 100 km/h decreases by 1.6 s. Increasing the gear shift speed for every 0.5 s reduces the acceleration time by 2 s.

The influence of the engine power on the acceleration time is nonlinear. An increase in the nominal engine power for every 10 kW leads to a decrease in the acceleration time by 1.6-5.3 s. Larger values refer to the low power range, lower values – to the relatively high power range.

The drag coefficient and vehicle height do not significantly affect engine acceleration. This is due to the fact that
these parameters determine the drag force. However, at speeds up to 100 km/h, the specific contribution of the drag force to the total driving resistance to movement during acceleration is not significant. The main component of the total resistance is the inertial force.

Fig. 5 Influence of the ZAZ-Sens car parameters on the acceleration time from 0 to 100 km/h

Fig. 5 shows that a decrease in the static tyre radius for each centimeter improves the acceleration time of the car by about 0.8 s. This is due to the fact that with a constant gear ratio, the engine runs at high speeds. This achieves high maximum power and tractive effort. However, it should be noted that this measure of improving acceleration time is undesirable, since simultaneously with a decrease in the size of the wheels, the wear of the protectors increases, the friction in the transmission increase, and, consequently, the fuel consumption increases and the reliability of the car decreases. In addition, the driving comfort is deteriorated due to increased vibration when driving on the road surface.

The way of shifting has a similar effect on the car acceleration. Later shifting leads to an increase in engine speed, power and traction. Accordingly, the acceleration time decreases.

Thus, the developed mathematical model allows determining the quantitative impact of changes in the parameters of an engine and a car on the dynamics of its acceleration, to choose the parameters of the vehicle at the stage of its design.

5. Conclusions

The paper presents the mathematical model of a car dynamics, which takes into account the impact on this process gear shifting speed. The model allows to research the performance of an engine and a vehicle during acceleration, determine the influence of car parameters on these processes and to carry out optimization studies.

Using this mathematical model, the influence of the ZAZ-Sens car parameters on the acceleration time from 0 to 100 km/h has been researched. It is shown that the mass of the vehicle, the rated power of the engine and shifting gear time affect the acceleration dynamics to the greatest extent. The influence of other parameters is not so significant. The explanation of the obtained results is given.
References

Unmanned Aerial Vehicles as a Tool for Monitoring and Protection of Physical Infrastructure Systems

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Abstract

The issue of the use of unmanned aerial vehicles (hereinafter UAV, drone) in monitoring the technical condition and operation of infrastructure systems has been addressed more intensively, especially in the last decade. Shortly after the application of unmanned aerial vehicles in the defence industry, technology companies began to develop suitable applications for other sectors such as energy, transport, rescue services, security of strategic facilities, etc. The aim of the paper is to present the possibilities of using unmanned aerial vehicles in selected industrial applications such as inspections in energy, monitoring of traffic flow and transport infrastructure elements, creation of the BIM (Building Information Model) system, etc. The paper contains an overview of the commercial use of UAVs in practice, focusing on selected technologies of technical inspections of energy infrastructure systems and their elements, aerial mapping and laser scanning of infrastructures and terrain, as well as the use of UAVs in security services and operational activities within rescue services.

KEY WORDS: Unmanned aerial vehicle, drone, infrastructure system, bridge, industry, monitoring, safety

1. Introduction

The greatest development in the use of unmanned aerial vehicles has been recorded in the last 10 years, when unmanned aerial vehicles (UAVs) became available not only for the commercial sphere, but also for individual use. Different countries have chosen different approaches and possibilities of using UAVs in real practical applications to ensure the operation and safety of elements of infrastructure systems [1]. The valid legal framework of the Slovak Republic unconditionally requires the registration of an unmanned aerial vehicle, the performance of UAV pilot tests, the notification of planned flights, the assigned license for aerial work, as well as the subsequent control of the created records by the police. This procedure is a major complication for owners and administrators of infrastructure systems and their key facilities.

In this context, several workshops were organized in order to discuss the possibilities of using unmanned aerial vehicles by operators of critical infrastructure elements in the Slovak Republic. The first workshop was organized at the University of Žilina in Žilina in 2018. The main topics were the use of unmanned aerial vehicles and their potential not only in the areas of infrastructure systems and industry, but also physical security, protection of buildings and rescue work. The second workshop, organized by the Academy of the Police Force in Bratislava, was in 2019. The aim was to provide updated information on the organization of UAV operations and legislation for their use, as well as technical support and new technological solutions. The main topics were legislation and responsibility for the use of unmanned aerial vehicles, updating the rules for the use of UAVs, protection of privacy and classified information, forecasts of the development of unmanned systems, their use in industry and private security, as well as other uses of UAVs in the private sector. The third event with the active participation of the authors’ workplace was the NATO Advanced Training Course (ATC) in Morocco [2]. The course was organized by Poznan University of Technology in 2019 with the participation of experts from nine countries. The focus of ATC was broad, from the use of UAVs in the defence industry, through applications in security and rescue activities, applications in industry, to the deployment of drones in humanitarian operations and ensuring community security.

An example of the effective deployment of unmanned aerial vehicles is mainly the field of energy but also transport infrastructure and its facilities, such as bridge piers, hard-to-reach places of bridges, tunnels, elements of transport and communication systems and many other applications. At regular intervals, UAVs allow the monitoring of large line and area objects in order to analyze their technical condition, identify equipment damage, monitor the security and possible disruption of important objects, conduct an initial survey in crisis situations and more. The paper contains a description of selected possibilities of commercial use of UAVs in practice, focusing on technical inspections of energy infrastructure elements, aerial mapping, laser terrain scanning and infrastructure layout, as well as indicating the possibilities of using UAVs in bridge diagnostics and security services.

2. Use of Unmanned Aerial Vehicles in Industrial Applications

According to [3], in 2017 about 60% of drones were used mainly for communication and media purposes, e.g.
filmmaking or commercial photography. However, drones are also appearing more and more often in applications with higher added value, where their use is more suitable than traditional methods of performing activities, they have a lower price and operating costs. Various sensors installed on drones can collect a lot of data which helps e.g. when digitizing objects or streamlining operational processes in an industrial environment. From this point of view, drones will also play an important role in the concept of the industrial Internet of Things [4].

2.1. Specifications of UAVs for Industrial Use

Possibilities and experience with drones intended e.g. for filming, can also be used in industrial applications. This is especially the possibility when various types of sensors, recording devices and specific accessories are suitably attached to the drone or UAV models resistant to various influences (e.g. increased electromagnetic interference, chemicals, vapours, etc.) are used. The most widespread trend is to mount suitable types of sensors and devices necessary for a specific type of use (visualisation, thermal imaging, X-ray, aerial scanning and more) under commercially available drones.

The key functions of drones for industrial applications [5] are currently mainly autopilot and data transmission capability what is often very demanding in industrial applications with various interferences. In an environment that does not allow sufficient zoom to the object, the possibility of high-quality optical zoom is required. When manoeuvring indoors, the size and performance of the drone is important. On the contrary, in the case of mapping larger areas, flight time is an important parameter. From the point of view of safety, if the UAV flies over specific objects (e.g. significant assets, the possibility of human occurrence), the parachute system is an important equipment.

The limits of commercially used drones in terms of load capacity, range and use of specific accessories in the segment of the middle quality class are conditioned mainly by sufficient miniaturization of sensors that the UAV can easily carry them. Modern sensors enable direct storage or sending of collected data, with the possibility of assigning GPS coordinates, what allows the scanned information to be spatially arranged, etc.

2.2. Actual Possibilities of Using Drones in Industrial Applications

The actual use of drones in industrial applications is mainly in maintenance and inspections within network industries such as electricity, piping systems - oil, gas and water industry, monitoring the utilization of elements of transport infrastructure and transport flows, but also in mining, construction and other fields. The advantage of UAVs in industry is the fact that personnel do not have to enter dangerous zones, overcome large height differences and it is possible to carry out maintenance and inspection activities more efficiently and safely.

In the field of energy, drones can be used to monitor energy infrastructure facilities and to perform maintenance, inspections and revisions of various infrastructure systems and their components [6]. The most frequently are performed visual inspection of transmission lines after failures, identification of the place and type of failure, inspection of works during the removal of vegetation, surface inspection of electric power equipment and large photovoltaic power plants, GPS parameters of line elements, detection of gas leaks and oil leaks and many others. In addition to the standard function of visual recording or online transmission of scanned data, it is possible to place an infrared (thermal) camera together with a conventional camera under a commercial UAV and perform a visual and thermographic inspection at the same time for one take-off.

A laser scanner mounted on a drone is used e.g. when checking the environment under the masts of the power system [7] or also when monitoring the track spacing, when it is possible to scan the entire sections of the railway line in detail in a relatively short time [8]. The advantages of drones in the inspection of elements inside buildings, where there are various piping and cable systems, boilers, collectors, etc., which are difficult to access for inspection and maintenance in terms of their location, are not negligible. The use of drones in obtaining thermal imaging images of objects is widespread, through which it is possible, for example. detect cracks, leaks, thermal bridges, excessive thermal load, etc. [9].

The use of drones in an environment with a potentially explosive atmosphere is significant. For example, in the event of a gas leak at the valve, the location of the leak can be monitored from a safe distance by means of a drone and suitable sensors and infrared cameras or remote leak detectors enable to identify the problem and its extent [10].

Another field with great potential for the use of UAVs is construction. E.g. measuring cubature’s or creating so-called digital elevation model, designed to obtain the current state of a certain surface. Using a drone, the space is scanned, digitized and based on the created model, it is possible to e.g. precisely rock excavation work or the required amount of concrete [11]. Very often, a combination of geodetic and drone measurements is realized, which is applied especially in the creation of 3D models of various line structures, such as water dams or roads and their elements (bridges, tunnels, level crossings, etc.).

3. Selected Technologies Implemented Using UAV

Due to the nature of infrastructure systems, e.g. energy equipment and power lines, the control of elements is often relatively difficult and often impossible (e.g. placement at heights, elements under high voltage, placement in locations with difficult access, etc.). In principle, there are two options for carrying out inspections: air inspection or inspection using UAVs which is cheaper, increases the safety and efficiency of inspection work.
3.1. Digital Recording of Objective Reality

Drones with a camera capture and record video which can later be viewed, analysed or used for further processing, e.g. 3D modelling and creation of digital terrain models (DTM) or digital surface models (DSM). The standard is to record the image on a memory card, the pilot does not see the recording during the flight.

Drones with online transmission of recorded data are currently the most used. In addition to image recording, it is possible to view the currently recorded data. They are suitable for performing visual inspection of infrastructural elements (Fig. 1).

![Fig. 1. Focus on detail (authors)](image)

Application: Making recordings of scanned objects. Performance of visual inspections, such as checking the condition of chimneys, high-rise buildings, transmitters, masts, but also bridges and other little accessible places. Inspections of point and area objects, large-scale infrastructure systems such as product pipelines - gas, oil, water, ..., oil and natural gas storage facilities, etc. Use of the record in the creation of various 3D models of objects, topology of systems and territory. Advantageous use in poorly accessible terrain.

3.2. Infrared Thermography – Thermovision

The thermal vision drone can be used to detect and identify the origin and extent of damage. It is possible to detect even the smallest deviations, it is often used in rescue operations, in industry and transport, but e.g. also in nature protection and monitoring. Infrared diagnostics applications in industry are mainly focused on diagnostics of production machines, lines and systems in terms of their overheating and abnormal temperatures.

The field of industrial thermal vision includes fault identification by searching for temperature field inhomogeneity, monitoring of power lines and their damage, control of thermal parameters of power lines, switchboards, low voltage to very high voltage substations, transformers, electric motors, pipes, insulation, leak detection, etc.)

![Fig. 2. Examples of the use of infrared thermography [12]](image)

Application: Analysis of power elements and networks (e.g. thermal inspections of lines, transformers and photovoltaic power plants). Identification of heat leaks and leaks (roofs, buildings, industrial complexes), control of building cladding, control of roof insulation. Detection of leaks of liquids and gases on technical infrastructure equipment, especially in thermal or gas installations. Inspection of product pipelines (natural gas, oil, storage tanks, etc.), tracing of hot water pipelines, steam pipelines ...). Location of hidden fires in landfills. Rescue services and search for people and animals. Supervision of fire extinguishing, etc.
3.3. Aerial Laser Scanning

The uniqueness of LiDAR (Light Detection and Ranging) technology lies in the ability to effectively target large and complex systems (e.g. power line systems). The combination of drone and LiDAR scanning technology significantly expands the usability of standard aerial photography [13]. Aerial air scanning enables the creation of accurate documents for design and land use planning. In addition, if the outputs from aerial scanning by LiDAR are combined with traditional aerial mapping, the result is the most spatially and visually most comprehensive and accurate data (Fig. 3) on the surveyed area and its infrastructure.

Application: Design and engineering. Spatial planning and urbanism, mapping of towns and villages, GIS [14]. Energy - aerial scanning of lines, pipelines. Rescue services - creation of flood maps and modelling of flood areas. 3D modelling, creation of digital terrain models (DTM), creation of digital surface models (DSM), etc.

3.4. Building Information Modelling

Building Information Modelling (BIM) is an efficient combination of software solutions and aerial mapping into a compact logical unit. This approach combines the accuracy of aerial records and the added value of 3D models with an intuitive cloud environment. Quality implementation of BIM brings new possibilities in planning and monitoring of constructions, streamlining of team cooperation and process control [15]. Thanks to aerial images from the drone and their processing using BIM, it is possible to ensure better cooperation of construction teams and a greater overview of the spatial arrangement of the construction site (Fig. 4).

Application: monitoring and planning the development of the construction site, control of the transfer of materials on the construction site, team cooperation in large construction projects.

4. Use of UAV in the Field of Infrastructure Systems

4.1. Technical Inspections of Bridge Structures

A typical procedure of bridge inspection using UAV presents some issues such as localization of a UAV under the bridge and high-resolution image capture, deep learning-based algorithms for classifying, localizing and quantifying several damage types (e.g., cracks, corrosion, spalling, efflorescence, etc.) in an automatic manner [16]. All the procedures listed above are valid for all types of structures (steel, concrete, masonry in buildings and bridges). UAVs turned out to be very useful mostly for steel structures; indeed, they allow getting also imaging of coating thickness and corrosion area in steel structures. For this purpose, an UAV applicable line laser thermography (LLT) system is proposed [17]. Once the LLT system moves over the steel structures, the LLT system generate thermal waves on the steel structure using a continuous-wave laser and measures the corresponding thermal responses as infrared (IR) images using an IR camera. Then, the measured IR images are integrated to map the thermal waves measured from the multiple areas of steel structure taken under the moving conditions. Finally, the integrated IR images are processed for imaging as well as quantifying the coating thickness and corrosion area. This system offers the following advantages: coating thickness and corrosion area visualization can be carried out in a noncontact manner as the inspections are carried during the moving conditions; spatial constraints on structural inspection overcome through the convergence of UAV and LLT system. A schematic diagram of the line laser thermography is shown in Fig. 5.
The large amount of data collected by UAVs inspection represent actually an optimal input data layer for machine learning algorithms, that can thus have trained to auto-detect many type of defect on various bridge construction materials. The use of UAV in the non-destructive testing during inspections permits to achieve state detection, damage analysis and condition monitoring of an infrastructure. Fig. 6 shows a schematic representation of UAV inspections workflow. Recently, Unmanned Aerial Vehicles (UAVs) have shown a great advantage in inspection applications, showing potentialities such as extended flight time, great stability [18]. Remote controlled UAV equipped with high definition photo and video cameras can be used to get high quality inspection data. The use of robotics is a new and powerful trend for the automation of inspection/maintenance [19]. Although automated and robotic systems for inspection, together with newer measurement techniques can significantly enhance structures and infrastructures inspections, the development level of these robotic systems is still much lower than in other areas and needs to be better developed. In this sense, automated or semi-automated inspection process will reduce costs; reduce the inspection time, increase accuracy and safety. Compared with human inspection, the robotized inspection could scan vertical surfaces of bridges as well as horizontal surfaces at the bottom of bridge decks, reach hard-to-access places, take close-up pictures, collect NDT data and transmit to host PC for further analysis.

4.2. Technical Inspections of Energy Systems

In order to ensure the optimal operation of any technical equipment, it is necessary to carry out not only regular inspections and maintenance but also the diagnosis of errors and faults occurring during the service life [20]. Thermography is the basic method of diagnostics in energy. The usual method of thermography performed by the operator (by hand) is not nearly as effective as thermal imaging inspection from a drone, enabling the diagnosis of the largest projects and subsequent software analysis.

Visual and thermographic UAV inspections reduce the time required to identify errors and faults or already their consequences. All the data captured by the drone with the camera is then evaluated by a unique inspection software which significantly simplifies the analysis of the outputs from the inspection flights. The use is suitable for a comprehensive assessment of the technical or emergency condition of equipment and its elements, assessment of structural changes or fatigue of the material, regular or preventive maintenance, measurements in hard-to-reach places [21] and more. A drone equipped with a powerful zoom lens (Fig. 7) can capture the smallest details even from hard-to-reach places or views. From the obtained data it is possible to detect cracks, fissures, corrosion, etc. When using a thermal imager, it is possible to detect overheating parts of structures, heat leaks, damage to insulation and various other deviations and changes in the system.
4.3. Use of Drones in the Performance of Security Services

In addition to the above-mentioned possibilities of using UAV in industry, with a focus on the energy sector, the benefits of drones are also used in construction [22], cartography and geodesy, agriculture, sporting and social events, over the safety and fluidity of traffic flows, special activities of the armed forces and the police. In a global sense, the current area of application is, for example, the protection of tankers and oil rigs [23]. Main areas of use of drones in security services:

- monitoring of persons and objects in places with problematic deployment of monitoring groups;
- obtaining evidence of crime, unless evidence can be obtained by other means;
- a record of the course of the intervention against the perpetrators of the crime;
- control of the movement of unwanted persons near the guarded area [24];
- cooperation with other units of the integrated rescue system
- use as an accompanying navigation element in the evacuation of a large number of people, etc.

5. Conclusions

Unmanned Aerial Vehicle technology is now gaining ground in various industries. The use of drones is especially suitable for visual inspections of power lines, electrical masts, but also inspections of product pipelines, tanks and various elements of technological equipment. Current legislative activities focus mainly on finalizing legislation and standards for the safe and effective use of drones. The biggest expectations are in the field of preparation of rules for autonomous flights and related e.g. inspections of long-distance pipelines, delivery of consignments, or persons. At the European Union level, the introduction of an identification plate for drones is planned. The range of the drone, its ability to carry a heavier load or other specific equipment will change more and more. At the same time, work is being done to master a robotic swarm of drones that are capable of coordinating with each other. The purpose of the paper was to present selected application possibilities of unmanned aerial vehicles in the industrial environment, such as inspections in energy, monitoring of traffic and elements of transport infrastructure, terrain imaging and more.

Acknowledgments

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 project VI20192022151 CIRFI 2019: Indication of critical infrastructure resilience disruption.

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Analysis of the Use of Electromobility by Business Entities in the Czech Republic from Accounting and Tax Perspective

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Abstract

This paper deals with the analysis of the use of electromobility by business entities in the Czech Republic from accounting and tax perspective. In recent years, electromobility has become a hot topic not only in the world but also in the Czech Republic. It can be stated that in 2020 and 2021 the market for electric cars in the Czech Republic has started to grow significantly compared to the previous period and it is expected that there will be a continued increased interest in the use of electromobility not only in business. The paper focuses on selected aspects of electromobility in terms of the development of their use, possible methods of acquisition, accounting and tax depreciation of electric cars and also in terms of the possibility of claiming expenses associated with the operation of an electric car as a tax-deductible expense under current Czech legislation. Furthermore, the advantages and disadvantages of using electromobility in business are defined, including selected ecological aspects.

KEY WORDS: electromobility, car, accounting, taxes, financing, trends

1. Introduction

Electromobility is understood as a comprehensive solution for the movement of vehicles using electricity, or the operation of electrically powered vehicles. This includes recharging vehicles through the electrical network, either directly from a socket, via a special home station (wallbox) or via a public charging station [10]. The main reason for the use of electromobility is zero emissions and thus a significant reduction in environmental impact. Electric vehicles (EVs) have lower operating costs and lower failure rates. The introduction of electromobility is supported by various instruments such as the bonus-malus system, which is generally designed as a combination of a tax or a fee associated with the acquisition or registration of a less clean (conventional) vehicle (malus) and a direct subsidy or tax credit (bonus) provided to the cleaner technology. Overall, the most important tools in terms of the expansion of electric vehicles are tax savings and support for the construction of charging stations, along with financial support for the purchase of EVs. Electromobility has become a modern trend in recent years. It can be stated that in 2020 the EV market in the Czech Republic has started to grow significantly compared to the previous period. While in 2016 200 new EVs were released to the Czech market per year, in 2018 and 2019 it was about 50 per month, in 2020 it was already about 1,500 electric cars and about 10,000 hybrids, and the statistics do not include the so-called mild hybrids. Škoda played its role in the significantly accelerated pace. The company started selling electric Citigo and hybrid Superb in January 2020; although in this segment the trend is ruled by Toyota with a firm hand, the hybrids of which were of great interest in the Czech Republic. Nevertheless, compared to other countries, electromobility in the Czech Republic is still lagging behind. The major benefits of electromobility include zero emissions, low noise levels, improved urban traffic dynamics, rationality, efficiency, simple design, better driving performance and characteristics, the ability to run on sustainable renewable energy, stabilization of RES and reduction of carbon fuel consumption, independence and self-sufficiency in energy for transport, and other positives and life assurances. EVs use regenerative braking, so they have significantly lower particulate emissions from the brakes. In combination with low noise, they significantly improve the quality of life not only in urban agglomerations.

According to a survey conducted this year by EY in cooperation with research agency STEM/MARK, 55% of drivers would consider buying an EV. Moreover, the state is also starting to support electromobility through its ministries. The first call of the Ministry of Industry and Trade for the purchase of electric vehicles and chargers for companies and entrepreneurs has appeared, and the Ministry of the Environment is preparing a call for the purchase of electric vehicles for municipalities [15]. In the Czech Republic, combustion vehicles and fuels are not heavily taxed, so the development of electric vehicles is a bit slower than elsewhere. But being technologically in is becoming fashionable in the Czech Republic. For many people, technology is more important than ecology. Over the last 5 years, the number of EVs has increased by 74% year-on-year. [12, 13]. Table 1 provides an overview of the best-selling EVs and hybrids in 2020.
Overview of the best-selling EVs and hybrids in the Czech Republic in 2020

<table>
<thead>
<tr>
<th>Number</th>
<th>List of best-selling EVs</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Škoda Citigo e iV</td>
<td>732</td>
</tr>
<tr>
<td>2.</td>
<td>Hyundai Ioniq</td>
<td>158</td>
</tr>
<tr>
<td>3.</td>
<td>Hyundai Kona</td>
<td>133</td>
</tr>
<tr>
<td>4.</td>
<td>Renault Zoe</td>
<td>101</td>
</tr>
<tr>
<td>5.</td>
<td>Volkswagen ID.3</td>
<td>53</td>
</tr>
<tr>
<td>6.</td>
<td>BMW i3</td>
<td>51</td>
</tr>
<tr>
<td>7.</td>
<td>Audi E-tron</td>
<td>42</td>
</tr>
<tr>
<td>8.</td>
<td>Kia Niro</td>
<td>33</td>
</tr>
<tr>
<td>9.</td>
<td>Mercedes-Benz EQC</td>
<td>26</td>
</tr>
<tr>
<td>10.</td>
<td>Nissan Leaf</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>List of best-selling hybrids</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Toyota Corolla</td>
<td>1102</td>
</tr>
<tr>
<td>2.</td>
<td>Toyota RAV4</td>
<td>969</td>
</tr>
<tr>
<td>3.</td>
<td>Skoda Superb</td>
<td>620</td>
</tr>
<tr>
<td>4.</td>
<td>Toyota C-HR</td>
<td>603</td>
</tr>
<tr>
<td>5.</td>
<td>Mazda CX-30</td>
<td>428</td>
</tr>
<tr>
<td>6.</td>
<td>Ford Puma</td>
<td>405</td>
</tr>
<tr>
<td>7.</td>
<td>Suzuki Ignis</td>
<td>396</td>
</tr>
<tr>
<td>8.</td>
<td>Toyota Yaris</td>
<td>381</td>
</tr>
<tr>
<td>9.</td>
<td>Mazda 3</td>
<td>325</td>
</tr>
<tr>
<td>10.</td>
<td>Honda CR-V</td>
<td>321</td>
</tr>
</tbody>
</table>

Source: A own processing in accordance with [9]

2. Methods

In the paper, classical types of scientific procedures were applied using theoretical and empirical methods which include description, analysis, synthesis, induction, deduction, comparison and evaluation and so on.

3. Results and Discussion

The market with the supply of EVs is relatively wide and its further growth is expected, which can be concluded from the development of the number of registered EVs in the Czech Republic, for example, in 2010 there were 15 registered EVs and in 2019 it was already 8,180 EVs, see Figure 1. Although the number of registered EVs to date, based on data from the Department for Transport, is still only a fraction of the number of registered petrol or diesel cars, as can be seen in Fig. 2. Nevertheless, EVs are finding their customers and it can be assumed that the future belongs to them. Businesses that plan to use an EV for their business activities have many options for acquiring such car. One of the most common ways of purchasing is by buying it directly from authorised EV dealers. The purchase can then be made by full payment in cash, or business entities can use leasing or a loan obtained from banking institutions. Of course, the easiest way to buy a new vehicle is by paying cash directly. This method of acquisition, however, means that the accounting entity has sufficient funds and that a cash purchase will not have a negative impact on its cash flow. It is the immediate expenditure of a relatively large amount of funds when buying in cash that often leads business entities to prefer the acquisition of a new car in the form of financial or operational leasing that comes with certain advantages. The last option to acquire an EV is in the form of a loan, which the accounting entity obtains by entering into a loan agreement with a selected banking institution. This is a so-called consumer loan, where the accounting entity immediately becomes the owner of the car and is obliged to repay the car to the bank regularly in agreed instalments, which include both the value of the acquired property and the remuneration for providing the loan in the form of interest. The borrower repays the funds provided either in annuity instalments, where the instalment includes both interest and amortization and their proportion varies over time, or separately. All three methods of acquisition bring both advantages and disadvantages. The decision is therefore always up to the buyers and depends on their needs, requirements and, of course, financial possibilities.

![Fig. 1 Development of the number of passenger EVs registered in the Czech Republic in 2019. Source: own processing in accordance with [18]](image1)

![Fig. 2 Number of passenger cars by type consumed energy registered in the Czech Republic in 2019. Source: own processing in accordance with [18]](image2)

Despite some travel restrictions due to the COVID-19 pandemic, the need to transport people and cargo remains one of the basic needs in the business activities of both individuals and legal persons. From the point of view of the
possibility of claiming expenses related to the operation of an EV as tax deductible costs, it is necessary to distinguish whether the vehicle is a company EV (a vehicle classified as business assets) or a private EV, i.e., an EV that is not classified as business asset for individuals. If used as a company EV, depreciation (accounting and tax), electricity consumption, insurance premiums, repair and maintenance expenses, including technical inspections, can be included in the expenses related to the use of the EV. In this context, it should be noted that even in the case of an EV, a lump sum transport expense of 5,000 CZK per month can be claimed instead of the electricity consumed pursuant to Section 24(2)(zt) of the Act on Income Tax. [8].

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 EV is valued in the accounts and should express the actual degree of wear and tear of the property. They are calculated with an accuracy of months and rounded up to the nearest whole crown. The methodology of accounting depreciation of an EV is selected by the accounting entity itself. The entity can use the following methods: time-based methods (straight-line accounting depreciation, degressive (accelerated) depreciation method and progressive (decelerated) accounting depreciation), performance-based methods and component depreciation methods. The time depreciation methods are based on the useful life of an EV, and accounting theory distinguishes between straight-line, degressive or progressive depreciation. One of the most used methods of depreciation of a is linear or straight-line accounting depreciation. The amount of monthly depreciation is determined as the ratio of the purchase price of an EV to the number of months of its useful life. When using the degressive or accelerated depreciation method, accounting depreciation is reduced over the life of an EV, 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 an EV as they do not express the actual degree of wear during its useful life. Both methods are listed here for information only. When calculating the permanent reduction in value of an EV, the most appropriate method seems to be the performance depreciation method, which is based on a certain capacity of the asset, which is the maximum number of kilometres driven during its useful life. The performance method is strongly focused on the physical wear and tear of the EV, 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 EV by driving one kilometre. Component depreciation of tangible assets is another option that can be used in accounting, but it is hardly used for depreciating an EV. This is due to the fact that an EV 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 [4].

Tax depreciation represents the part of the acquisition cost of an EV that the accounting entity can claim as a tax-deductible expense for the relevant tax period. Tax depreciation is regulated in Sections 26 to 32 of the Act No. 586/1992 Sb., on Income Tax. For the purposes of the Act on Income Tax, tangible property means separate tangible movable things that have operational and technical functions for more than 1 year with an acquisition price exceeding a given value threshold. For many years in the Czech Republic, this limit was 40,000 CZK. If the thing was put into use after 1 January 2020, this limit was increased to 80,000 CZK. After a passenger car is put into use, the accounting entity classifies it into one of the six depreciation groups listed in Appendix No. 1 to the Act on Income Tax. Passenger cars and therefore EVs as well are included in depreciation group 2 with a depreciation period of five years. A passenger 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 EV 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 an EV to 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. 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. [4]. 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. Under Section 30a of the Act on Income Tax, extraordinary depreciation may now be applied to tangible property classified in depreciation groups 1 and 2 to support the investment activity of Czech companies and entrepreneurs. An accounting entity may also apply extraordinary depreciation to an EV provided that it was acquired in the period from 1 January 2020 to 31 December 2021 if the entity is its first depreciator. In result an EV can be written off without interruption in 24 months instead of the standard 5 years. For the first 12 months, depreciation of up to 60% of the acquisition cost of the tangible asset may be applied on a straight-line basis, and for the immediately subsequent 12 months, depreciation of up to 40% of the acquisition cost of the tangible asset may be applied. From the above follows that it is necessary to determine the exact moment of putting the assets into use. In case of extraordinary depreciation, it does not apply that full depreciation is applied only to assets registered at the end of the tax year, nor that half depreciation is applied to assets registered only at the beginning of the tax year.
EVs are environmentally friendly, with lower operating and consumption costs than vehicles with internal combustion engines. EVs are not subject to road tax as they are exempt from road tax according to the Act No. 16/1993 Sb., on Road Tax (Section 3(f)). Declared engine life is up to 40 years. The amount of compulsory car insurance corresponds to the lowest category of vehicles, i.e. vehicles up to 1,000 cm³. The price per kilometre driven is about 70% lower in case of an EV [7]. The costs associated with measuring emissions, which combustion engine cars have to undergo regularly, are also completely eliminated for electric cars. The methodology for determining the cost of fuel consumed in the form of electricity for electric vehicles included in business assets is of fundamental importance for business practice. This applies both to vehicles owned by individuals and to all vehicles owned by legal persons. In addition to that, EVs, unlike hydrocarbon-fuelled cars, lead in practice to a situation where the employer's vehicle is recharged by the employee from his home electricity grid, and it is not clear how to determine the amount of the employee's liability to the employee in this respect [5]. A solution to the situation where the price of electricity consumed for the operation of an EV is not clearly proven from the perspective of the employer's tax expenses was brought by the amendment to the Act on Income Tax, which thanks to the new wording of Section 24(2)(k) of the Income Tax Act allows to use the average price of electricity to determine the expenditure on fuel consumed by an vehicle with electric drive for the purposes of providing travel allowances under the Labour Code, that is for the price of 4.80 CZK/kWh in 2020 or 5 CZK/kWh in 2021. The following three basic methods or variants of charging are used in practice: charging from a socket, using a special charger (wallbox) or a public charging station. The first and technically simplest way to charge an electric car is to use an electrical socket. The advantage of charging electric cars in this way is that it can be done while the car is parked, whether at the employee's or entrepreneur's home or at the company's (employer's) headquarters. Actual tax expenses can be claimed if the cost and quantity of energy consumed can be proven. In other cases, a reference price of 5 CZK/kWh can be used (2021). Another way to recharge an EV is with a special charger such as wallbox. These are mostly three-phase devices up to 22 kW/32 A for alternating current. In terms of the Act on Income Tax, it is necessary to address the assessment of these special recharging devices in relation to the determination of tax depreciation. Due to the considerable variability of wallboxes with different technical designs, in many cases it will be advisable to request their statistical classification from specialised departments. In relation to statistical classification, a wallbox can be considered as an accessory of an EV, a separate movable thing or a part of an immovable thing. The last option for charging electric vehicles is public charging stations. In terms of tax expenditures, the use of public charging stations should not cause problems, as the situation is similar to that of hydrocarbon fuel stations. After recharging, each customer receives a receipt for the amount and price of energy consumed, and the price of energy consumed is proven in this way [6]. The current unfavourable situation in connection with COVID-19 has been reflected in all sectors of the economy. Businesses in the current uncertain times, when they are facing a number of economic impacts of the global pandemic, may choose to acquire an EV for their business activities, e.g., by renting a car from a car rental company. In this case, the entity does not have to deal with insurance, servicing, or a vignette. All these costs are already included in the rental cost. If the rental company is a VAT payer, the rental fee will be calculated including VAT. If the accounting entity is also a VAT payer, it can claim a deduction for the VAT paid on the rental cost. In the case of a borrowed car, the business entity must also take into account a refundable deposit. The refundable deposit serves as insurance for the rental company in case the customer returns the car damaged or not at all. In the event that the electric car is returned in good condition, the full refundable deposit is returned to the customer. The deposit is charged without VAT and is therefore outside the VAT regime. The rental price depends, among other things, on the type of vehicle and the rental period of the electric vehicle, see Table. 2 - Example of a Renault ZOE EV rental amount and, of course, the offer of car rental companies. The amount of the deposit is set at 25,000 CZK regardless of the rental period [17]. Another cost associated with renting a car is the cost of electricity to charge the car. Typically, an EV consumes about 18 kWh/100 km. The C27d rate is designated for entrepreneurs [11]. In the case of companies, the special distribution rate is exclusively for charging an EV and the cheaper electricity cannot be used for other appliances. The charging equipment must be fed by a separate supply and measured by a separate measuring device. The rate in the high tariff is 2,165.83 MWh including VAT, in the low tariff it is 164.45 CZK/MWh including VAT [16].

### Table 2

#### Example of Renault ZOE rental fee in CZK

<table>
<thead>
<tr>
<th>Days</th>
<th>Price (no VAT)</th>
<th>Price (VAT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 800</td>
<td>2 178</td>
</tr>
<tr>
<td>2 - 5</td>
<td>1 500</td>
<td>1 815</td>
</tr>
<tr>
<td>6 - 10</td>
<td>1 400</td>
<td>1 964</td>
</tr>
<tr>
<td>11 - 15</td>
<td>1 300</td>
<td>1 573</td>
</tr>
<tr>
<td>16 - 29</td>
<td>826</td>
<td>999</td>
</tr>
</tbody>
</table>

Source: own processing in accordance with [17]

The tax-deductible costs associated with the operation of an EV that has not been included in a business asset and is therefore a private vehicle can be divided into two parts, namely the basic compensation and the reimbursement of expenses for electricity consumed (unless a lump sum transport expense is claimed). In the Czech Republic, proving the cost of electricity consumption was one of the biggest practical barriers to the widespread use of EVs in the business as EVs lacked rules for proving actual consumption or the amount of compensation for electricity consumed during their
operation. The calculation of compensation for fuel consumed, including electricity, is based on the actual distance travelled, the average consumption stated in the vehicle registration certificate and the proven price of the fuel purchased. Instead of the actual price of the fuel purchased, the Labour Code allows to use for the calculation of compensation the prices set out in the regulation of the Ministry of Labour and Social Affairs of the Czech Republic. However, if a private EV is used for business purposes, there has long been no uniform electricity price for determining the reimbursement of the costs incurred in charging such a vehicle. The change occurred only recently, with the adoption of regulation No. 358/2019 Sb., which for the first time included a reference price for electricity consumed as fuel when charging electric vehicles for 2020. The regulation states that the average price of fuel pursuant to Section 158(3) of the Labour Code is 4.80 CZK per 1 kWh of electricity. For 2021, the regulation No. 589/2020 Sb. states a price of 5 CZK/kWh. An individual (entrepreneur) who does not include an EV into business property and uses it to carry out his or her business activity may claim the tax-deductible costs for each kilometre driven in connection with such activity the sum of the basic reimbursement rate and the reimbursement of expenses for energy consumed. The price of energy can be proven by proof of purchase or the price set by regulation No. 589/2020 Sb., which also specifies the rate of basic compensation for the use of a road motor vehicle (for 2021 at the amount of 4.40 CZK/km). The self-employed person claims travel expenses in the same way as an employee claims them from the employer when travelling for work.

When purchasing a car for business, the entrepreneur has a choice of several options, which have already been mentioned in the previous sections. The basic decision should focus on the question of whether to finance the car from own, external or alternative sources of financing. Leasing is one form of alternative source of financing. The term leasing is derived from the English term "lease", meaning a lease or rental agreement. Leasing can be defined as a contractual agreement between a lessor and a lessee to lease an asset where the ownership rights vest in the lessor for the term of the lease. Only the right to use the property passes to the lessee. There are two basic types of leasing for which you can buy a car. These are financial leasing and operational leasing, which differ in the extent of transfer of user rights, risks and the right to ownership of the asset at the end of the lease period. A financial leasing can be defined as a long-term lease where the lease term is the same as the economic life of the asset and ownership passes to the lessee at the end of the leasing term. A financial leasing can therefore also be defined as the permanent acquisition of an asset by way of instalments [1]. During the contractual arrangement, the lessor does not provide any additional services and all risks associated with the rental of the car are transferred to the lessee. An operational leasing can be characterised as a short-term lease where the leasing term usually does not exceed the economic life of the leased asset. Another important feature of this type of lease is that at the end of the leasing period, there is no transfer of ownership from the lessor to the lessee and the car is returned to the lessor. Costs related to repairs, maintenance or servicing of the car are usually covered by the lessor. The accounting for finance and operating leasing is almost identical, except for the use of accrual accounts for the first increased payment under financial leasing, which does not arise under operational leasing. There is a difference only at the end of the leasing, when the car is transferred to the property or to consumption in the case of a financial leasing, whereas in the case of an operational leasing the car is returned to the lessor. According to Czech accounting standards, off-balance sheet accounts are used to record the leasing with the lessee. The off-balance sheet thus provides the entity with information about the use of foreign assets [2]. However, the recognition of leasing in off-balance sheet accounts does not affect the content of the financial statements. A lease payment means a periodic payment for the provision of the subject of the leasing contract, usually determined by a payment schedule. Lease payments can be fixed or variable. Repayments at a constant rate are charged in the accounts to account 518 - Other services, against account 321 - Trade debts. Variable repayments must be accrued through account 381 - Deferred expenses. At the end of a passenger car leasing, one it is important to distinguish whether it is an operational leasing or a financial one [4]. For an operational leasing, the cars are returned to the lessor without any accounting impact. Only the cancellation of the recording entries for assets from off-balance sheet records is performed. In the case of a financial leasing, where the leased asset is transferred to the lessee, the lessee must classify the leased asset as a business asset, with different accounting treatment depending on the method of leasing termination and the purchase price. For a financial leasing, the subject of the leasing may pass to the lessor free of charge or for consideration. The method of reporting leasing in Czech accounting differs from most current national accounting treatments in other countries and also from IFRS [3]. The advantages of purchasing a car on operational leasing from the lessee's point of view are immediate mobility, affordability at the time of high prices of new EVs, efficient and optimal cost management, full outsourcing of services, immediate tax aspect of installments. The disadvantages lie mainly in the fact that the vehicle remains the property of the lessor. The advantages of acquiring a vehicle under a financial leasing include, in particular, the option of time distribution of payments, which favourably affects cash flows, the subject of the leasing is immediately available and the entrepreneur applies the accrued instalments to the tax-deductible costs to reduce the tax base. The disadvantages include the fact that the instalment is usually increased by a relatively high margin, the lessee becomes the owner of the thing only after the termination of a leasing contract, and if the thing is lost, the leasing contract cannot be suspended.

4. Conclusions

In 2020, the number of EVs and plug-in hybrids more than doubled compared to the previous year. There is no doubt that electromobility is gaining popularity in the Czech Republic. The growing EV trend continues in 2021, with 563 registrations for EVs and 942 for plug-in hybrids in the first quarter of 2021 [14]. In the current COVID-19 pandemic, buying an EV with cash is not one of the most sought-after acquisition methods. Businesses prefer to choose another type of acquisition (leasing, loan) in order to be able to use financial resources for other core business activities. The investment
in the purchase of an EV, long-term loans or long-term operational leasing contracts will be a very risky choice for many businesses in the uncertain times of a global pandemic. In addition to a short-term rental of an EV, carsharing can be another solution, where the business entity does not own the EV but shares it. The disadvantage of this way of using an EV is the frequent change of drivers. EVs are electric vehicles (powered by an electric motor instead of an internal combustion engine); they are environmentally friendly and have low running and mileage costs. The disadvantages are another solution, where the business entity does not own the EV but shares it. The disadvantage of this way of using an EV, long-term loans or long-term operational leasing contracts will be a very risky choice for many businesses in the uncertain times of a global pandemic. In addition to a short-term rental of an EV, carsharing can be another solution, where the business entity does not own the EV but shares it. The disadvantage of this way of using an EV is the frequent change of drivers. EVs are electric vehicles (powered by an electric motor instead of an internal combustion engine); they are environmentally friendly and have low running and mileage costs. The disadvantages are another solution, where the business entity does not own the EV but shares it. The disadvantage of this way of using an EV is the frequent change of drivers. EVs are electric vehicles (powered by an electric motor instead of an internal combustion engine); they are environmentally friendly and have low running and mileage costs. The disadvantages are another solution, where the business entity does not own the EV but shares it. The disadvantage of this way of using an EV is the frequent change of drivers. EVs are electric vehicles (powered by an electric motor instead of an internal combustion engine); they are environmentally friendly and have low running and mileage costs. The disadvantages are another solution, where the business entity does not own the EV but shares it. The disadvantage of this way of using an EV is the frequent change of drivers. EVs are electric vehicles (powered by an electric motor instead of an internal combustion engine); they are environmentally friendly and have low running and mileage costs. The disadvantages are another solution, where the business entity does not own the EV but shares it. The disadvantage of this way of using an EV is the frequent change of drivers. EVs are electric vehicles (powered by an electric motor instead of an internal combustion engine); they are environmentally friendly and have low running and mileage costs.

Clarification of the tax aspects related to electromobility can facilitate the economic decision of individuals (entrepreneurs) and commercial corporations whether and to what extent they will use EVs for their business activities. Apart from purely market-economic considerations, the final decision may also be influenced by the fact that the use of EVs is quite strongly supported by both state and multinational institutions. In terms of taxation (excluding income taxes), it is the exemption of electrically powered road vehicles from road tax and, indirectly, the fact that electricity, unlike competing hydrocarbon fuels, is not directly burdened by excise duties. Apart from the taxation, there is support available that can be used under the operational programme of Enterprise and Innovation for Competitiveness and, from 2021, the Operational Programme Technologies and Applications for Competitiveness [5].

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Simulation Research of All-purpose Interface Model Between Interlocking System and Block System

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Abstract

The paper presents the results of the sixth 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).

The paper presents a description of a test stand for testing standardized interfaces. A description of the operation and operation of the IXL-LB interface simulator was presented, as well as the obtained results of simulation tests carried out with the use of the IXL-LB interface model between interlocking system and the line block system. The purpose of the simulation tests was to verify the adopted functional requirements resulting from the specification of standard for the interface: interlocking system – line block system and the correctness of data transmission using the developed UDPS data transmission standard prepared under stages 2 and 3 of the NCBiR project.

The tests were performed on a simulation stand (a test environment) with RAMS performance and reliability parameters corresponding to the requirements of real railway traffic control devices used on the PKP PLK S.A. network, enabling the implementation of simulation software for railway traffic control devices (line block, level crossing, interlocking, user interface, ...) and all-purpose digital interfaces (software) for the exchange of process data within an isolated Ethernet network ensuring data exchange.

KEY WORDS: control command systems, standardization of interfaces, simulation research

1. Introduction

Currently, there is no comprehensive standardization, both in terms of requirements and specifications for the use of interfaces in rail traffic control systems [1-3, 5]. This problem is faced by both designers, contractors involved in the implementation of these systems and infrastructure managers. The rail market is becoming more open and the number of manufacturers of rail traffic control equipment and systems is growing rapidly. In order to fill the existing gap in this field, a project to develop a scope was undertaken, which can be used as an effective tool for organizing the use and connection of interfaces for rail traffic control devices in a fully practical way [11].

The project described in this article, under the name of “Standardization of selected interfaces of railway traffic control equipment and systems” POIR.04.01.01-00-0005/17, has been created as part of the BRIK (Research and Development in Railway Infrastructure) program and has been co-financed both by the NCBiR (The National Centre for Research and Development), as well as the PKP Polskie Linie Kolejowe S.A. (PKP PLK - Polish State Railways) - which is a dominant operator of the railway in Poland.

The aim of the project was to develop the requirements and specifications for interfaces used in computer control devices. For this purpose, research and tests were carried out, the results of which allow to verify the correctness of the adopted main research assumptions. The result of the work can be a guiding document, which would include standards, requirements and recommendations for the design and implementation of combining various types and different manufacturers of railway traffic control devices and systems.

The paper presents a description of a test stand for testing standardized interfaces. A description of the operation and operation principle of the IXL-LB interface simulator was presented, as well as the obtained results of simulation tests carried out with the use of the IXL-LB interface model between interlocking devices and the line block. The purpose of the simulation tests was to verify the adopted functional requirements resulting from the standard specification for the interface: interlocking devices - line block. And the correctness of data exchange using the developed UDPS data transmission standard developed under stages 2 and 3 of the NCBiR project [11].

2. Definition the Scope of the Interface

The interface connects functionally autonomous systems (devices), providing such a system with the implementation of extended functionality in relation to the scope implemented by one system. From the point of view of ensuring safety for the assumed scope of performed functions, it is one of the links in the data processing chain (inputs - outputs). Therefore, standardization of the interface and its implementation by various manufacturers, i.e. the scope of the interface must be related to its definition and the set of features interfering with the process of data transfer and
processing. The scope of the interface includes the following topics [10]:
- The scope of data exchanged by the interface used by individual systems for their needs, divided into safe and non-safe related.
- Identification of threats, the source of which may be hardware damage and software errors of the communication system and their impact on the operation of other programs in the system.
- Risk reduction by mitigating the effects of dangerous failures to the level acceptable by the system user (maintaining the required system performance, throughput, information transfer time).
- Ability to obtain quantitative values of RAMS (Reliability, Availability, Maintainability and Safety) parameters of a technical interface solution that meets the acceptable risk level, taking into account the operating and environmental conditions affecting the equipment and the link.
- Assignment of the SIL safety integrity level to the interface for the calculated quantitative hazard index target (according to PN EN 50129 [7]), and obligatory techniques and methods for this SIL in terms of software development (according to PN EN 50128 [8]).

The definition of the interface adopted in project [9] says that it is: "the system of inputs and outputs of a given device (system, subsystem) together with the signals transmitted by them and the corresponding logic and sequences of the device's operation, enabling connection and cooperation between this device and another device ". This definition is complete, i.e. it defines the purpose of the interface and its elementary components related to the processing of process data (sequences of actions, data exchange protocol) and structure (inputs, outputs being the sources of data to be exchanged) and does not refer to technology.

3. Simulation Model of the Interface and Data Exchange Between the Line Block and Interlocking Devices

The tested data exchange interface between the LB line block and IXL interlocking devices accordance with national law, Regulation 720 [4] does not require obtaining a certificate of release to service for the type of equipment intended for railway traffic, however, according to the definition of the structural subsystem "control", the interface is assessed part of this subsystem and is used to ensure the cooperation of 2 systems listed in Regulation 720 [4] for which separate operating admittance certificates issued by the National Safety Authority are required:
- station railway traffic control devices (§6 3 a));
- line block devices (§6 3 c));

therefore, it was assumed that the scope of checks should include groups of tests, i.e. for a device that is subject to technical tests in the scope defined in § 13.2 of this regulation. This chapter presents the model of application data prepared for simulated rail traffic control objects, between which interfaces can be implemented and tested. The application data has been prepared according to the technical design of virtual facilities on the railway network, mapping the actual stations, routes, railway level crossings and remote control areas as well as all railway traffic control devices located in these areas. The presented model of railway traffic control facilities is only an example of the implementation area of standard interfaces and was built to better present the location of the standard interface in the railway system.

In accordance with the requirements contained in [9], it was assumed that due to the fact that the transmission takes place in a closed network, in which devices with implemented safety cooperate with each other, according to the requirements [7] [9], it is possible to secure transmission with the use of class A0 telegrams (authorized access only). In such a case, the telegram frame is not encrypted, it is only secured with cyclic codes protecting against corruption in transmission. However, the cyclic code also protects to a certain extent against the unauthorized generation of false frames. The correctness of data exchange was verified with the use of the UDPS data transmission standard developed under the project [10].

3.1. The Goal and Scope of Simulation Tests

The aim of the laboratory tests was to check that the functional requirements resulting from the specification developed for the LB-IXL interface were met, in the conditions of technical implementation. Verification of the correctness of the functions performed by the interface in question allowed for the elimination of potential errors and irregularities in its operation even before its implementation in the conditions of actual operation on the railway network. Positive results of laboratory tests will be the basis for the commencement of further development works of the interface in accordance with the requirements of the PN-EN 50xxx (CENELEC) series standards [6][7][8][9].

The LB - IXL interface tests were carried out on a software simulator including [10]:
- actual interface applications;
- software of the station (interlocking) system with a simulator of external devices states;
- line block system software.

The scope of the LB - IXL interface laboratory tests included:
- functional checks of transmission of interlocking reports from the line block to the interlocking system;
- functional checks of forwarding additional reports (e.g. diagnostic) from the line block to the interface system;
- functional checks of the issued commands from the interlocking system to the line block.
The tests were conducted in two groups:
- under normal operating conditions;
- in conditions of simulated faults (including errors in telegrams, e.g. incorrect addressing, incorrect command codes, incomplete telegram, transmission loss, ...).

Additional tests resulting from the recommendations of data transmission protection [12]:
1. Checking the detection of errors in the UDPS telegram, e.g.:
   - incorrect addressing;
   - incorrect CRC code;
   - incorrect command code;
   - an order directed at an unauthorized object.
2. Verification of resistance to transmission disappearance.
3. Checking the performance of the interface and the ability to establish a connection.
4. Checking the interface for verification of the authenticity of the telegram (UDPS).
5. Checking the interface for integrity and consistent of the telegram (UDPS).
6. Checking the interface for unauthorized access (security according to the recommendations contained in the standard [9])

The test results were interpreted on the basis of appropriate feedback reports generated by software simulations of rail traffic control systems in response to commands or reports sent to them via the interface.

### 3.2. Structure of the Simulation Software

The specificity of the simulation model of digital interfaces determines the configuration of the test stand. In accordance with the assumptions adopted in the project [10], the test stands allowed for the implementation of software ensuring the functioning of this software, the possibility of recording and storing data obtained during the simulation. The test stand consists of workstations (test consoles) and a collective data server and has been built on the principle of a separate computer network (with a specified number of remote computers) with a secure connection to the Internet for remote model update and software supervision. Access to workstations (local and remote) required authorization - unauthorized access to the workstation was excluded.

The software functions basically include simulating the operation of the interface with the possibility of sending and observing states and commands transferred between systems. In accordance with the adopted assumptions, the states of elements and orders are transferred between the two systems A and B in a fixed data format. In order to illustrate individual states and messages from issued orders, the simulator application was supplemented with an appropriate user interface. The created user interface allows to enter orders, view states, and introduce disturbances. The division of the application window is shown in the figure below (Fig. 1) using the IXL and SN simulator as an example, but in other cases this division will be analogous.

The simulator between interlocking devices and the IXL-LB line block consists of two cooperating software modules [10]:
- BRIK_Symulator_urzadzen_LB_IXL_SN.exe – IXL and SN systems simulator (master system);
- BRIK_Symulator_urzadzen_LB_.exe – line block simulator.

The modules of the IXL - LB simulator can be run on separate computers and cooperate with each other by sending telegrams, using the Ethernet network, just like the target IXL - LB interface. Both simulator modules can also be run on one computer and cooperate via the IP address 127.0.0.1 (localhost).

The simulator modules are launched with the use of batch files (.bat) that define the software operating parameters and the directory with data files.

The IXL and SN simulator application window (Fig. 1) consists of four basic fields:
- LB-IXL - interlocking states;
- LB-SN Orders – Messages;
- transmission states between LB and IXL and SN;
- viewing the content of sent telegrams.

Description of individual application windows of the IXL and MV simulator presented in Fig. 1.
- The "LB-IXL - Interlocking states" field (1) is used to set and observe the IXL binary states and to observe the LB binary states. In the "Test window" tab in the IXL area (interlocking devices), the IXL states sent to the LB are presented. The change in the cell is sent to the LB simulator. In the "LB line block" area, the binary states LB are received by the IXL. LB states can be changed from the LB simulator.
- The "LB-SN Orders - Messages" field (2) is used to send orders and messages between LB and SN. This field consists of four tabs:
  - "Command issuance", the tab contains a selection list of commands that can be issued from SN to LB;
  - "Inquiries about the enforceability of commands", the tab contains a list of orders to LB. Clicking the button "Send a query to all orders" sends the orders and checks their feasibility;
  - "Configuration file";
  - "Connection disturbances", the tab presents the possible types of interface disturbances introduced during the simulation of its operation.
The data transmission status field (3) allows to view the transmitted orders and messages as well as the current transmission parameters. The upper area of the data transmission status field enables the observation of the commands and messages currently transferred between the simulator modules. Below there are three areas presenting the current transmission parameters between:
- LB and SN in terms of state transmission;
- LB and SN in terms of transmission of orders and messages;
- LB and IXL in terms of the transmission of interlocking states.

In the event of a transmission interruption, the background of the above-mentioned areas is highlighted in red.

There are eight areas in the telegram content area (4) that allow to view the full content of recently sent telegrams.

3.3. Summary of Tests

The test methodology consisted in forcing states in devices (sending telegrams - messages and commands) and observing the responses of devices receiving telegrams, and observing the compliance of the obtained system responses in terms of transmitted and selected information. If the tests are carried out without simulated faults in the transmission, and the consistent state on the sending and receiving sides is obtained, the test is marked as: Positive, which is tantamount to the test result indicating the correct operation of the interface (sending and receiving a status or command telegram). According to the adopted assumptions, the simulation models do not reflect the interlocking in the systems connected with the tested interface, but allow for "imposing" specific types of messages and commands and introducing disturbances in the data transmission path.

The general view of the test stand is shown in Fig. 2.
The results of the tests carried out in the field of [10]:

- Verification of the correctness of transmission of messages transmitted by LB in the IXL direction - it was found that the transmitted and received states are compatible with the LB-IXL interface. The scope of information transferred on the interface for the IXL-LB direction complies with the interface specification.

- Verification of the correctness of the transmission of messages transmitted by IXL in the LB direction - it was found that the states transmitted and received through the LB-IXL interface compatible (direction from IXL to LB). The scope of information transferred on the interface for the IXL-LB direction complies with the interface specification.

- Verification of the correctness of the transmission of commands transmitted through the SN (LB) interface - it was found that the states transmitted and received through the LB-SN interface are compatible. The scope of information transferred on the interface for the SN-LB direction is consistent with the interface specification.

- Checking the detection of transmission errors on the sending and receiving side of telegrams in the UDPS standard - in accordance with the Test Program and the specification defining the safety of data transmission [10], in order to meet the adopted assumptions, the UDPS protocol must be resistant to interference in the transmission: repetition, deletion, insertion, error, delay. As a result of the tests carried out for all the above mentioned disturbances and transmission errors, it was found that for the tested communication variants between LB-IXL (states and orders) and LB-SN (states) the UDPS transmission protocol [10] meets the requirements for safe transmission. An exemplary simulation window in the state of detection of transmission disturbances defined in the requirements of the standard, discussed in [12] (Fig. 3).

- Checking the performance and efficiency of the transmission link (including individual transmission parameters for channels) - as a result of the observations carried out during the tests, it was found that the transmission links are working stably, ensuring adequate capacity and transmission speed, and transmission faults and errors are detected.

Fig. 3 The window of the IXL-LB application with the function of introducing disturbances in the transmission (delay)

4. Conclusions

Overall: on the basis of the test results obtained, it is concluded that:

- The performed scope of tests is consistent with the framework test program [10], and exhausts the test possibilities of the test stand and the simulation model.

- The obtained positive test results confirmed that the LB-IXL interface works in the full range of data sent in real time (i.e. telegrams of command and message states) and the compliance with the correctness of telegrams sent and received by IXL and LB using the tested interface was confirmed, hence that the simulation model of the LB-IXL interface was defined in accordance with the interface specification [10].

Bearing in mind the above statements, it is considered that the defined test objective, i.e. "verification of the adopted standards and design assumptions", has been achieved.

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Selection of Delivery Vehicle Using Integrated Objective-subjective MCDM Model

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Abstract

The transport system as part of the logistics system has a huge impact on the development of the entire economic system. Thanks to the daily movements of goods flows, which are becoming more and more extensive from year to year, transport has become one of the key links of the economy. Therefore, it is very important to pay adequate attention to transport and delivery vehicles. The aim of this paper is the selection of adequate delivery vehicle for the needs of a newly established company by applying a subjective-objective MCDM model. Five potential solutions (delivery vehicles) were considered based on seven selected criteria. First, the objective CRITIC (CRiteria Importance Through Intercriteria Correlation) method was applied, and then the subjective FUCOM (FUll COnsistency Method), on the basis of which the importance of the criteria for the selection of a delivery vehicle was determined. The MARCOS (Measurement of Alternatives and Ranking according to COMpromise Solution) method was applied to rank delivery vehicles and select the most acceptable solution from the set of considered alternatives. The results showed that the purchase price plays the most important role in choosing a delivery vehicle, while the Peugeot Boxer was chosen as the best solution for a given transport company.

KEY WORDS: delivery vehicle; transport; CRITIC; FUCOM; MARCOS

1. Introduction

Everyday movement of goods flows requires detailed knowledge of all the characteristics of the logistics subsystem of transport, especially when it comes to organizing international transport. It is necessary to access the solution of every problem that may occur in transport in a systematic way, and they are most often related to the means of transport. The main aim of the paper through which the contribution can be manifested is reflected through the creation of an integrated model for the selection of a delivery vehicle. The created model has been applied in one new transportation company. The first alternative is the Renault Master van (A1), the second the Volkswagen Crafter (A2), the third the Citroen Jumper (A3), the fourth the Fiat Ducato (A4) and the fifth the Peugeot Boxer (A5). The criteria for these alternatives are as follows: price in BAM (C1), load capacity in kg (C2), age of the vehicle shown in months (C3) because owner have decided to not buy new vehicle, mileage in km (C4), size of cargo space in euro pallet (C5), engine power in KW (C6), and fuel consumption l/100km (C7). The created model can be applied in other areas of decision-making.

The rest of the paper is structured through the following chapters. The second chapter presents the methods used in this paper. CRITIC, FUCOM, and MARCOS algorithms are given, which means showing the steps of these methods. The third part of the paper briefly describes a case study with the input parameters of the MCDM model. Also, the most important results obtained by applying an integrated objective-subjective model are presented. The fourth chapter presents the verification of results through comparison with two other MCDM methods and changing the values of the criteria. The fifth chapter summarizes the most important results and contributions of the research. Also, guidelines for further research are given.

2. Methods

This section presents the methods used through three subsections. Detailed steps of all methods are given: CRITIC, FUCOM and MARCOS.

2.1. CRITIC method

This method consists of the following steps [1]:
Step 1: Forming an initial matrix
where \( x_{ij} \) represents the characteristics of \( i \) alternative in relation to the \( j \) criterion.

Step 2: Normalization of the initial matrix depending on the type of criteria:

\[
\begin{align*}
   r_{ij} &= \frac{x_{ij} - \min_{j} x_{ij}}{\max_{j} x_{ij} - \min_{j} x_{ij}} \quad \text{if} \ j \in B \rightarrow \max; \\
   r_{ij} &= \frac{x_{ij} - \max_{j} x_{ij}}{\min_{j} x_{ij} - \max_{j} x_{ij}} \quad \text{if} \ j \in C \rightarrow \min.
\end{align*}
\]

Step 3. Determining a symmetric linear correlation matrix

\[
r_{ij} = \frac{n \sum x_{i} y_{j} - \sum x_{i} \sum y_{j}}{\sqrt{n \sum x_{i}^{2} - (\sum x_{i})^{2}} \cdot \sqrt{n \sum y_{j}^{2} - (\sum y_{j})^{2}}}
\]

Step 4. Calculation of the standard deviation (\( \sigma \)) (5) and calculation of the sum of the matrix 1-\( r_{ij} \) (6):

\[
\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_{i} - \bar{x})^{2}},
\]

where \( n \) represents the total number of data in a sample, \( \bar{x} \) is the mean value of the data in a sample.

\[
\sum_{j=1}^{n} (1-r_{ij}).
\]

Step 5. Determining the amount of information in relation to each criterion by Eq. (7):

\[
C_{j} = \sigma \sum_{j=1}^{n} (1-r_{ij}).
\]

Step 6. Calculation of criterion weights by Eq. (8):

\[
W_{j} = \frac{C_{j}}{\sum_{j=1}^{n} C_{j}}.
\]

2.2. FUCOM Method

The FUCOM method is based on the principles of pairwise comparison and validation of results through deviation from maximum consistency [2]. Benefits that are determinative for the application of FUCOM are a small number of pairwise comparisons of criteria (only \( n-1 \) comparison), the ability to validate the results by defining the deviation from maximum consistency (DMC) of comparison and appreciating transitivity in pairwise comparisons of criteria. Figure 1 presents the FUCOM algorithm [3].
Input: Expert pairwise comparison of criteria

Step 1: Expert ranking of criteria/sub-criteria

Step 2: Determining the vectors of the comparative significance of evaluation criteria

Step 3: Defining the restrictions of a non-linear optimization model

Restriction 1: The ratio of the weight coefficients of criteria is equal to the comparative significance among the observed criteria

Restriction 2: The values of weight coefficients should satisfy the condition of mathematical transitivity

Step 4: Defining a model for determining the final values of the weight coefficients of evaluation criteria

Step 5: Calculating the final values of evaluation criteria/sub-criteria

Output: Optimal values of the weight coefficients of criteria/sub-criteria

Fig. 1 FUCOM method algorithm

However, unlike other subjective models, FUCOM has shown minor deviations in the obtained values of the weights of criteria from optimal values [4, 5].

2.3. MARCOS Method

The MARCOS method developed by Stević et al. [6] consists of the following steps:

Step 1: Formation of an initial decision-making matrix.

Step 2: Formation of an extended initial matrix. In this step, the extension of the initial matrix is performed by defining the ideal (AI) and anti-ideal (AAI) solution:

\[
A_{AI} = \begin{bmatrix}
    x_{a_{i1}} & x_{a_{i2}} & \cdots & x_{a_{in}} \\
    x_{a_{11}} & x_{a_{12}} & \cdots & x_{a_{1n}} \\
    x_{a_{21}} & x_{a_{22}} & \cdots & x_{a_{2n}} \\
    \vdots & \vdots & \cdots & \vdots \\
    x_{a_{m1}} & x_{a_{m2}} & \cdots & x_{a_{mn}} \\
    x_{a_{w1}} & x_{a_{w2}} & \cdots & x_{a_{wn}}
\end{bmatrix},
\]

where \( B \) represents a benefit group of criteria, while \( C \) represents a group of cost criteria.

Step 3: Normalization of the extended initial matrix \( X \). The elements of the normalized matrix \( N = \left[ n_{ij} \right]_{m \times n} \) are obtained by applying Eqs. (12) and (13):
\[ n_{ij} = \frac{x_{ij}}{x_{ij}} \text{ if } j \in C ; \]
\[ n_{ij} = \frac{x_{ij}}{x_{ij}} \text{ if } j \in B , \]

where elements \( x_{ij} \) and \( x_{ij} \) represent the elements of the matrix \( X \).

Step 4: Determination of the weighted matrix \( V = \left[ v_{ij} \right]_{m \times n} \), Eq. (14):
\[ v_{ij} = n_{ij} \times w_i , \] (14)

Step 5: Calculation of the utility degree of alternatives \( K_i \) applying Eqs. (15) and (16):
\[ K_i^- = \frac{S_i}{S_{mi}} ; \] (15)
\[ K_i^+ = \frac{S_i}{S_m} , \] (16)

where \( S_i (i = 1,2,...,m) \) represents the sum of the elements of the weighted matrix \( V \), Eq (17):
\[ S_i = \sum_{i=1}^{n} v_{ij} . \] (17)

Step 6: Determination of the utility function of alternatives \( f(K_i) \) defined by Eq. (18):
\[ f(K_i) = \frac{K_i^+ + K_i^-}{1 + f(K_i^-) + f(K_i^+)} ; \] (18)

where \( f(K_i^-) \) represents the utility function in relation to the anti-ideal solution, while \( f(K_i^+) \) represents the utility function in relation to the ideal solution.

Utility functions in relation to the ideal and anti-ideal solution are determined by applying Eqs. (19) and (20):
\[ f(K_i^-) = \frac{K_i^+}{K_i^+ + K_i^-} ; \] (19)
\[ f(K_i^+) = \frac{K_i^-}{K_i^+ + K_i^-} . \] (20)

Step 7: Ranking the alternatives. Ranking of the alternatives is premised on the final values of utility functions. It is desirable that an alternative has the highest possible value of the utility function.

3. Case Study

“TH Transport” company was founded on June 1, 2020 with its headquarters in Doboj. For now, this company owns one delivery vehicle and employs one logistician. They quickly fit into the organization and implementation of international transport, and are trying to expand their vehicle fleet.

3.1. Forming Multi-Criteria Decision-Making Model

In consultation with the owner of the company, an initial matrix of five alternatives and seven criteria was created, on which the selection of delivery vehicle depends. The first alternative is the Renault Master van (A1), the second the Volkswagen Crafter (A2), the third the Citroen Jumper (A3), the fourth the Fiat Ducato (A4) and the fifth the Peugeot Boxer (A5). The criteria for these alternatives are as follows: price in BAM (C1), load capacity in kg (C2), age of the vehicle shown in months (C3) because owner have decided to not by new vehicle, mileage in km (C4), size
of cargo space in euro pallet (C5), engine power in KW (C6), and fuel consumption l/100km (C7). According to these data the initial decision-making matrix is formed (Table 1):

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>25,600</td>
<td>1212</td>
<td>28</td>
<td>285,000</td>
<td>10</td>
<td>125</td>
<td>8.2</td>
</tr>
<tr>
<td>A2</td>
<td>35,000</td>
<td>1290</td>
<td>14</td>
<td>140,900</td>
<td>10</td>
<td>132</td>
<td>7.2</td>
</tr>
<tr>
<td>A3</td>
<td>20,000</td>
<td>1400</td>
<td>35</td>
<td>183,920</td>
<td>10</td>
<td>110</td>
<td>7.4</td>
</tr>
<tr>
<td>A4</td>
<td>32,000</td>
<td>1300</td>
<td>17</td>
<td>118,355</td>
<td>9</td>
<td>130</td>
<td>7.5</td>
</tr>
<tr>
<td>A5</td>
<td>34,000</td>
<td>1150</td>
<td>15</td>
<td>80,800</td>
<td>8</td>
<td>121</td>
<td>7.5</td>
</tr>
</tbody>
</table>

3.2. Determining Criteria Weights Using CRITIC and FUCOM Methods

Matrix normalization using CRITIC method is performed using Eqs. (2) and (3) in the following way:

\[ x_{i1} = \frac{25600 - 35000}{20000 - 35000} = 0.627 ; \]

\[ x_{i7} = \frac{8.2 - 8.2}{7.2 - 8.2} = 0. \] It is important to note that the second, the fifth and the sixth criterion belongs to benefit group, while other belongs to cost group. Normalized decision-making matrix and standard deviation calculated using equation (5) is shown in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.627</td>
<td>0.248</td>
<td>0.333</td>
<td>0.000</td>
<td>1.000</td>
<td>0.682</td>
<td>0.000</td>
</tr>
<tr>
<td>A2</td>
<td>0.000</td>
<td>0.560</td>
<td>1.000</td>
<td>0.706</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>A3</td>
<td>1.000</td>
<td>1.000</td>
<td>0.000</td>
<td>0.495</td>
<td>1.000</td>
<td>0.000</td>
<td>0.800</td>
</tr>
<tr>
<td>A4</td>
<td>0.200</td>
<td>0.600</td>
<td>0.857</td>
<td>0.816</td>
<td>0.500</td>
<td>0.909</td>
<td>0.700</td>
</tr>
<tr>
<td>A5</td>
<td>0.067</td>
<td>0.000</td>
<td>0.952</td>
<td>1.000</td>
<td>0.000</td>
<td>0.500</td>
<td>0.700</td>
</tr>
<tr>
<td>STDEV</td>
<td>0.424</td>
<td>0.379</td>
<td>0.441</td>
<td>0.384</td>
<td>0.447</td>
<td>0.397</td>
<td>0.378</td>
</tr>
</tbody>
</table>

Determining the correlation between the criteria has been performed using Eq. (4) as follows:

\[ r_{12} = \frac{5 \cdot 1.725 - 1.893 \cdot 2.408}{\sqrt{(5 \cdot 1.437 - 1.893)^2 + (5 \cdot 1.893 - 2.408)^2}} = 0.565. \] In such way matrix of linear correlation coefficients has been obtained (Table 3).

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1.000</td>
<td>0.565</td>
<td>-0.997</td>
<td>-0.641</td>
<td>0.529</td>
<td>-0.783</td>
<td>-0.351</td>
</tr>
<tr>
<td>C2</td>
<td>0.565</td>
<td>1.000</td>
<td>-0.533</td>
<td>-0.125</td>
<td>0.623</td>
<td>-0.355</td>
<td>0.416</td>
</tr>
<tr>
<td>C3</td>
<td>-0.997</td>
<td>-0.533</td>
<td>1.000</td>
<td>0.682</td>
<td>-0.556</td>
<td>0.771</td>
<td>0.383</td>
</tr>
<tr>
<td>C4</td>
<td>-0.641</td>
<td>-0.125</td>
<td>0.682</td>
<td>1.000</td>
<td>-0.733</td>
<td>0.136</td>
<td>0.762</td>
</tr>
<tr>
<td>C5</td>
<td>0.529</td>
<td>0.623</td>
<td>-0.556</td>
<td>-0.733</td>
<td>1.000</td>
<td>-0.038</td>
<td>-0.133</td>
</tr>
<tr>
<td>C6</td>
<td>-0.783</td>
<td>-0.355</td>
<td>0.771</td>
<td>0.136</td>
<td>-0.038</td>
<td>1.000</td>
<td>0.014</td>
</tr>
<tr>
<td>C7</td>
<td>-0.351</td>
<td>0.416</td>
<td>0.383</td>
<td>0.762</td>
<td>-0.133</td>
<td>0.014</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The forming of the next matrix is performed by subtracting the correlation matrix from number one. When subtraction is performed, the values are summed by columns for all criteria (Eq. (6)). Multiplying the standard deviation value by the previously obtained individual sum value per column (Eq. (7)) is for example: C1 = 0.424*7.679 = 3.258. Their sum is 17.499. The values of the weighting coefficients are obtained when the individual value of Cj is divided by the previous sum (Eq. (8)), for example: \[ w_1 = \frac{3.258}{17.499} = 0.186. \] Other values were obtained in the same way: \[ w_2 = 0.117; w_3 = 0.157; w_4 = 0.130; w_5 = 0.161; w_6 = 0.142; w_7 = 0.106. \]

In the next part, the FUCOM method was used, by which we will determine the values of weight coefficients. The first step is to rank the criteria from a predefined set of criteria. Ranking is done \( C1 > C4 > C3 > C6 >> C5 > C7 > C2 \) according to importance of criteria using preferences of decision makers. In the second step of FUCOM method comparison between criteria has been performed and shown in Table 4.
Table 4
Comparison between criteria

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C4</th>
<th>C3</th>
<th>C6</th>
<th>C5</th>
<th>C7</th>
<th>C2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.4</td>
<td>1.8</td>
<td>2.4</td>
<td>2.9</td>
<td>3.4</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Using the next steps of the FUCOM method the final model based on which the final values of the criteria are obtained is presented as follows:

\[
\min \chi \quad \text{s.t.} \quad \begin{align*}
\frac{w_1}{w_4} - 1.40 & \leq \chi, \\
\frac{w_1}{w_4} - 1.29 & \leq \chi, \\
\frac{w_1}{w_5} - 1.33 & \leq \chi, \\
\frac{w_1}{w_6} - 1.21 & \leq \chi, \\
\frac{w_1}{w_7} - 1.17 & \leq \chi, \\
\frac{w_2}{w_2} - 1.18 & \leq \chi,
\end{align*}
\]

After solving this model obtained criteria weights are: \( w_1 = 0.280; \) \( w_2 = 0.070; \) \( w_3 = 0.155; \) \( w_4 = 0.200; \) \( w_5 = 0.096; \) \( w_6 = 0.116; \) \( w_7 = 0.082. \)

Final criteria weights obtained using both methods (CRITIC and FUCOM) are as follow: \( w_1 = 0.233; \) \( w_2 = 0.094; \) \( w_3 = 0.156; \) \( w_4 = 0.165; \) \( w_5 = 0.129; \) \( w_6 = 0.129; \) \( w_7 = 0.094. \) We use the collected weight coefficients for further calculations with the MARCOS method.

3.3. The Selection of Delivery Vehicle Using MARCOS Method

Using MARCOS methodology final results are obtained and shown in Table 5.

Table 5
Delivery vehicles ranking using MARCOS method

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>Ki-</th>
<th>Ki+</th>
<th>fK-</th>
<th>fK+</th>
<th>Ki</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAI</td>
<td>0.613</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>0.722</td>
<td>1.178</td>
<td>0.722</td>
<td>0.620</td>
<td>0.380</td>
<td>0.586</td>
<td>5</td>
</tr>
<tr>
<td>A2</td>
<td>0.822</td>
<td>1.342</td>
<td>0.822</td>
<td>0.620</td>
<td>0.380</td>
<td>0.667</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>0.790</td>
<td>1.289</td>
<td>0.790</td>
<td>0.620</td>
<td>0.380</td>
<td>0.641</td>
<td>4</td>
</tr>
<tr>
<td>A4</td>
<td>0.807</td>
<td>1.318</td>
<td>0.807</td>
<td>0.620</td>
<td>0.380</td>
<td>0.655</td>
<td>3</td>
</tr>
<tr>
<td>A7</td>
<td>0.837</td>
<td>1.365</td>
<td>0.837</td>
<td>0.620</td>
<td>0.380</td>
<td>0.679</td>
<td>1</td>
</tr>
<tr>
<td>A1</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1</td>
</tr>
</tbody>
</table>

Ranking is done based on the final values of the utility functions from highest to lowest. Therefore, the ranking of alternatives is as follows: \( A5 > A2 > A4 > A3 > A1. \) The most suitable delivery vehicle for TH Transportation company is the Peugeot Boxer.

4. Sensitivity Analysis

In this part of the paper two verification analyses have performed. The first represent comparison analysis with two MCDM methods: SAW [7] and WASPAS [8] where initial results are confirmed, which mean that no any change in ranking delivery vehicles.

In the next validation phase, the we have analysed the impact of the change in the two most important criteria (C1 and C4) on the rating. The Eq. (21) helped to form 12 scenarios. Results are shown on Fig. 2.

\[
W_{eff} = \frac{W_{0}}{(1-W_{0})} \quad (21)
\]

As can be seen from Fig. 2 in scenarios S1-S6 where values of the first (most important criterion) have been changed (decreased) in intervals of 15-90% no changes in rank results. However, if considering scenarios S8-S12, can be concluded that the second most important criterion mileage (C4) has large influence on delivers vehicles ranking because the best solution causes even fourth position.
5. Conclusion

In this paper an integrated objective-subjective model for delivery vehicles selection has been developed. Consist of three methods: CRITIC and FUCOM for determining criteria weights and MARCOS method for ranking delivery vehicles. Real case study in one new established company has been performed. According to their needs and requests multi-criteria decision-making model including seven criteria and five alternatives has been created. Results show that the best alternative is a delivery vehicle "Peugeot Boxer", and the second best alternative is a delivery vehicle "Volkswagen Crafter".

The future plans of the company "TH Transport" are the constant development of companies and the conquest of the market, so this work should help their development and improvement.

Acknowledgement

This work has been supported by the Ministry of Education and Science of the Republic of Serbia, within the Project: Innovative scientific and artistic research in the domain of FTN activities, University of Novi Sad, Faculty of Technical Sciences.

References

Optimization of the Enterprise Railcar Fleet Structure for the Transportation of Iron Ore Raw Materials

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Abstract

The paper is devoted to the transportation issues of iron ore raw materials by railway transport. The purpose of the research is determining the number of private cars a mining enterprise should have to transport its products. The research is performed using the methods of the theory of railways operation, economic and mathematical modeling, mathematical statistics and direct methods of minimization. During the research the task for determining the number of private cars of the enterprise is reduced to the stochastic problem of minimizing the modified reduced costs of the enterprise, which are represented by a piecewise nonlinear function of one variable. The originality of the work is related to the fact that it has improved the method for calculating the car fleet of enterprises by taking into account differences in the technology of loading private cars and the involved cars of operator companies. The practical value of the work lies in the fact that the proposed method allows one to reduce the logistics costs of mining enterprises due to a more accurate assessment of the costs associated with the development and operation of the car fleet, as well as the accompanying railway infrastructure of sidings.

KEY WORDS: railways, ore transportation, railcar fleet, optimization

1. Introduction

Twenty percent of the world's iron ore reserves are located on the territory of Ukraine. Ukraine ranks first in the world in terms of reserves of iron ore raw materials, and seventh in terms of production volumes. Iron ore is used both by the metallurgical industry of Ukraine and is exported. At the same time, the share of iron ore is about 7% of Ukraine's merchandise exports in monetary terms. Delivery of iron ore raw materials (pellets, iron ore concentrate) from mining sites to sites of processing or transshipment to sea transport is associated with the need to move significant cargo volumes and the main transport mode in Ukraine is rail transport. The share of iron ore in the volume of rail transport in Ukraine is about 20%. Considering the relatively low cost of iron ore raw materials, a significant part of its cost for the end user is associated with logistics costs; therefore, reducing the cost of transporting iron ore raw materials by rail is an important problem for both individual enterprises and the Ukrainian economy as a whole. One of the tasks arising in this case is to determine the size and structure of the car fleet required by a mining enterprise to perform transportation. This article is devoted to solving this problem.

2. Literature Review and Purpose of the Study

The methods of calculating the car fleet required for transportation practically used in railway transport at present are based on the results of a statistical analysis of the use of rolling stock in previous periods. Engineer N. Kulzhynskyi proposed this approach back in 1878. Already at the beginning of the 20th century, there were various formulas linking various indicators of the operational work of railways and the required fleet for its development. As examples of such formulas, the expressions connecting the size of the operating car fleet $N$ with the work of the car fleet $U$, cars, mileage $\sum NS$, car-km and cargo turnover $Pl_{tg}$, t-km net are given below.

$$N = U \theta ; \quad N = \frac{\sum NS}{S} ; \quad N = \frac{Pl_{tg}}{Wr},$$

where $\theta$ - car turnover, day; $S$ - average daily car mileage, km/day; $Wr$ - average daily car productivity, t-km net/car.
If the assessment of the need for car fleet is carried out in the process of medium-term and long-term planning, then it is necessary to take into account the unevenness of the volume of freight operation in time, as well as the fact that some of the cars are under repair and cannot be used for transportations. The simplest approach to accounting of these factors is associated with the use of multiplying factors. Thus, in [1], it is proposed to determine the car fleet necessary for transportations of goods by the following formula:

\[ N = \frac{U_m \theta}{30.4, k, k_r}, \]

where \( U_m \) – the planned volume of loading cars during the month, cars; 30.4 – average number of days in a month, days; \( k_r \) – coefficient taking into account the car stay under repair; \( k_r \) – loading irregularity coefficient.

Another way of accounting the irregularity of transportations is given in the work [2], where the irregularity of the car turnover value when calculating the operating fleet is taken into account using the coefficient of variation:

\[ N = \frac{Q}{p_d t_c}(1 + CV), \]

where \( t_c \) – the number of the car turnovers during the planning period; \( CV \) – coefficient of variation of the car turnover duration.

It should be noted that the parameters of all the above calculation formulas are random values. Their values can differ significantly from the average ones and change over time. A significant drawback of direct using statistical data on the operation of cars to estimate the number of cars required for transportation in the future is associated with the fact that the management of the existing fleet may not be optimal. This problem is considered in detail in [2], where an element-by-element analysis of the car turnover process during the chemical products transportation is carried out. In the same paper, the reasons for car delays in different service phases are considered and approaches to their minimization are proposed. There is a significant number of works in which the size of the car fleet is established as a result of solving optimization problems for organizing the movement of car traffic volumes in the network [3-10]. The main part of these works is aimed at optimizing the size of the car fleet of carriers and operators.

In general, the literature analysis shows that modern methods for calculating the car fleet required for transportation were formed at the end of the 19th – beginning of the 20th centuries and have not changed significantly since that time. The main tasks that are currently being considered are the structure optimization of the car fleet in the context of changing traffic volumes and the duration of car turnover, as well as increasing the efficiency of using freight cars in order to optimize the size of their fleet. The main methods of scientific research that were used by the authors of scientific works in this case are the methods of mathematical statistics, economic and mathematical modeling, as well as operations research. The relevance of this study is due to the fact that the tasks the consignors face when forming a car fleet for the transportation of their products differ from the tasks of carriers and car operators when forming car fleets to provide services to third-party consumers. And the conditions for the transportation of iron ore raw materials differ from those of transportation of other goods considered in scientific papers. Therefore, the methods for calculating the size of the car fleet needed for carrying out the transportation of iron ore raw materials requires improvement. The aim of the work is to improve the methods for calculating the size of the private car fleet to perform transportations in the context of changing the volumes of work. In the course of the study, the following tasks are being solved: study of the actual conditions of transportation of iron ore raw materials; construction of economic and mathematical model to assess the required size and structure of the car fleet to transport iron ore raw materials; selection of the method and solution of the optimization problem of the required size and structure of the car fleet to transport iron ore raw materials.

3. Solution Methodology

Mining and processing enterprises make shipments of iron ore raw materials to the address of metallurgical enterprises and seaports. These transportations are characterized by significant volumes and a relatively small number of possible destinations. Ferrexpo Poltava Mining is considered as an example. It is the largest producer and exporter of iron ore pellets in Ukraine. The modern production facilities of the enterprise ensure the production of 12 million tons of pellets per year. At the same time, the actual production volumes are 10-12 million tons. Pellets are shipped in three main directions: the Seaport of Pivdennyi (Khimiichna and Berehova stations), the Port of Izmail (Izmail station) and western land border crossings (Chop, Batievo and Uzhhorod stations). These directions differ significantly in the distance of transportations, which for the Seaport of Pivdennyi (hereinafter STPY) is 514-525 km, for the Port of Izmail (hereinafter ISTP) – 831 km and for western border crossings (hereinafter WBC) – 1203-1226 km, which causes a significant difference in car turnover duration on these routes. Fig. 1, a shows the dynamics of the value of the seasonality coefficient of the loading volumes, which for the \( i \)-th \( (i = 0...3) \) direction \( (i = 0 \) corresponds to the total volume of loading PM) in the \( j \)-th month \( (j = 1...12) \) was determined by the formula:

\[ \gamma_{ij} = \frac{Q_{m;ij}}{Q_{m;ij}}, \]
where $\bar{Q}_{m,ij}$ - average daily traffic volumes in the $i$-th direction in the $j$-th month; $\bar{Q}_{j,i}$ - average daily traffic volumes in the $i$-th direction during the year.

Analysis of statistical data shows that the shipment of finished products by the enterprise occurs quite evenly and the total monthly volumes of shipment vary within $0.75\div1.2$ of the average annual. At the same time, the shipment volumes in certain directions change significantly. The greatest fluctuations are observed when transporting to the Izmail port, where in some months there are no shipments, and in some months, they exceed the average annual two times. Fig. 1, b shows the dynamics of the seasonality coefficient value of the car turnover, which for the $i$-th ($i = 1\ldots3$) direction in the $j$-th month ($j = 1\ldots12$) was determined by the formula:

$$\varphi_{ij} = \frac{\bar{Q}_{m,ij}}{\bar{Q}_{j,i}},$$

where $\bar{Q}_{m,ij}$ - average car turnover in the $i$-th direction in the $j$-th month; $\bar{Q}_{j,i}$ - average car turnover on the $i$-th direction during the year.

The size of the car fleet required by a mining enterprise to carry out transportation during the $j$-th month can be set as:

$$N_j = \sum_{i=1}^{k} \frac{\bar{Q}_{m,ij} (\bar{\tau}_{ij} + t_{pu})}{p_{sl}},$$

where $\bar{\tau}_{ij}$ - the duration of the car location outside the siding of a mining enterprise when carrying out transportation to the $i$-th direction in the $j$-th month, days; $t_{pu}$ - standard duration of a car location on the siding of a mining enterprise, days; $k$ - the number of directions to which iron ore raw materials are shipped.

The need to divide the duration of car turnover $\bar{Q}_{m,ij}$ into components $\bar{\tau}_{ij}$ and $t_{pu}$ is due to the fact that, as a rule, industrial enterprises use a simplified system for accounting the turnover duration of their cars and the duration of car location on the siding includes both the time spent on loading cars itself, idle time for repairs, and time on staging tracks, etc. It is also assumed in the calculations that the capacity reserves of the railway infrastructure and the productivity of the loading and unloading mechanisms of the consignor and consignees are sufficient to smooth out the daily irregularity of the volume of freight work. Considering that the values of $\bar{Q}_{m,ij}$ and $\bar{\tau}_{ij}$ are random, the number of cars $N_j$ required to ensure transportations during a separate month is also a random variable. The histogram of the random variable $N_j$ is shown in Fig. 2.

Based on the analysis of the statistical series of a random variable $N_j$, it was hypothesized that the parent universe has a normal distribution. Testing this hypothesis using the Pearson's goodness-of-fit test $\chi^2$ showed that there is no reason to reject the hypothesis about the normal distribution law of a random variable of the car number, which is used by Poltava Mining and Processing Plant during a separate month for the transportation of pellets.

The technology of work with private cars and cars of the third-party operators on the loading siding is different. Private cars are supplied for loading without preliminary preparation. In the case of a drop in traffic volumes so that $N_j < n_o$ ($n_o$ here is the number of cars of private fleet of the enterprise used for transportation), private cars go to the staging. At the same time, if $n_o - N_j \leq Mhd$ (here $Mhd$ is the capacity of staging tracks on the siding), then the staging is performed on the own tracks of the enterprise, otherwise it is performed on the tracks of other owners for a fee $c_{hd}$. In the case of traffic volume increase so that $N_j > n_o$, the cars of other owners are additionally used for transportation.
Before the supply of these cars for loading, their preparation is carried out, additional costs for which are $c_{pt}$. The number of cars of other owners, supplied for loading during the day, should not exceed the throughput capacity of the point for preparing cars for transportation $H_{pc}$.

![Fig. 2 A histogram of a random value of the number of cars required to carry out transportation within a month](image)

It should be noted that a change in the car fleet might also be accompanied by a change in the capacity of staging tracks and the throughput capacity of the point for preparing cars for transportation. In this regard, we can consider $k$ variants of the technical equipment of the siding. They are characterized by different capacities of the staging tracks $M_{st,q}$, the throughput capacity of the point for preparing cars for transportation $H_{pc,q}$, the cost of preparing a car for transportation $c_{pt,q}$, as well as the value of capital investments in the development of capacities for staging cars and a point preparing for transportation, respectively $C_{inf,q}$ and operation of the track infrastructure of the enterprise $C_{t,q}$ (here $q$ is the number of variant $q = 1..k$). The terms of payment for cargo transportation services in own cars of the enterprise and the cars of the operator differ as well. When transporting iron ore in own cars of the enterprise, the transportation fee includes payment for the services of railway infrastructure and locomotive traction when transporting a loaded and empty car and is defined as:

$$c_{a,j} = c_j(l_i) + 4c_e(l_i),$$

where $c_j(l_i)$ - rate for the transportation of a loaded car on the $i$-th route over a distance $l_i$ per car; $c_e(l_i)$ - rate for the transportation of an empty car on the $i$-th route over a distance $l_i$ per axle.

When transporting iron ore in the cars of the carrier or operators, the transportation fee includes payment for railway infrastructure and locomotive traction services for the transportation of a loaded car, as well as payment for using the car:

$$c_{a,j} = c_j(l_i) + w_c(t_{ij} + k_e t_{ej}) + c_{pt}t_{pm},$$

where $w_c$ - rate for using the car, UAH per day; $t_{ij}$, $t_{ej}$ - terms of delivery of loaded and empty cars on the $i$-th route; $k_e$ - empty mileage coefficient; $c_{pt}$ - rate for using the car during the performance of a cargo operation, UAH per hour; $t_{pm}$ - duration of car location on the siding of a mining enterprise, hour.

Considering that the conditions for using private cars and cars of the third-party operators when transporting iron ore raw materials by a mining complex differ, the problem of optimizing the size of private car fleet arises. As a rule, such a problem arises in the case of production development and is associated with an assessment of the need to purchase an additional car fleet for mastering traffic volumes $Q$. The number of cars of own fleet of the enterprise is chosen as the variable $x$ in this task. As an optimality criterion, the minimum of modified reduced PVC costs was chosen, while the objective function is formulated as:

$$PVC(x,Q) = C_{vq} (x-N_o) + C_{st,q} + \left( LCC-C_{vq} \right) x + C_{v,q} \left( x, Q \right) \frac{1-(1+R)^{-T}}{R} \left( 1-\varphi \right) \frac{1-(1+R)^{-T}}{R} \rightarrow \min_{q=1..k} x = k,$$  \hspace{1cm} (1)

where $C_{vq}$ - cost of a new car without VAT, UAH; $N_o$ - existing private car fleet, units; $LCC$ - life cycle cost, UAH; $C_{v,q} (x,Q)$ - annual expenses for the transportation of the cargo volume $Q$ with the size of the private car fleet $x$ and the $q$-th variant for the siding development, UAH; $R$ - discount rate, share; $T$ - life cycle duration of the car, year; $\varphi$ - profit tax rate, share; $A$ - depreciation of the car per year, UAH.
The life cycle cost $LCC$ of the car and its depreciation cost $A$ are calculated using known methods. The annual transportation costs $C_{p,q}(x,Q)$ for the $q$-th variant of technical equipment of the siding infrastructure of a mining enterprise are determined as:

$$C_{p,q}(x,Q) = 365\left(\overline{N}_o(x,Q)c_o + \overline{N}_a(x,Q)(c_{pr,q} + c_{pr,q}) + \overline{N}_e(x,Q)c_{ad}\right) + C_{i,q},$$

(2)

where $\overline{N}_o(x,Q)$ - average daily number of the own cars of the enterprise, which is used to transport the cargo volume $Q$ with a private car fleet $x$; $\overline{N}_a(x,Q)$ - the average daily number of cars of the third-party operators, which is used to transport the cargo volume $Q$ with a private car fleet $x$; $\overline{N}_e(x,Q)$ - the average daily number of private cars that are located on the staging tracks of the third-party owners when transporting the cargo volume $Q$ and with the private car fleet $x$.

The values of the parameters $\overline{N}_o, \overline{N}_a, \overline{N}_e$ of function (2) can be established by the method of statistical tests (Monte Carlo method).

The values of the variable $x$ in the objective function (1) are limited based on the throughput capacity of the station for preparing cars for transportation and the total amount of investment funds allocated for the development. The system of task constraints can be represented as:

$$\begin{cases}
    x \geq \left(1.15M[N] + 1.892\sigma[N] - \overline{H}_{pc,q}\right)k_r, \\
    x \leq \frac{C_{max} - C_{inf,q} + N_o}{C_{cr}},
\end{cases}$$

(3)

where $M[N], \sigma[N]$ - mathematical expectation and mean square deviation of a random value of the car number required for transportation during the day, car.

The objective function (1) and the system of constraints (2) represent an economic and mathematical model that is used to assess the required size and structure of the car fleet. For a given traffic volume $Q$, for each of the $k$ variants of the technical equipment of the siding, its own values of capital investments in the infrastructure development $C_{inf,q}$, and annual transportation costs $C_{p,q}(x,Q)$ can be set within the limits (3). Based on these data, a dependence $PVC_q(x,Q)$ corresponding to this variant can be obtained. An example of the dependence of the modified reduced costs on the number of the enterprise’s own cars is shown in Fig. 3. The optimum number of cars in example that shown on Fig. 3 is 4768.

Fig. 3 The order of train formation using the nominal destination numbers PVC, mln USD

4. Research Results

Each of the dependences $PVC_q(x,Q)$, as well as function (1) as a whole $PVC(x,Q) = \min_q \left(PVC_q(x,Q)\right), q = 1,k$, are piecewise nonlinear integer functions of one variable $x$. Thus, the studies
performed allow us to reduce the calculation of the size of the mining enterprise’s car fleet for transportation to solving the problem of optimizing a nonlinear nonsmooth objective function of one variable under constraints. In this case, the reduced modified costs act as an objective function, and the size of the private car fleet serves as a variable. Taking into account the nature of the objective function, the problem can be solved by direct search methods, for example, the golden section method.

The work originality is due to the fact that it has improved the method for calculating the car fleet of enterprises by taking into account the differences in the loading technology of their own cars and the involved cars of operator companies. The practical value of the work lies in the fact that the proposed method allows one to reduce the logistics costs of mining enterprises due to a more accurate assessment of the costs associated with the development and operation of the car fleet, as well as the accompanying railway infrastructure of the sidings.

5. Conclusions

The studies performed allow us to draw the following conclusions:

1. The conditions for solving the problem of optimizing the size of the car fleet of industrial enterprises used to transport their own products have significant differences from the solution of the problem of optimizing the size of the car fleet of carriers and operators that are used to provide transport services. For the transportation of products of the mining industry, both own cars of the mining enterprises and cars of the carrier or operators can be used. In this regard, as a result of solving the problem of determining the size of the private car fleet required for the enterprise to master the planned volume of transportation, it is necessary to establish a rational ratio of the number of private cars of the enterprise and the cars of other owners, which, under the conditions of random factors, will allow the enterprise to ensure the lowest transportation costs. At the same time, it is necessary to take into account the difference in the conditions of rate-setting for transportations and the technology of their passage on the loading siding.

2. As a result of the study, a method was developed for solving the problem of optimizing the size of the car fleet of mining enterprises for the transportation of iron ore raw material. The proposed method is based on the formalization of this problem as a stochastic optimization problem for a nonlinear nonsmooth integer objective function of one variable under constraints. In this case, the reduced modified costs act as an objective function, and the number of private cars serves as a variable. The problem is limited by the throughput capacity of the enterprise infrastructure when servicing private cars and the cars of the other owners. The solution to the problem can be obtained by direct search methods.

References

Management of Liquefied Natural Gas

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Abstract

The usage of natural gas has been rapidly increasing in the modern world. For logistical reasons, natural gas is only transported as liquid (LNG). Mathematical modelling allowed understanding and managing LNG ageing process during marine transport and processing on Floating Storage Units (FSU) and Floating Storage Regasification Unit (FSRU). The purpose of analyses was to investigate the changes of initial physical properties and chemical composition of LNG during its storage and regasification processes as well as factors that affect the ageing process. These include the daily changes in the content of methane and nitrogen as well as the calorific value and the Wobbe index. All models were verified using collected data of three different periods obtained from FSRU tanks measurement system to predict changes of physical properties and chemical composition of LNG following its maximum allowable storage period for 60 days. The created model could be useful in case of LNG market oversupply or with existing demand to storage LNG as a reserve.

KEYWORDS: LNG, LNG ageing, FSRU, boil-off gas, Wobbe index, higher heating value, modelling

1. Introduction

Natural gas is a mixture of light hydrocarbons such as methane (85–98% (volume basis)), with small quantities of ethane, propane, higher hydrocarbons (C4+), nitrogen and other compounds [1]. During transportation and subsequent storage, constituents, which have the lowest boiling points (nitrogen and methane), start to vaporize due to the heat input entering from surrounding. The vaporization of methane and nitrogen causes changes of initial composition and properties of the LNG. This process of preferential vaporization is known as weathering or ageing. The changes of properties such as gross calorific value, Wobbe index, density of LNG could influence the price and quality of the gas [2-4].

The boil-off gas (BOG) in the tank resulting from evaporation must be removed to protect the tank from overpressure. BOG covers above the liquid in the tank and sends from the tank for utilization. As the amount of BOG in the tank increases, the ageing process of the natural gas increases [5]. Ageing prediction of stored LNG could be made by BOG management model that accounts for variations in BOG mass flow, fluid composition, and fluid properties during a voyage and period of storage.

Various models have been developed to predict the ageing process of LNG in storages mainly to reduce the BOG loss during ship transport. [6] developed a useful tool called MOLAS for predicting changes in LNG composition at any time during the voyage and it send [6]. [1] described a mathematical model for determining the changing LNG energy content of unloaded from the ship’s tanks to storage tanks in the receiving terminal. [7] proposed a model to predict the ageing of LNG stored in containment tanks, typically used in regasification terminals, due to the effects of heat ingress and boil-off-gas release. [8] proposed two models based on the premises of considering evaporation rate or considering heat flow transferred to the hydrocarbons mixture and validates the results with a database containing experimental measurements at the loading and unloading ports for 558 voyages by a number of different LNG carriers. [9] applied algorithm of inverse methods to improve LNG storage management. It requires an individually adjusting of heat- and mass-transfer coefficients via inverse methods for each tank. [10] developed a robust model which correlates explicitly for isobaric specific heat capacity. [11] presented a simple method with sufficient accuracy for engineering purposes to easily, quickly, and inexpensively evaluate the performance potentials of working fluids in organic Rankine cycles.

This research work is concerned on creation of mathematical model, which can predict changes of LNG physical properties and composition during its storage in FSRUs tanks. Therefore, investigation took place with variety of models in order to determine thermodynamic properties between vapour and liquid equilibrium in the storage tanks.

2. Methodology

Data for validation of mathematical modelling came from three different periods obtained from FSRU tanks measurement system. In the ship, there are placed four double insulated cargo tanks. This insulation system was
developed to keep the ship's evaporation losses low and to reduce the penetration of heat from the environment and from solar heating. Evaporation is less than 0.12 vol% of the total tanks content per day. Measurement periods consist of the storage time without ongoing further processing and the storage time during regasification up to the consumption of the respective LNG quantity (Table 1).

Mathematical modelling of the LNG ageing built on the previously published LNG ageing models [1, 7, 8, 10-12] which included LNG involvement and thermodynamic equitation and predictions of thermodynamic property changes. This modelling concerned mathematical predictions with LNG properties and quality changes in time. In this study, the mathematical modelling based on trend models, multiple regression and t-test. Analysis of LNG ageing process, the value of nitrogen and methane (vol. %), higher heating value and Wobbe index were calculated per day to predict LNG composition and quality changes for 60 days period. Data analysis was performed R-project open source program and MS Excel.

Mathematical modelling of the LNG ageing analysed changes of initial LNG composition during storage and factors which could influence major impact of ageing process. Multiple regression model was used to determine the influence of nitrogen and methane content reduction on factors as vapour pressure, LNG temperature, LNG volume and technological processes.

For the suitability of natural gas in different markets higher heating value and Wobbe index calculated from LNG composition of selected data according to standard ISO 697-1995 and Mc-Kinkley method.

Multiple regression model is based on extensive period of LNG storage and predictions to determine influence nitrogen and methane evaporation of vapour pressure of tank, volume changes, technological processes and LNG temperature. For the statistical analysis multiple regression and t-test was used.

The technological processes are involved as dummy variable $x$ in the multiple regression model. The dummy variable is important for verifying BOG generation (nitrogen and methane evaporation) during LNG regasification (9 days) and storage (46 days) processes. This dummy variable indicates the evaporated nitrogen and methane amount of LNG in that case if dummy variable influences LNG evaporation in multiple regression model. BOG generation is caused by heat leakage to the cryogenic tanks and related recirculation pipeline used for LNG cold insulation. During recirculation, the heat entered through pipeline is brought into the LNG tanks by LNG, increasing BOG [1].

The following equation gives the multiple regression model:

$$Y = a + b_{\text{methane}} \cdot x_{\text{methane}} + b_{\text{ethane}} \cdot x_{\text{ethane}} + b_{\text{propane}} \cdot x_{\text{propane}} + b_{\text{butane}} \cdot x_{\text{butane}} + b_{\text{nitrogen}} \cdot x_{\text{nitrogen}} + b_{\text{boog}} \cdot x_{\text{boog}} + b_{\text{dummy}} \cdot x_{\text{dummy}}$$

To consider if nitrogen and methane evaporation does not depend on factors which are defined in the initial multiple regression model, the statistical hypotheses are expressed as:

$$H_0: b_{\text{ethane}} = b_{\text{propane}} = b_{\text{butane}} = b_{\text{nitrogen}} = 0$$
$$H_1: \text{at least one } b_i \neq 0$$

### 3. Results and Discussions

In this study, the data for mathematical modelling is performed. Three LNG storage periods were used for the further analysis. Trend model is developed by analysis of LNG composition and quality property changes. Trend models were tested using collected data to predict LNG properties changes following LNG storage for 60 days in FSRU if LNG is not out-of-specification according to industrial requirements.

**Time series analysis.** BOG in the tanks influenced the use of LNG. Therefore, it is important to observe nitrogen and methane evaporation process [5].

For nitrogen and methane evaporation process, the following exponential trend model was used after the graphical analysis:

<table>
<thead>
<tr>
<th>Composition of LNG</th>
<th>I measurement period</th>
<th>II measurement period</th>
<th>III measurement period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane, vol %</td>
<td>92.19</td>
<td>92.1</td>
<td>92.01</td>
</tr>
<tr>
<td>Ethane, vol %</td>
<td>5.64</td>
<td>5.62</td>
<td>5.63</td>
</tr>
<tr>
<td>Propane, vol %</td>
<td>1.24</td>
<td>1.27</td>
<td>1.27</td>
</tr>
<tr>
<td>Nitrogen, vol %</td>
<td>0.64</td>
<td>0.59</td>
<td>0.59</td>
</tr>
<tr>
<td>Butane, vol %</td>
<td>0.29</td>
<td>0.42</td>
<td>0.5</td>
</tr>
<tr>
<td>Higher heating value, MJ m$^{-3}$</td>
<td>40.100</td>
<td>40.240</td>
<td>40.423</td>
</tr>
<tr>
<td>Wobbe index, MJ m$^{-3}$</td>
<td>51.717</td>
<td>51.816</td>
<td>51.818</td>
</tr>
<tr>
<td>Periods of LNG storage, days</td>
<td>45 =32 days of storage + 13 days of regasification</td>
<td>46 = 18 days of storage + 28 days of regasification</td>
<td>55 = 46 days of storage + 9 days of regasification</td>
</tr>
</tbody>
</table>
In all models, the coefficient $b_1$ appeared as negative, therefore this means that in the beginning corresponding element evaporates quite fast but after while it stabilizes around $b_0$.

Table 2 summarizes the change in nitrogen and methane composition of LNG and BOG generation as function of time (60 days). The coefficient $b_1$ of the model proved that evaporation intensity of nitrogen varies from 0.025 to 0.028 vol. % per day. Results of the evaporation models showed that the evaporation intensity of nitrogen is quite similar of different analysed periods: I period – 32 storage days of LNG, II period – 18 storage days of LNG, III – 46 storage days of LNG. In addition, results could also predict that the same heat ingress entered LNG tanks, which generated the similar evaporated amount of nitrogen per day in the observed periods (this evaporated nitrogen amount included in BOG, which utilized in FSRU).

Furthermore, observing methane changes of LNG, it is determined that evaporation intensity of methane varies from -0.00008 to -0.0001 vol % per day. Trend models indicate that methane didn’t evaporate fast because of nitrogen evaporation.

Nitrogen and methane values of observed periods were taken to calculate HHV and WI of LNG. Both HHV and WI of LNG were calculated according to formulas 1–4 using temperature $t$ and pressure – 101.325 kPa, respectively as the reference. For calculated HHV and Wobbe index values logarithmic models were estimated to predict the daily changes:

$$y = b_0 + b_1 \ln(t).$$

(3)

As $b_1$ is positive, at the beginning of variable (HHV and WI) increases but later it stabilizes to around $b_0$. The logarithmic trend results showed that nitrogen and methane evaporation influences HHV and WI increase. The evaporation of nitrogen and methane is defined by the negative coefficient $b_0$ and it indicates that LNG – the increase of HHV and WI values. The increase in the HHV and WI is determined by a positive coefficient $b_1$.

Table 3 shows that HHV change for different storage periods varies from 0.160 MJ m$^{-3}$ to 0.137 MJ m$^{-3}$ as well as WI change varies from 0.132 MJ m$^{-3}$ to 0.146 MJ m$^{-3}$ per day which predict the slight weathering effect on HHV and WI. Due to LNG volume changes during its storage, it is important to verify that LNG components are heavier in hydrocarbons volume that could influence HHV and WI. As the LNG evaporates (methylene and nitrogen), the LNG become richer in heavier hydrocarbons [7]. For ethane and propane volume changes of LNG according to graphical analysis, linear trend models were estimated:

$$y = b_0 + b_1 t.$$  

(4)
**Table 4**

Parameters of estimated ethane and propane trend models

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Model coefficients</th>
<th>Parameters of evaluated ethane model</th>
<th>$R^2$</th>
<th>Parameters of evaluated propane model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I period</strong> (32 storage days of LNG, 13 days of regasification)</td>
<td>$b_0$</td>
<td>5.5354</td>
<td>0.759</td>
<td>1.1653</td>
<td>0.762</td>
</tr>
<tr>
<td></td>
<td>$b_1$</td>
<td>0.0104**</td>
<td></td>
<td>0.0029*</td>
<td>0.9331</td>
</tr>
<tr>
<td><strong>II period</strong> (18 storage days of LNG, 28 days of regasification)</td>
<td>$b_0$</td>
<td>5.5576</td>
<td>0.934</td>
<td>1.2539</td>
<td>0.9331</td>
</tr>
<tr>
<td></td>
<td>$b_1$</td>
<td>0.0123*</td>
<td></td>
<td>0.0028*</td>
<td>0.9331</td>
</tr>
<tr>
<td><strong>III period</strong> (46 storage days of LNG, 9 days of regasification)</td>
<td>$b_0$</td>
<td>5.6496</td>
<td>0.7053</td>
<td>1.2653</td>
<td>0.7605</td>
</tr>
<tr>
<td></td>
<td>$b_1$</td>
<td>0.0101*</td>
<td></td>
<td>0.0017*</td>
<td>0.9331</td>
</tr>
</tbody>
</table>

* estimated parameters are significant at 0.05 level of significance;  
** estimated parameters are significant at 0.01 level of significance

Table 4 illustrates results of ethane and propane linear trend models, which could predict ethane and propane volume changes during LNG storage. In all models, coefficient $b_1$ appears as positive, which means that ethane and propane volume increases of LNG when nitrogen and methane evaporates and generates into the BOG. It is determined that increase of ethane varies from 0.0101 to 0.0123 vol. % units and propane vary from 0.0017 to 0.0029 vol. % units per day.

**Table 5**

Practical applications of trend models

<table>
<thead>
<tr>
<th>Parameter</th>
<th><strong>I period</strong> (32 storage days of LNG, 13 days of regasification)</th>
<th><strong>II period</strong> (18 storage days of LNG, 28 days of regasification)</th>
<th><strong>III period</strong> (46 storage days of LNG, 9 days of regasification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results of the 1st day (measurement)</td>
<td>After 60 days (forecasted value)</td>
<td>Variaton of the results from 1st to 60 days</td>
<td>Results of the 1st day (measurement)</td>
</tr>
<tr>
<td>Methane, vol%</td>
<td>92.190</td>
<td>91.831</td>
<td>0.359</td>
</tr>
<tr>
<td>Ethane, vol%</td>
<td>5.63</td>
<td>6.43</td>
<td>0.79</td>
</tr>
<tr>
<td>Propane, vol%</td>
<td>1.27</td>
<td>1.42</td>
<td>0.15</td>
</tr>
<tr>
<td>Nitrogen, vol%</td>
<td>0.639</td>
<td>0.180</td>
<td>0.459</td>
</tr>
<tr>
<td>Higher heating value, MJ m$^{-3}$</td>
<td>40.100</td>
<td>40.559</td>
<td>0.459</td>
</tr>
<tr>
<td>Wobbe index, MJ m$^{-3}$</td>
<td>51.200</td>
<td>52.140</td>
<td>0.940</td>
</tr>
</tbody>
</table>

Table 5 verified the predictions (LNG storage for 60 days) of trend models with measured LNG data for the observed periods. The results from 1st and 60 days were compared by the three different periods.

The maximum difference of the CH$_4$ content results from 1st to 60th days in estimated III period (46 storage days of LNG, 9 days of regasification), which has the most significant effect on HHV forecasted value comparing with HHV values of other observed periods (I, II). Due to the maximum difference methane content results from 1st to 60th days, which estimates in the III period, it could be seen that the forecasted ethane and propane values increased the most in the III period comparing with ethane and propane values of the I and II periods. Otherwise, it could be seen that the difference of the nitrogen content (nitrogen evaporation) from 1st to 60th days of the III period was not as intensive as in I and II periods. The highest nitrogen content difference of the results from 1st to 60th days was determined in the II period (18 storage days of LNG, 28 days of regasification). In this period, there was the shortest LNG storage duration in the tanks (18 storage days) and the largest duration of the regasification process (28 days) which could have affect nitrogen evaporation. Moreover, during regasification process, some amount of the LNG (volatile components as nitrogen and methane) could be evaporated due to the vaporized form of natural gas increases the tank inlet pressure [13].

In addition, the highest nitrogen content difference of the II period (18 storage days of LNG, 28 days of regasification) has effect on WI value. Variation of the results from 1st to 60th days showed that the increasing WI value is not as fast as in other observed periods (I, III). In natural gas market, nitrogen is used as additive to lower WI value because of increase in the molecular weight of the resulting no extra heating value in burning process.

The trend model results showed that LNG is still marketable, and it is not out-off specification according to the industrial requirements despite the fact that the results are slightly different in the observed periods.

**Multiple regression model** based on largest period III (46 storage days of LNG, 9 days of regasification) of LNG storage was used to determine influences of vapour pressure, volume changes, technological processes and LNG temperature of evaporation of methane and nitrogen. The statistical analysis concerned multiple regression and t-test.
**Multiple regression model of nitrogen evaporation.** The initial model describing the evaporation of nitrogen based on vapor pressure, volume changes, technological processes and LNG temperature is multiple regression model. Results of estimated model are provided in Table 6.

### Table 6

<table>
<thead>
<tr>
<th>Data unit</th>
<th>Initial multiple regression model coefficients of nitrogen evaporation</th>
<th>Final multiple regression model coefficients of nitrogen evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determination coefficient</td>
<td>0.871</td>
<td>0.872</td>
</tr>
<tr>
<td>a (coefficient of the quantity variation of the model)</td>
<td>-36.0505**</td>
<td>-35.8973**</td>
</tr>
<tr>
<td>Volume of LNG, m³</td>
<td>1.09E-06</td>
<td>-</td>
</tr>
<tr>
<td>Temperature of LNG, ºC</td>
<td>-0.21203**</td>
<td>-0.212**</td>
</tr>
<tr>
<td>Vapour pressure, kPa</td>
<td>0.2157**</td>
<td>0.2126**</td>
</tr>
<tr>
<td>Dummy variable (0 – storage of LNG; 1 – regasification of LNG)</td>
<td>0.0254</td>
<td>-</td>
</tr>
</tbody>
</table>

* estimated parameters are significant at 0.05 level of significance;  
** estimated parameters are significant at 0.01 level of significance

The coefficient of determination ($R^2$) of multiple regression model is 0.871. The p-values of the t-test (significance of the estimated parameters) determined that the volume of LNG and dummy variable are not significant. It could be stated that the nitrogen vaporization hardly depends on the technical conditions and the volume of the LNG. This could be explained by the fact that the boiling point of the nitrogen is approximately 30ºC below the methane and therefore does not depend on the chemical but only on the thermodynamic conditions. After re-estimation procedure only two significant variables were determined: vapour pressure and LNG temperature. Additionally, $R^2$ increased up to 0.872. This nitrogen multiple regression model appropriately could observe the flow of nitrogen of LNG storage period.

**Multiple regression model of methane evaporation.** The initial model describing the evaporation of methane based on vapor pressure, volume changes, technological processes and LNG temperature is multiple regression model. Results of estimated model are provided in Table 7.

### Table 7

<table>
<thead>
<tr>
<th>Data unit</th>
<th>Initial multiple regression model coefficients of methane evaporation</th>
<th>Final multiple regression model coefficients of methane evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determination coefficient</td>
<td>0.9039</td>
<td>0.9010</td>
</tr>
<tr>
<td>a (coefficient of the quantity variation of the model)</td>
<td>84.37**</td>
<td>90.51153**</td>
</tr>
<tr>
<td>Volume of LNG, m³</td>
<td>3.1E-05**</td>
<td>3.38E-05**</td>
</tr>
<tr>
<td>Temperature of LNG, ºC</td>
<td>-0.039</td>
<td>-</td>
</tr>
<tr>
<td>Vapour pressure, kPa</td>
<td>0.00407</td>
<td>-</td>
</tr>
<tr>
<td>Dummy variable (0 – storage of LNG; 1 – regasification of LNG)</td>
<td>0.14729**</td>
<td>0.158408**</td>
</tr>
</tbody>
</table>

* estimated parameters are significant at 0.05 level of significance;  
** estimated parameters are significant at 0.01 level of significance

$R^2$ of multiple regression model is 0.9039. The p-values of the t-test determined that LNG temperature and vapour pressure are not significant. The model results indicated that the LNG temperature and vapour pressure are not changing enough during storage period and it could be predicted that BOG above liquid in the tank was not sent to utilize or liquefy. After re-estimation procedure only two significant variables were determined: the volume of LNG and dummy variable. $R^2$ decreased up to 0.9010. Multiple regression model of methane evaporation used in BOG management based on volume changes and technological processes.

Further model for evaporation of methane, based on vapour pressure, volume changes and LNG temperature during LNG storage in the tanks without regasification process was estimated. Results of estimated model are introduced in Table 8. $R^2$ of multiple regression model is 0.9497. The p-values of the t-test determined that vapour pressure is not significant. After re-estimation procedure significant variables were determined: the volume of LNG and LNG temperature. $R^2$ increased up to 0.9672. Multiple regression model of methane evaporation could be used for BOG management based on volume and LNG temperature changes in the tanks.

Additionally, the multiple regression model for methane of LNG acquired regasification. The p–values of the estimated parameters showed that vapour pressure, temperature of LNG and LNG volume are not significant. During regasification process, equilibrium between BOG and the liquid phase lacks observation time, which directly affect the lack of analysed data. Thus, this leads to assumption that for the future analysis there is a need for more in-depth data to analyse regasification process.
Table 8

Multiple regression model of methane evaporation during LNG storage

<table>
<thead>
<tr>
<th>Data unit</th>
<th>Initial multiple regression model coefficients of methane evaporation</th>
<th>Final multiple regression model coefficients of methane evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determination coefficient</td>
<td>0.9497</td>
<td>0.9672</td>
</tr>
<tr>
<td>a (coefficient of the quantity variation of the model)</td>
<td>81.363**</td>
<td>84.748**</td>
</tr>
<tr>
<td>Volume of LNG, m³</td>
<td>2.636E-05**</td>
<td>3.07E-05**</td>
</tr>
<tr>
<td>Temperature of LNG, °C</td>
<td>-0.0576**</td>
<td>-0.03704**</td>
</tr>
<tr>
<td>Vapour pressure, kPa</td>
<td>0.0243</td>
<td>-</td>
</tr>
</tbody>
</table>

* estimated parameters are significant at 0.05 level of significance;  
** estimated parameters are significant at 0.01 level of significance

4. Conclusions

It could be stated that suggested models could be useful in case of LNG market oversupply or with existing demand to storage LNG as a reserve.

The functions corresponding to evaporation of methane and nitrogen determined that methane evaporation intensity varies between 0.00008–0.0001 vol% per day, as well as nitrogen evaporation intensity varies between 0.025–0.028 vol. % per day. Higher heating value changes varies between 0.160–0.137 MJ m⁻³ per day, Wobbe index – 0.132–0.146 MJ m⁻³ per day. Moreover, increase of ethane varies between 0.0101–0.0123 vol. % units, propane – from 0.0017 to 0.0029 vol. % units per day.

Multiple regression model of nitrogen has two significant variables: vapour pressure and LNG temperature. The used model could appropriately observe the flow of nitrogen of LNG storage period. However, multiple regression model of methane evaporation with two (the volume of LNG and dummy variable) significant variables can be used for BOG management based on volume changes and technological processes.

A model for evaporation of methane during LNG storage in the tanks without regasification could be used for BOG management based on volume and LNG temperature changes in the tanks.

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The SSR Surveillance Coverage Mapping Based on Aircraft’s Replies Processing

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Abstract

The paper introduces the method to mapping the Secondary Surveillance Radar (SSR) Mode S operational coverage based on passive receiving and analysis of replies from aircraft. The article presents the achieved results using data obtained from the OpenSky Network database. The OpenSky Network is a non-profit organization providing an extensive database with a global reach based on the collection of aircraft information over the publicly accessible 1090 MHz radio frequency channel. These data allowed us to carried out analysis over a large area of Europe and verify whether the method based on the analysis of All-Call replies brings usable results for determining operational coverage of secondary surveillance radars used by individual Air Navigation Service Providers (ANSP).

KEY WORDS: SSR, Mode S, Radar, Surveillance Coverage, Interrogator Code

1. Introduction

IC allocation process is directly connected with the setting of coverage map of particular radar. The purpose of the IC allocation process is to manage the interrogator codes allocation for Mode-S stations in a way that in the same geographical area Mode S stations use different IC or the coverage of two or more Mode S stations having the same IC does not overlap [1]. Under European regulation fixed civil Mode S interrogators are required to be capable of locking-out replies to their All-Call interrogations using an allocated IC code. Mode S ICs are used to lockout replies from transponders to All-Call interrogations, thereby reducing FRUIT (False Replies Unsynchronized In Time) level. Consequently, re-use (or unauthorized use) of an IC within overlapping coverage may induce a situation in which one of the interrogators would not see an aircraft locked-out by the other interrogator. Such IC conflicts should be avoided [1]. That the reason why centralised IC allocation service (by means of EUROCONTROL MICA Cell) is provided in the ICAO EUR region and the ICAO Middle East Region. The allocation of the Interrogator Codes (IC) follows a cyclic procedure, the length of which is 168 days, aligned with the AIRAC dates. Details can be found in [1].

Data over a large geographical area was necessary to obtain and analyze to achieve relevant results. Archived data from the OpenSky Network were used for the outputs presented in this paper. The OpenSky Network is a non-profit organization providing an extensive database with a global reach based on the collection of aircraft information over the publicly accessible 1090 MHz radio frequency channel. More information about the OpenSky Network and current world coverage can be found in [5].

2. Methodology and Data Processing

The method presented in this paper is based on the processing of replies received from an aircraft located in a known position and determining the radar which the replies elicited. The determination of SSR which elicits the reply is based on IC included in the reply. The position of the aircraft is determined via ADS-B 1090 ES position messages, which each aircraft transmits approximately twice per second.

The replies of Downlink Format (DF) 4, 5, 20 or 21, which are used for common data exchange between the radar and the aircraft, not possible to use to identification of the radar that elicited the replies because such information is not contained within their data block. The reply DF11 is the only one that carries the IC of the radar which interrogated the aircraft. However, using DF11 messages to determine the operational coverage of the radar is not straightforward.

First of all, the DF11 message could represent the so-called Acquisition Squitter, which the aircraft transmits spontaneously approximately every second. The distinction between an Acquisition Squitter (with IC≠0) and a reply to an All-Call interrogation (with IC=0) is through the Parity/Interrogator Identifier (PI) field. In the case of All-Call reply the code used in downlink PI field generation shall be formed by a sequence of 24 bits, where the first 17 bits are ZEROs, and three bits are replica of the Code Label (CL) field and the last four bits are the replica of the Interrogator Code (IC) field. CL field defines the content of the IC field, i.e. whether the IC field contains Interrogator Identifier (II) code or the lower 4 bits of the 6-bit Surveillance Identifier (SI) code [4]. In the case of an Acquisition Squitter, the PI field would consist of a sequence of 24 zero-bit.

In fact, the last 24-bits sequence in the received reply does not directly contain the sequence of PI bits as was explained above but contain the parity sequence. Cyclic Redundancy Check (CRC) algorithm (Cyclic polynomial
method) is used to detect and in some cases to correct, errors occurring during the transmission of Mode S messages. The whole message (data block and parity sequence) is divided by the generator polynomial (see [1]) and the remainder represent the PI field in the case of DF11 message.

Another complication for determining operational coverage based on DF11 messages used in the All-Call period is the fact that the radar uses these replies only for the acquisition process (the initial detection) of the new aircraft when entering the radar coverage area. They are no longer transmitted after the acquisition process is accomplished. Targets that have been acquired in the all-call period are subsequently selectively interrogated for surveillance information in the Roll-Call period. Control information within the interrogation allows the ground sensor to apply lockout which means that the target (aircraft) will not reply to an all-call (i.e. don’t transmit DF11 messages) with that IC for 18 seconds. This will be applied by the sensor for all acquired Mode S targets in all areas for which it has responsibility for maintaining lockout [6].

The method is based on detecting the boundary between the end of the radar lockout map (which commonly corresponds to the surveillance map) and the area where the radar unintentionally elicits All Call replies beyond its operational coverage (surveillance map). DF11 messages (All-Call replies) that do not carry any position information have been paired with the nearest positional ADS-B message captured from the aircraft.

3. Achieved Results

DF11 messages were processed from aircraft in the area defined by latitude between 43°N and 54°N, longitude between 0°E and 23°E, based on pairing with ADS-B messages. The messages were filtered for each Interrogator Code (II) from 1 to 15 and for Surveillance Identifier (SI) from 1 to 63 and then their position was plotted on the map at the time of transmission. To reduce “noise” as much as possible, messages from aircraft flying above 8000 m above mean sea level (AMSL) were processed only.

Each message was plotted to the map base, where one picture was generated for each II or SI code. Cut out such graphical output for II = 8 and SI = 53 is shown in Fig. 1 and Fig. 2 respectively. A broader perspective for European region for II = 11 and SI = 12 is depicted in Fig. 3 and Fig. 4. The four-hour data record from the OpenSky Network from 2021-06-23 was used for the creation of these figures. The cone of silence directly above a particular position of the radar is also clearly recognisable.

Fig. 1 Messages DF11 with II=8 plotted to the map
Fig. 2 Messages DF11 with SI=53 plotted to the map
4. Discussion

If a sufficiently large dataset is used, it is possible to recognize a clear boundary between the area where the radar blocks All-Call replies, and the area tightly behind, where All-Call replies (DF11 messages) are elicited. Because, except in exceptional cases, All-Call lockout is applied for all radar coverage to reduce the load of the 1090 MHz band, (i.e. the lockout map corresponds to the surveillance map), it is possible to reveal a typical circular pattern of individual radars. It has been found that the coverage of some radars is quite clearly visible, however, on the contrary, for some codes, there no circular (or other expectable) pattern was recognizable due to the presence of a high level of noise. Noise in this context means DF11 replies that are more or less randomly distributed across all area that make more difficult to distinguish particular message pattern.

Possible main reasons making it difficult or impossible to detect the SSR Mode S operational cover boundary are
as follows:

- Badly “degarbled” messages - due to the overlap of two or more messages, the distortion of the bits in the IP field may occur so adversely that the message after cyclic redundancy check (CRC) appears valid, although the last bits in the PI field will not represent the correct IC.
- Stochastic lockout override - some radars may operate a so-called ”lockout override” which allows forcing the aircraft to reply to All-Call interrogations even though it is locked to the IC.
- Incomplete coverage due to a gap in data provided by OpenSky Network. Exact coverage for a particular day can be found on the website [5].
- Radar clustering - only the boundaries of the whole cluster can be detected, not the coverage of individual radars that are part of the cluster. (Mode S fixed ground interrogators have the capability of being networked into functional groups known as “clusters” to greater operational efficiency. Further details in [6].)

5. Conclusions

The main goal was to find out how the method based on the analysis of DF11 messages using data available from the OpenSky Network is applicable to determine the operational coverage of SSR Mode S. Although some of the radars are quite clearly visible as presented in the paper, unfortunately a relatively high number of radars are not recognisable after analysing the data across the entire range of II and SI codes. Some relevant causes were mentioned in the discussion. The improvement could be achieved by more sophisticated method for data filtering applying in the level of association of messages with a flight in order to suppress useless or erroneous DF11 messages.

References

**Mathematical – Graphic Analysis of Traffic Accident with the Assessment of Intervention Activities Fire Brigades**

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**Abstract**

The paper focuses on security issues and intervention activities at level crossings. The authors of the article assess the origin and the course of the selected traffic accident at the level crossing. Using mathematical - graphical analysis the interaction between the vehicle and the train during the collision has been detected, and based on their movement after the collision. Part of the paper is to define the initial model intervention activities of fire brigades for that type of accident, which is one of the most difficult and complicated technical interventions. Solution of follow-up processes intervention activity is subject to a detailed analysis in terms of time.

**KEY WORDS:** car accident, analysis, intervention activity, fire brigade

1. **Introduction**

   From the point of view of safety on the railway line, the most dangerous place is the level crossing of the railway line with the road. The number of traffic accidents at railway crossings is still high. It is necessary to subject these objects to a thorough analysis, this means taking into account technical and legislative aspects, as well as human factors issues, which would lead to a comprehensive risk assessment and management at level crossings. From the point of view of intervention activities, railway crossings are one of the most difficult and the most complicated technical interventions. This is mainly due to physical demands, bad terrain and access to the scene and the complicated cooperation of several stakeholders. Practical experience shows that traffic accident scenarios at level crossings are different and rescue services must always be prepared to deal with these events. In this article, we performed an analysis of a traffic accident at the railway crossing and in addition we have defined the initial model of intervention activity, which contributes to the education of members Fire and Rescue Corps.

2. **Analysis of a Traffic Accident at a Railway Crossing**

   The place of the accident was located on the single-track electrified railway line of the 1st category Čadca - Škalité - Zwardoň (PL), in the interstation section Škalité - Čiernne near Čadca, at an active level crossing (Fig. 1). The active level crossing is equipped with a light crossing safety device, without barriers. The railway line is crossed by a road to the local part of the village. The crossing angle is 60°, the width of the crossing is 10.80 m, the length of the crossing is 5 m, the width of the road is 8.10 m, the surface of the crossing is formed by an all-rubber construction with asphalt risers. Longitudinal slope of the road to the railway line in the direction of stationing it increases by 4% on the left and decreases by 3% on the right [1, 2, 3, 7].

   ![Satellite image of the accident site](image1.png)

   **Fig. 1** Satellite image of the accident site (blue arrow shows the direction of movement of the vehicle, red arrow shows the direction of movement of the train set) [1]
To assess the origin and course of the accident, it is necessary primarily on the basis of objectively determined documents: documented tracks at the site of the accident, adhesive properties of the road surface and surrounding areas, damage to the vehicle and train set, final positions of the vehicle and train and other facts. In the following pictures is a graphical representation of the course of an accident under the above conditions. The Fig. 2 also show the data showing the values of time, distance and speed of the vehicle and train at a given moment:

- A positive time value indicates the time which has elapsed from the moment of the onset of the driver's reaction to the moment shown in the figure.
- A positive track value indicates the distance which the vehicle or trainset has overcome from the place in which they were at the time of the onset of the driver's reaction to the place in which they are located in the displayed image.
- The speed value indicates the instantaneous value of the vehicle and trainset speed at a given moment [1, 4-6, 12].

Mutual position, time, speed and track data of the vehicle and trainset (with the above input data) at the moment when the driver has started the rapid braking of the trainset (moment of the start of the braking performance of the trainset). The time before the collision is also displayed [1, 3].

Based on damage to the vehicle and trainset, their relative position at the point of collision, crash sites, final positions of the vehicle and train set and individual admission and control values, the vehicle impact calculation was performed and train set. It follows from the above calculation that that the impact speed of the trainset was about 95.9 km/h and the speed of the vehicle at the time of the collision was about 8.9 km/h. The position, time, speed and track data of the trainset (with the above input data) at the moment of stopping the trainset in the final position are shown in Fig. 3. The train was stopped after crossing the track 429 m from the start of rapid braking (the moment of the beginning of the onset of the braking effect of the train). At the moment the train starts to brake, the front part of the train set was located at a distance of approx. 48 m from the railway crossing [1, 3, 8, 9, 12].

The vehicle did not leave any such traces after its movement before the moment of collision, on the basis of which it would be possible to judge the movement of the vehicle before the moment of collision. To calculate the movement of the vehicle in a time period before the moment of collision was therefore considered that the driver was
driving at the same speed in 1st gear. By applying data from the recording unit of the trainset and based on the above was in the program PC Crash performed calculation of mutual movement of a train set and vehicles. The results are shown in Figs. 4 and 5 [1, 3, 8, 9, 11].

Two fundamental facts follow from the analysis of the accident. First of all, that the train set was moving at a speed of about 95.9 km/h just before the collision. The vehicle passed through a railway crossing from right to left (from the driver's point of view) at a speed of 8.9 km/h. The driver of the vehicle did not react to the lit red light crossing signaling equipment, nor to an incoming train set and entered the railway crossings smoothly on which there was a collision with a trainset. The driver responded to the incoming vehicle to the level crossing at the moment when he could recognize from the speed and distance of the vehicle, that this is unlikely to stop at a level crossing (at a time of about 2.97 s before the moment of precipitation). The driver reacted to the occurrence of a collision situation by using rapid-acting braking, already colliding with a passing vehicle across the level crossing could not prevent. The technical cause of the accident in question has been established on the basis of the following definition: The technical cause is those elements of the accident which arose contrary to the technical interpretation of the rules of the road and which either caused a collision situation or made it impossible to prevent an accident. In the present case, a conflict situation has arisen due to incorrect driving technique (delayed reaction) driver of the vehicle in the length of about 4.39 s on a red light warning sign on the arrival of the train. Due to the delayed reaction, the driver of the vehicle made it impossible to prevent an accident. If the conductor reacts in about 4.25 s before the moment of collision and after the reaction time has elapsed, it would brake intensively, the vehicle would stop just before the train corridor. Driver after recognizing a collision situation (the fact that a vehicle is approaching the level crossing, which does not stop in front of the level crossing but enters it smoothly) he no longer had the technical ability to prevent an accident [1, 2, 8-10, 12].

3. Defining the Model of Intervention Activities of Fire Brigades

Within the Slovak Republic, they form the basic organizational structure of the integrated rescue system - ministries, district offices and rescue services. The fire and rescue corps forms the core of the main components of the integrated rescue system. Their activity is focused on extinguishing fires, liquidation of the consequences of extraordinary events and the performance of other tasks related to the protection of the population. In terms of intervention, the railway crossing is one of the most difficult and the most complicated technical interventions. Following the analysis of the accident mentioned in Chapter 2 of the article, the initial model of intervention activities of fire brigades will be defined. Fig. 6 shows the optimal location of the vehicles of the components of the integrated rescue system at the scene of the accident [11, 13, 14].

To develop or assess existing procedures for dealing with follow-up processes, applied to specific situations, requiring solutions and management, especially in terms of time, when indicators are secondary, it is advantageous to use the network analysis method. In terms of the mentioned specifics of dealing with accidents at level crossings these are methods which deal with the time analysis of follow-up activities. In this part of the article, we will perform a calculation of a network graph of the PERT type and its analysis by conversion to a deterministic model. The individual activities in Table 1 are directly related to the analyse traffic accident and their definition contributes to the education of members of the Fire and Rescue Service [7, 11, 14].
Activities performed by fire brigades in the event of accidents

<table>
<thead>
<tr>
<th>Designation</th>
<th>Activity schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Notification of an accident at a level crossing / exit of fire brigades</td>
</tr>
<tr>
<td>B</td>
<td>Arrival at the scene of the accident</td>
</tr>
<tr>
<td>C</td>
<td>Deployment of firefighting equipment</td>
</tr>
<tr>
<td>D</td>
<td>Survey of the scene of an accident</td>
</tr>
<tr>
<td>E</td>
<td>Organization of the accident site</td>
</tr>
<tr>
<td>F</td>
<td>Provision of extinguishing agent</td>
</tr>
<tr>
<td>G</td>
<td>Ensuring safety in the event of an intervention</td>
</tr>
<tr>
<td>H</td>
<td>Car stabilization</td>
</tr>
<tr>
<td>I</td>
<td>Deactivation of passive safety elements</td>
</tr>
<tr>
<td>J</td>
<td>Entrance to the car</td>
</tr>
<tr>
<td>K</td>
<td>First aid</td>
</tr>
<tr>
<td>L</td>
<td>Fixation of the affected person and his release from the car wreck</td>
</tr>
<tr>
<td>M</td>
<td>Creating space for the release of the disabled person</td>
</tr>
<tr>
<td>N</td>
<td>Transport of the disabled person</td>
</tr>
<tr>
<td>O</td>
<td>Elimination of the consequences of a traffic accident</td>
</tr>
</tbody>
</table>

A system of time indicators is being built on the basis of clearly defined durations of activities in the event of an accident at a level crossing. Within a qualified estimate of the duration of the activities consultations were held with members of the Fire and Rescue Corps. It was determined optimistic, a pessimistic and most accurate estimate of the duration of an individual activity, which are carried out in the framework of intervention activities. The following are step-by-step calculations of the average duration of the activity, range, variance and standard deviation. These quantities are sufficient to calculate a network graph of the PERT type and the analysis itself can then be performed by reduction to a deterministic model.

In order to complete the solution with the PERT method (Fig. 7) in the phase of calculation of term indicators and determining the probability of a critical path we would "degrade" an essentially stochastic method to a deterministic model, except that in order to determine the duration of the activities, with which we perform calculations, we use three estimates. In order to take full advantage of all the advantages of the PERT method, we approach the next phase of the solution, to additional probabilistic calculations, which are shown in Table 2.
Fig. 7 Calculation and notation of term indicators in the network - PERT method

Estimation of the probability of compliance with the planned time units of the intervention activity, as the termination of the entire intervention activity of fire brigades at the railway crossing. Probability that the activity "O" (and thus the whole intervention activity) will end at time $T = 95$ min. is $0.003264$. At time $T = 105$, the probability is $0.807850$ and at time $T = 110$, the probability is $0.995975$. Each intervention is unique and therefore it is not possible to determine exactly when the entire intervention activity is terminated. Analysed accident, represents a model situation for the intervention activity and therefore brings closer and draws attention to the estimated duration of individual activities within the intervention and points out from the point of view of the activities of fire brigades on the complexity and in terms of the duration of the entire intervention activity [9-11,14].

4. Conclusions

It is still occurring at railway crossings in the Slovak Republic to a large number of deaths and injuries. Railway infrastructure managers of EU member states regularly issue declarations that that about 95% of traffic accidents at level crossings are caused by road users, who intentionally or unintentionally violate road traffic rules. A high number of deaths and injured road users at railway crossings in the Slovak Republic is given mainly by the historical development of the number of level crossings of the railway line and roads and at the same time an increase in road traffic intensity.

In this case, in others, the failure of the human factor. However, appropriate measures (installation of barriers) could create conditions at the site that to completely rule out the possibility of such an accident. The application of intervention activities to the analysed traffic accident, approximates and points out the time consuming nature of the intervention activity. It sets out an overview of activities and defines their sequence.

It should also be noted that it plays a role in transport safety the combination of several factors plays an important role in the occurrence of accidents and their consequences. Benjamin Franklin, in his publication Poor Richard's Almanack, wrote: Because of the horseshoe nail, they lost a horseshoe. Because of the horseshoe about a horse. Because of the horse about the rider. They lost the battle because of the rider and lost the kingdom in battle. And all this for an ordinary horseshoe nail! This also applies to a large extent to safety, because accidents can be described as multifaceted. Prevention in this direction is focused to eliminate causal factors or interfering in the relationship between them.

Acknowledgement

Article created with the support of the scientific research project VEGA 1/0159/19 Evaluation of the level of resilience of key elements of land transport infrastructure.
References

Selected Issues of Geographic Data Description for Infrastructure Elements in RailML

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Abstract

In various areas of modern technology, dedicated XML applications are used for storing and exchanging data. Such an application for ICT systems in railway industry is RailML. Its current version RailML 3.1 uses another XML application, the Geography Markup Language (GML), to describe geographic data of infrastructure elements. The authors discuss the current status of the RailML standard and place special focus on the methods used to describe geographic data. They also present proprietary software designed to work with RailML and GML files.

KEY WORDS: RailML, GML, ICT systems, railway industry, infrastructure

1. Introduction

Modern information technologies are often used in modern railway systems, which allows to efficiently and effectively manage both railway traffic and infrastructure [14, 15]. However, the diversity of solutions used by manufacturers creates a barrier to the interoperability of systems produced by different suppliers. On the other hand, there is a legitimate need to ensure their cooperation, with appropriate requirements for their safety [17].

An increasingly common solution to this problem is the direct or indirect use of structures defined in the RailML and RailTopoModel (RTM) standards for data exchange [23, 24]. Both mentioned standards often require temporal or spatial location of the described objects. At the same time, additional requirements in this regard were caused by the INSPIRE directive, which requires that also in the field of geographic information, interoperability in the field of spatial data exchange should be ensured in the future. For such tasks, the OpenGIS consortium has defined the Geography Markup Language (GML) standard [21]. GML was originally intended to be used to exchange spatial data between different systems. Recently, it has also been used to describe data structures in various systems. Also, the RailML specification defines a corresponding data sub-schema that allows spatial data to be referenced in a standardized format.

2. XML and Its Application

XML meta-language (eXtensible Markup Language) was designed by the W3C consortium [2, 12, 25] as a tool for designing other specialized markup languages as its applications. Many applications of this type for various purposes have been developed. These are, for example: CML (Chemical Markup Language) for recording information about chemical compounds and reactions, Math ML (Mathematical Markup Language) for writing mathematical expressions and symbols, MusicXML designed for the representation of music scores, Office Open XML - an open ISO standard for electronic documents, such as text documents, spreadsheets or multimedia presentations, RailML, which is used in applications built for railway transport, or SVG (Scalable Vector Graphic), which is a universal format for two-dimensional vector graphics.

The great advantage of XML is platform independence, which allows heterogeneous systems to work together. This advantage has contributed to its huge popularization in the era of using multi-platform web applications. XML documents are in text form, and the XML standard defines their correct structure and the types of constituents, which additionally should be properly nested in the document. The basic elements of documents are tags and their attributes, but it can also contain comments, entities, and text sections (CDDATA). Due to the ability to create XML applications that contain self-defined elements and attributes, the rules for XML files are strict and inviolable. Using additional schemas, for example, DTD or XML Schema, it is possible to validate XML documents by checking their structural correctness (compliance with the used schemas) [9, 10, 18].

Because of their textual form, XML files are significantly larger than other files with the same data. However, this is a conscious decision by the XML designers. Due to the adopted form, if necessary, it is possible to read the data without any problems and the disadvantages of file size can be easily compensated by the compression [12, 13].

2.1. Geography Markup Language

GML is used as a modeling language for geographic systems as well as an open exchange format for geographic
transactions on the web. GML is also an ISO standard (ISO 19136:2007). As with most XML-based grammars, a GML grammar consists of two parts, a schema that describes the document and an instance document that contains the actual data [16, 21]. A GML document is a typical XML document containing a set of XML tags representing real objects and their spatial or temporal properties. The basic element of geographic information in GML are objects and objects collections. An object is an GML element with a complex structure that models the selected real-world object. A objects collection is a group of GML elements that collectively describe a fragment of reality. The GML language can also be used to describe information about the coordinate reference systems, coverage, dynamic aspects of geographic information or the cartographic representation adopted for the transferred data.

In GML, a set of spatial (geographic) elements is defined using XSD schemas to describe the properties of the defined objects. The current GML 3.2.1 specification [21] defines, inter alia, the schemas in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Schema</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>basicTypes.xsd, gmlBase.xsd, directions.xsd</td>
<td>Schemas that declare a set of base elements used in other GML schemas.</td>
</tr>
<tr>
<td>3</td>
<td>geometryBasic0d1d.xsd, geometryBasic2d.xsd, geometryPrimitives.xsd</td>
<td>Definitions of basic types of geometry model, e.g. point, line, polygon.</td>
</tr>
<tr>
<td>4</td>
<td>geometryComplexes.xsd, geometryAggregates.xsd</td>
<td>Definitions of complex geometric objects.</td>
</tr>
<tr>
<td>5</td>
<td>dictionary.xsd</td>
<td>Dictionary definitions.</td>
</tr>
<tr>
<td>6</td>
<td>defaultStyle.xsd</td>
<td>Object definitions that allow to specify styles for graphical presentation of objects.</td>
</tr>
<tr>
<td>7</td>
<td>gml.xsd</td>
<td>The basic schema of the GML language.</td>
</tr>
<tr>
<td>8</td>
<td>feature.xsd, dynamicFeature.xsd, coverage.xsd, observation.xsd, grids.xsd;</td>
<td>Schemes related to the description of geographical features.</td>
</tr>
<tr>
<td>9</td>
<td>topology.xsd</td>
<td>Diagram that defines the topology notation.</td>
</tr>
<tr>
<td>10</td>
<td>units.xsd, measures.xsd, valueObjects.xsd;</td>
<td>Specification of units, measures and values.</td>
</tr>
</tbody>
</table>

### 2.2. RailML

RailML is another of the XML meta-language applications. Work on this standard was undertaken in 2002 as part of the railml.org initiative [7, 23]. The creation of the RailML scheme was a response to numerous difficulties related to the cooperation of railway IT applications and the exchange of data between them [5, 6, 11, 22]. In 2014, cooperation with the International Union of Railways (UIC) was launched, following which many railway companies joined the initiative. In addition, an attempt to standardize the data model for railway infrastructure was made, that gave rise to the UIC IRS 30100 standard, which was then subsequently implemented in RailML version 3.0 [7, 19].

To define the structure of the document, as in all XML applications, a tree structure is used, in which elements are placed hierarchically inside the root, which is `<railml>` tag. Each of them can be further described by its own attributes allowing for a more precise description of the element. The most important RailML schemas defined in the current releases of the standard (RailML 3.1) are shown in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Schema</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>feature.xsd, dynamicFeature.xsd, coverage.xsd, observation.xsd, grids.xsd;</td>
<td>Schemes related to the description of geographical features.</td>
</tr>
<tr>
<td>2</td>
<td>topology.xsd</td>
<td>Diagram that defines the topology notation.</td>
</tr>
<tr>
<td>3</td>
<td>units.xsd, measures.xsd, valueObjects.xsd;</td>
<td>Specification of units, measures and values.</td>
</tr>
</tbody>
</table>

### Earlier versions of RailML

Earlier versions of RailML allowed railway IT systems to exchange data relating to rolling stock and railway traffic management, timetables, passenger information as well as booking and selling tickets [5, 6, 7, 23]. The latest version 3.1 has been enhanced with the `<interlocking>` sub-scheme for describing railway dependency systems [20], which allows not only to describe such systems, but also their formal verification [3, 4, 10, 18].
Table 2

<table>
<thead>
<tr>
<th>No.</th>
<th>Schema</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>infrastructure3.xsd</td>
<td>The schema is used to describe the railway infrastructure, including the track network and topology, coordinates, geometry and other infrastructure elements related to the railway, such as balises, railway crossings or platforms. It also includes intangible elements, e.g. speed profiles.</td>
</tr>
<tr>
<td></td>
<td>gml4raiml3.xsd</td>
<td>Definition of GML based elements for infrastructure sub-schema</td>
</tr>
<tr>
<td></td>
<td>rtm4railml3.xsd</td>
<td>Definition of RailTopoModel based elements for infrastructure sub-schema.</td>
</tr>
<tr>
<td>2</td>
<td>interlocking3.xsd</td>
<td>A schema that defines the tags necessary to describe railway interlocking systems.</td>
</tr>
<tr>
<td>3</td>
<td>rollingstock.xsd</td>
<td>The rollingstock subschema is used to describe rail vehicles, rail vehicles formations and their characteristics.</td>
</tr>
<tr>
<td>4</td>
<td>timetable3.xsd</td>
<td>A schema defining the elements necessary to describe railroad timetables.</td>
</tr>
<tr>
<td>5</td>
<td>common3.xsd</td>
<td>The schema includes common tags used by other schemas.</td>
</tr>
</tbody>
</table>

2.3. Using GML to Describe Geographic Data of Infrastructure Elements in RailML

For the purposes of RailML, and more specifically the <infrastructure> sub-schema, using the namespace in the gml4raiml3.xsd schema, the following types were defined, among others: <LineStringType>, <AbstractCurveType>, <AbstractGeometricPrimitiveType>, <AbstractGeometryType>, <AbstractGMLType>, <PointType>, <StringOrRefType>, <ReferenceType>, <DirectPositionType>, <DirectPositionListType>, <CodeType> and <CodeWithAuthorityType>. For example, <LineStringType> is a special curve that has been defined as a minimum of two sets of coordinates with linear interpolation between them. All types defined in the schema allow to conveniently create relationships between elements occurring in the <infrastructure> sub-schema and their position seen by means of primitives defined in XML.

Using this feature, in the <infrastructure> sub-schema, among other things, types describing infrastructure elements are defined. These are for example: <LineTypeCoordinate>, <PointTypeCoordinate>, or <GMLLocation>. In summary, it can be said that the GML specification itself as defined by the OpenGIS Consortium is abstract, but by using additional application schemas, as has been done in RailML, users can conveniently refer to railway lines, stations or bridges instead of points, lines and polygons.

3. RailML and GML File Editor

The development of the railML standard and its popularization is conditioned by the creation of software tools based on this specification. Therefore, the authors of the paper develop their own software "railML Editor", which allows not only viewing and editing railML files, but also visualization of data on GIS maps [8]. The data structure provided by railML.org [23] was used in presented example. A visualization of track network with infrastructure elements including switches, signals, train detection elements, and operational points is shown in Fig. 1. This enabled for the construction of classical topological representation, presented in Fig. 2, which is undirected complex graph of nodes and edges, where nodes refer to special points, e.g. buffer stops (B), switches (S), level crossings (L), and edges refer to connecting track routes.

Fig. 1 Sample track network with infrastructure elements [1]

Fig. 2 The classical topological representation [own study based on 1]
The basic functionality of the "railML Editor" software is the visualization of the data stored in the railML files and the possibility of editing them. Any changes made in the structure of the data are checked for syntactic correctness. The "railML Editor" main window with a sample file loaded is shown in Figure 3 and the "railML Editor" software data editor window is shown in Figure 4. The software is also capable of editing and validating other XML files, including GML files.

4. Conclusions

As mentioned before, RailML and GML were originally conceived as tools for exchanging data between different systems. When talking about data exchange, it is important to remember that there are no separately created systems with identical data structure, unless they were originally built using a common standard. Therefore, whenever transferring data from the exchange format and reflecting this format onto the data structure of the other system, only a certain subset of information will end up in it. Certain values of the attributes that will not be present in the transfer due to the different model can at most be completed with default or empty values. It is also obvious that no transfer format will improve the quality of the data itself. This applies to both the GML and RailML standards, which are sometimes presented as tools to solve all problems related to data exchange.

A completely different perspective is offered by systems built from the beginning according to a standardized model, for example, based on the RailTopoModel originally implementation in RailML 3. Even if they use their own internal data format, the topological data compatibility is guaranteed at the standard level. Usually, in the case of such
systems, the problem of data exchange becomes much easier to solve or even non-existent. In addition, the use of open standards, independent of manufacturers and individual applications, enables convenient cooperation with other systems used by railways, such as INSPIRE, RINF or ETCS, and facilitates the development of software, processes and services for the railway industry.

References

Monitoring Communication Design System for UAV Detection

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Abstract

The paper’s goal is to create a system that can identify unmanned aerial aircraft via radio communication sensing. The importance of UAV detection stems from a mix of factors, including their small size, sensor capabilities, autonomy, potential of misuse, and extensive usage by unprofessional operators who are ignorant of their own dangerous UAV handling. All of these variables can pose severe security risks and put human lives and infrastructure at risk. The radio communication detection technique presented in this work is part of a robust system in which radio detection is supported by other detection methods in order to increase the likelihood of UAV detection. Deeper examination of current advances received special consideration in the areas of radio communication detection systems, as well as an acoustic, a visual, and a radar detection. All systems were compared based on likelihood of detection and detection distances based on this analysis. The comparison of several detection methods, as well as their distinct qualities, served as a foundation for the final system concept. Radio detection was successfully developed as the major component, with a radar detection serving largely as a UAV localizer, and the acoustic system primarily served as a backup for UAV detection without a radio transmission, and the visual system for the visible confirmation of UAV presence.

KEY WORDS: UAV, drone detection, radio detection, unmanned aerial vehicle, detection system, neural network

1. Introduction

Primary objective of this paper is to design optimal system of UAV detection utilising radio communication monitoring. Reason for choice of this particular topic is rising numbers of UAVs which are being widely used professionally as well as unprofessionally, for example as a form of a hobby. Factors such as their compact size, availability, autonomous operation and possibilities of misusing them all add to the fact that they can pose as a serious threat to human lives, infrastructure and security. There are several examples of areas which were negatively impacted by UAVs in the past, therefore they could take advantage of UAV detection system. We can mention airports and aviation in general [1], threat to human lives and possible death mainly in areas where public events take place [2], privacy issues mainly in regard of UAVs with cameras [3], criminal activity and acts of terrorism in form of drug smuggling or UAVs carrying explosive devices [1, 4, 5] and possible cyber-attacks [6].

In theoretical phase of the paper, we focused on analysis of radiofrequency detection method, current progress in the area and principles of radio communication. Existing papers used as sources treat topic of radio detection with various approaches primarily because of diverse aims of their authors. Important example to mention can be paper focused on creation of database consisting of wide range of radio signals from UAVs. This database should serve as source to train neural networks and tool to identify UAVs [7]. Authors of another paper focused on detection of UAVs in ultrawideband radio spectrum, characterization of UAV’s motion and also identifying the point where detected UAV will cross the border of monitored area [8]. Common component of numerous systems are neural networks which are able to detect UAV and identify its type based on received radio signal. There are also papers which focus on short range detection, interior detection [8], long range detection [9], detection in environment with radio interference [10] and specific example is paper aimed to detect and localize UAV’s control station [11].

After theoretical phase, we focused on analysis of alternative methods of detection which helped to identify ways of supplementing radio detection, reducing its limitations and expanding its capabilities. Collected data were later used for comparison of methods and design of system where radio detection was used as primary component supplemented by alternative systems. Term alternative systems involves acoustic, radar and visual detection. These systems are used to supplement radio detection method and to maximize probability of UAV detection.

2. Methodology

Based on the knowledge from the theoretical phase, paper focused on the analysis of radio frequency detection as well as alternative methods. The aim of the analysis is accumulation of data and information sufficient for a in-depth comparison of the radio detection method and alternative detection methods. In order to collect relevant existing papers effectively, it was first necessary to determine criteria for their selection. Firstly, it was important to strictly determine classes of UAVs which would be considered in our paper. Definition of classes was based on EASA Delegated regulation (EU) 2019/945 and Implementing regulation (EU) 2019/947 [12, 13]. For our purpose, we use papers which focus on detection of consumer UAVs with MTOM between 0 kg and 4 kg. We also focused on papers which
specifically involve evaluation of detection probability and detection distance. As part of the research, paper also focused on the environment in which the measurements were performed. The reason was to find out whether the authors performed experiments in the selected paper in a real operating environment and in the presence of interference, or for example under the conditions of the occurrence of several UAVs at the same time. Used data were accumulated by systematic searching in the Scopus and Web of Science databases [14-17].

Our paper was further devoted to the evaluation of each detection method, based on the collected data. The aim of the evaluation was to summarize the information obtained from the work and evaluate the pros and cons of each method. Final part of our paper was aimed to compare detection methods based on the obtained data, on the probability of UAV detection and also the distance over which the systems are able to reliably detect UAVs [18, 19]. The comparison is performed based on the arithmetic mean of the probability values that authors of selected papers reached at specific detection distances. According to the comparison of probabilities, an evaluation is made of which method is most suitable at what detection distance [20]. For the purpose of system design, we decided to outline a simple scenario in which the system should be used. Subsequently, based on the information from the previous steps, a robust UAV detection system was designed, combining all methods to maximize the probability of UAV detection [21].

3. System Design and Operation

For the purpose of design, a simple detection scenario was outlined. The system was designed to monitor a restricted area with a radius of 100 meters. In order to reliably monitor the area and protect it from potentially malicious UAVs, it was necessary to monitor a wider area than just defined radius of 100 meters. For this reason, system monitors area with radius of 3 000 meters. Because of the size of monitored area, radio frequency detection system was supplemented with additional systems to maximize probability of detection.

3.1. Probability of Detection

The detection system is based on four different methods, which have different properties, advantages, disadvantages and therefore different levels of probability of detecting UAVs, under different conditions. For this reason, it was necessary to analyse the probabilities of each system and use results of this analysis to determine how to combine selected methods for maximum probability of detection.

In order to compare all detection systems, the entire 3000-meter-long detection range was divided into segments. Mentioned segments are not uniform throughout the detection distance. The reason is that the acoustic and visual detection system is able to function reliably over a shorter distance and therefore, the probability of detection drops significantly even when the detection distance changes only by several meters. Up to a distance of 10 meters, the segments are 5 meters long and up to 200 meters, the segments are 10 meters long. From a distance of 200 meters to 1500 meters, the segments are uniformly 100 meters long and in the distance from 1500 meters to 3000 meters it is 250 meters. The choice of segment lengths was based on the distances at which the authors of the selected works were able to reliably detect unmanned aerial vehicles.

The next step in the process was to determine the average probability of UAV detection by selected methods, given the specific detection distance. For this purpose, we used all papers that contained probability of detection expressed in percentage and the distance over which the probability was reached. This way, the probability of all four selected methods was determined, in the whole range from 0 meters to 3000 meters. Probability of detection using the radio frequency method, at a distance of 100 meters can serve as an example (Table 1). Firstly, it is necessary to determine what is the probability of detection in each work at this distance, and then an arithmetic mean is created based on the probability values.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.931</td>
<td>0.900</td>
<td>0.952</td>
<td>1.000</td>
<td>0.946</td>
</tr>
</tbody>
</table>

The comparison itself was performed in the Microsoft Excel environment, where a table was created with the full range of distances and probabilities of individual methods. Afterwards algorithm determined which method had the highest probability of detecting UAV based on a particular distance segment.

Using the results from the table, in combination with the knowledge of the selected methods, it was necessary to determine how all methods will be combined in order to maximize the reliability of the system. Based on probabilities, the methods are most reliable at the following distances (Table 2).
Table 2

Distances where methods reached the highest level of detection probability

<table>
<thead>
<tr>
<th>Distance [m]</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 – 80</td>
<td>Radiofrequency</td>
</tr>
<tr>
<td>90 – 150</td>
<td>Acoustic</td>
</tr>
<tr>
<td>160 – 180</td>
<td>Radiofrequency</td>
</tr>
<tr>
<td>190 – 500</td>
<td>Radar</td>
</tr>
<tr>
<td>600 – 1400</td>
<td>Radiofrequency</td>
</tr>
<tr>
<td>1500 – 3000</td>
<td>Radar</td>
</tr>
</tbody>
</table>

Due to the known properties of the systems, our system’s composition will not be strictly based on the previous table. Purpose of the design will be to use the advantages of the systems to complement the radio frequency system so the resulting detection probability will be optimal (Table 3).

Table 3

Complete table of detection probabilities

<table>
<thead>
<tr>
<th>Range [m]</th>
<th>Detection method</th>
<th>Maximum probability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Radiofrequency</td>
<td>Acoustic</td>
</tr>
<tr>
<td>5</td>
<td>0.973</td>
<td>0.962</td>
</tr>
<tr>
<td>10</td>
<td>0.969</td>
<td>0.962</td>
</tr>
<tr>
<td>20</td>
<td>0.965</td>
<td>0.951</td>
</tr>
<tr>
<td>30</td>
<td>0.961</td>
<td>0.909</td>
</tr>
<tr>
<td>40</td>
<td>0.956</td>
<td>0.867</td>
</tr>
<tr>
<td>50</td>
<td>0.956</td>
<td>0.825</td>
</tr>
<tr>
<td>60</td>
<td>0.954</td>
<td>0.705</td>
</tr>
<tr>
<td>70</td>
<td>0.951</td>
<td>0.642</td>
</tr>
<tr>
<td>80</td>
<td>0.948</td>
<td>0.642</td>
</tr>
<tr>
<td>90</td>
<td>0.946</td>
<td>0.963</td>
</tr>
<tr>
<td>100</td>
<td>0.946</td>
<td>0.963</td>
</tr>
<tr>
<td>110</td>
<td>0.942</td>
<td>0.963</td>
</tr>
<tr>
<td>120</td>
<td>0.939</td>
<td>0.963</td>
</tr>
<tr>
<td>130</td>
<td>0.935</td>
<td>0.963</td>
</tr>
<tr>
<td>140</td>
<td>0.932</td>
<td>0.963</td>
</tr>
<tr>
<td>150</td>
<td>0.929</td>
<td>0.963</td>
</tr>
<tr>
<td>160</td>
<td>0.925</td>
<td>0.963</td>
</tr>
<tr>
<td>170</td>
<td>0.922</td>
<td>0.963</td>
</tr>
<tr>
<td>180</td>
<td>0.918</td>
<td>0.963</td>
</tr>
<tr>
<td>190</td>
<td>0.915</td>
<td>0.963</td>
</tr>
<tr>
<td>200</td>
<td>0.911</td>
<td>0.963</td>
</tr>
<tr>
<td>300</td>
<td>0.903</td>
<td>0.963</td>
</tr>
<tr>
<td>400</td>
<td>0.897</td>
<td>0.963</td>
</tr>
<tr>
<td>500</td>
<td>0.917</td>
<td>0.963</td>
</tr>
<tr>
<td>600</td>
<td>0.963</td>
<td>0.963</td>
</tr>
<tr>
<td>700</td>
<td>0.969</td>
<td>0.963</td>
</tr>
<tr>
<td>800</td>
<td>0.975</td>
<td>0.963</td>
</tr>
<tr>
<td>900</td>
<td>0.981</td>
<td>0.963</td>
</tr>
<tr>
<td>1000</td>
<td>0.945</td>
<td>0.963</td>
</tr>
<tr>
<td>1100</td>
<td>0.944</td>
<td>0.963</td>
</tr>
<tr>
<td>1200</td>
<td>0.944</td>
<td>0.963</td>
</tr>
<tr>
<td>1300</td>
<td>0.943</td>
<td>0.963</td>
</tr>
<tr>
<td>1400</td>
<td>0.943</td>
<td>0.963</td>
</tr>
<tr>
<td>1500</td>
<td>0.943</td>
<td>0.963</td>
</tr>
<tr>
<td>1750</td>
<td>0.943</td>
<td>0.963</td>
</tr>
<tr>
<td>2000</td>
<td>0.943</td>
<td>0.963</td>
</tr>
<tr>
<td>2250</td>
<td>0.919</td>
<td>0.963</td>
</tr>
<tr>
<td>2500</td>
<td>0.898</td>
<td>0.963</td>
</tr>
<tr>
<td>2750</td>
<td>0.878</td>
<td>0.963</td>
</tr>
<tr>
<td>3000</td>
<td>0.878</td>
<td>0.963</td>
</tr>
</tbody>
</table>

3.2. Radiofrequency Detection

This method was chosen as the primary component of the system and based on the comparison of probabilities it can work reliably at the range from 0 meters to 1400 meters. The reason for this way of utilising radio method in the system is the overall reliability of the system and the specific advantages over other methods. Radio detection has a
defined area with a radius of 100 meters. In order to have better situational awareness and the possibility of timely
UAVs using a camera system.

Restricted perimeter. The last limit is the distance of 150 meters from the centre, where it is already possible to detect
located 250 meters away from the centre. The distance was also extended by placing microphones on the border of
restricted perimeter, 100 meters away from the centre. Radio detection is followed by acoustic detection, which is
extended from 1400 meters to 1500 meters due to the fact that the radio sensors are located on the border of the
restricted area. Another limit is 1500 meters, when the UAV is detected by a radiofrequency system. The data from the system is again processed by
operator and provides up-to-date information about its position. If the UAV continues to approach a restricted area and
would require placement of multiple sensors outside the restricted area, which may not be possible in all conditions.

3.3. Visual Detection

Visual detection has the shortest detection range, but it provides specific advantages over other methods that
these methods cannot provide. Based on the obtained data, we can see that visual detection can work reliably in the
range from 0 meters to 50 meters. The advantage of the system is in particular the fact that it provides the operator of
the detection system with visual material useful for verifying whether detected object really is a UAV, whether it is
equipped with a camera, a load and what model of unmanned vehicle it is. These advantages are also the primary
purpose for which visual detection is incorporated into the system.

3.4. Acoustic Detection

Acoustic detection according to the obtained data provides reliable detection in the range from 0 meters to 150
meters. The most significant advantage it provides in combination with radar and visual detection is the ability to detect
even UAVs that do not communicate in the radio frequency spectrum. Mentioned advantage is also the primary reason
why acoustic detection is utilised in the system. In addition, however, it’s important to mention that the system provides
reliable detection as well as identification of unmanned aerial vehicles within its range.

3.5. Radar Detection

Radar detection provides the highest values in terms of detection range and based on the analysed data it’s
possible to reliably detect flying objects up to a range of 3000 meters. Radar detection is used in the system in two
ways. One of them can be described as an early warning system. The radar would provide the system operator with
information about flying objects around the restricted area up to a range of 3000 meters. This would provide system
operator with sufficient situational awareness and reaction time. In addition, the system provides advantage in terms of
information about the position of the UAV. This can be also achieved with radio or acoustic detection but localization
would require placement of multiple sensors outside the restricted area, which may not be possible in all conditions.

3.6. Operation Principles

Approaching UAV is firstly detected by the radar system operating in the range of 0 meters to 3000 meters
(Fig. 1). Another limit is 1500 meters, when the UAV is detected by a radiofrequency system. The distance was
extended from 1400 meters to 1500 meters due to the fact that the radio sensors are located on the border of the
restricted perimeter, 100 meters away from the centre. Radio detection is followed by acoustic detection, which is
located 250 meters away from the centre. The distance was also extended by placing microphones on the border of
restricted perimeter. The last limit is the distance of 150 meters from the centre, where it is already possible to detect
UAVs using a camera system.

In the previous part of the paper, a detection scenario was outlined, in which the goal of the system is to protect a
defined area with a radius of 100 meters. In order to have better situational awareness and the possibility of timely
response to situations, system monitors the area up to a range of 3000 meters. The operation of the system will be
further described based on the model situation where an unmanned vehicle DJI Phantom is approaching the restricted
area. UAV begins the flight outside the monitored area, beyond the limit of 3000 meters.

After crossing the 3000-meter limit, the flying object is detected by radar (Fig. 1). Now CPU is responsible for
determining whether the detected object is UAV or not. When a UAV is detected, the system notifies the system’s
operator and provides up-to-date information about its position. If the UAV continues to approach a restricted area and
crosses the 1500-meter limit, it is detected by a radiofrequency system. The data from the system is again processed by
the CPU and artificial intelligence. Its task is again to decide and verify whether it is a UAV. Radio detection has higher
priority in the system therefore it confirms or refutes previous radar detection. In addition, the system can also be used
to identify the model of an unmanned vehicle. If the UAV continues to approach, it will be detected by an acoustic
system at the 250-meter limit. The task of the system is to verify again whether it is an unmanned vehicle. In case of a
situation where the UAV does not use radiocommunication and avoids detection by the radio frequency system, the
acoustic system detects this UAV and notifies the system operator. The last limit is the distance of 150 meters from the
centre of the restricted area where the UAV is detected by the camera system. It processes the acquired image data and
provides it to the responsible person, who can verify whether it is really a UAV. In addition, it is possible to determine
whether the unmanned aerial vehicle is equipped with a camera, a load and to accurately identify the model.
4. System Components

The purpose of this chapter is to clarify the basic components that the system should consist of. The designed system consists of four main separate components, one of which provides radar detection, another provides radio detection, another provides acoustic detection and the last one provides visual detection (Fig. 2). All parts are equipped with a separate computer responsible for data and signal processing. The reason is higher computing capacity and the ability of other systems to operate in case the processing unit of one of the systems fails.

The radar system is equipped with a radar antenna responsible for receiving and transmitting radar waves and an SDR device that is connected to a computer. The radiofrequency system is also equipped with an antenna, the purpose of which is to receive radio waves, the antenna is connected to the SDR and a computer. The main component of the acoustic system is antennas connected to a computer. The camera system must be equipped with cameras and they are also connected to a computer. In addition, the radio, acoustic and camera systems are equipped with artificial
intelligence, which is trained to recognize UAVs in the acquired data. All systems are then connected to an output device that provides information to the system operator.

![UAV detection system block diagram](Image)

**Fig. 2 UAV detection system block diagram (Source: authors)**

5. Conclusions

Based on the analysis, we successfully identified the need to detect unmanned aerial vehicles and areas for which such a system is useful.

In the section of system design, based on the knowledge from the theory, attention was given to a deeper analysis of the literature, relevant to the methods of UAV detection. The main purpose of the analysis was to find out the properties of systems designed by the authors of sourced literature, with a focus on the probability of UAV detection and the detection distance. Afterwards, all methods were compared together and the analysis together with the comparison served as a tool to propose a UAV detection system design. The design itself was proposed in a form of a robust system that includes a radio frequency detection method supplemented by alternative methods.

Radio detection is the primary component of the system and based on a comparison of probabilities, it can reliably work in the range of 0 meters to 1400 meters. Radio detection has a significantly greater range than the acoustic or visual method. In addition, it is not restricted by noisy environments and is not limited by weather conditions or poor visibility. Compared to radar detection, the advantage of radio detection is that it is not limited by the radar cross-section of the UAV nor by the detection of a swarm of closely flying UAVs. In addition, radar detection has a higher chance of false positive detection. This can happen for example when the system mistakes a flying object with a similar radar cross-section for a UAV, which is not a problem with radio detection. Overall, radio detection can be described as a highly reliable method.

The system we designed can serve in numerous areas in order to minimize or eliminate threats to human lives, property, infrastructure or security. Of course, there is also space for further research mainly in the area of practical experiments and further optimization of the system based on the results. The system has also the potential for modularity. This means it could be optimized based on specific operating conditions and environment. This also offers room in the field of research of methodology which could serve as a standard tool for mentioned optimisation.
Acknowledgements

This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: “Intelligent operating and processing systems for UAV, code ITMS 313011V422”, co-financed by the European Regional Development Fund”.

References

Method of Thermo-energy Gas Separation for Adaptive Temperature Regulation in Friction Contact of Railway Brakes

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Abstract

The frictional properties of railway brake elements can be regulated with different methods of controlling their surface temperatures. The known method of improving of frictional interaction in the system “pad - disk" or "pad - wheel", which is implemented by supply of compressed air from the brake line to cool the tribological contact, does not provide efficient convective heat transfer as supplied air has not been cooled. One of the promising methods of temperature stabilization is supplying cooled air to the contacting surfaces. The article provides analysis of the possibility of using vortex tube structures for control of railway brake frictional pairs. Usage the temperature separation effect can improve the conditions of friction in railway brakes tribosystem. The gas separation effect is environmentally friendly and available for implementation on railway transport. The article presents overview of gas separation constructions and their features. Experimental studies created opportunity to develop semi-empirical mathematical models for the calculation of Rankque-Hilsch tubes.

KEY WORDS: railway braking, frictional contact, cooling, vortex effect

1. Introduction

From the analysis of theoretical and experimental studies of tribological contact, it was found that to achieve consistently high adhesion qualities of tribological units, it is not enough to regulate only the mechanical component [1, 2]. The question of the influence of thermal processes on the stabilization of the friction coefficient has not been fully investigated. It was found that when the temperature in the metal contact reaches from 200 to 400°C, the strength properties of the surface layers change. Therefore, it is proposed to control the clutch of the tribological system disc-brake pad and wheel-brake-rail by controlling the local mechanical and temperature components depending on the conditions of frictional contact.

Experimental studies determining the effect of stabilization of temperature processes on the output parameters of the brake were carried out on a laboratory bench [3, 4]. The stand is designed to test various brake circuits and control their output parameters.

2. Research Results

Presentation of the main material of the study. The essence of the energy separation effect is that the compressed gas in a swirling flow is divided into two streams, one of which comes out as a cooled stream from the diaphragm, and the other - in the form of a hot stream - from the cross section of the throttle. The schematic design of the device by means of which the specified effect is realized, - a Rankque-Hilsch vortex tube presented in Figs. 1 and 2.

Fig. 1 Rankque-Hilsch vortex tube scheme: 1 – cylindrical tube; 2 – tangential nozzle; 3 – snail; 4 – diaphragm with axial hole; 5 – throttle
The designs differ, in particular, in the shape of the nozzle through which compressed air is supplied to the pipe, and the size of its vortex chamber, measured in calibers.

The constructions proposed by Hilsch [4] have one nozzle entrance, in the cross section of which there is a circle, and a rectangular entrance snail. Thus, a space is formed at the nozzle section, which contributes to the formation of turbulence.

Martynivsky and Alekseev [5], offer a way to solve this problem, which is to use a tangential-tray nozzle inlet. This model eliminated the turbulence zone and improved the operation of the gas separator, but the nozzle inlet became more difficult to perform. The best length of the vortex zone for such structures is 50 calibers.

The design feature of the product [6] has a cross section of the nozzle entrance in the shape of a rectangle, as well as the entrance snail has a similar shape. The Archimedean spiral is used in the construction of the snail. This helps to eliminate the zone of turbulence on the nozzle section, keeping the design uncomplicated by additional elements. Another difference is the reduction of the vortex chamber to 9 calibers along, which is possible due to the directing crosspiece, which has four blades, is located in front of the hot flow throttle and limits the vortex zone. The addition of these differences allowed to improve the vortex tube and reduce its size.

The vortex tube [7] has 4 (or 6) conical nozzle inlets and a length of a cylindrical vortex zone of 33 calibers.

Fig. 2 General view of the vortex tube

In his work, Hills introduced the values and criteria that are still essential for constructing the characteristics of a vortex tube.

If the total temperature and pressure of the incoming compressed gas entering the nozzle is denoted by \( T_1^* \) and \( P_1^* \), the cooled flow by \( T_c^* \) and \( P_c^* \), and the hot flow - by \( T_h^* \) and \( P_h^* \), the cooling effect of the cooled flow can be expressed as follows:

\[
\Delta T_c = T_1^* - T_c^* \quad (1)
\]

and the effect of heating the hot stream

\[
\Delta T_h = T_h^* - T_1^* \quad (2)
\]

With the total second weight flow of compressed air \( G \), the flow of cooled flow \( G_c \) and hot flow \( G_h \), the relative weight flow \( \mu \) (or weight fraction) of the cooled flow will be:

\[
\mu = \frac{G_c}{G} \quad (3)
\]

and the relative weight flow of the hot stream is determined in the flow equation

\[
G = G_c + G_h, \quad (4)
\]

whence after division by \( G \) we receive:

\[
\frac{G_h}{G} = 1 - \mu \quad . \quad (5)
\]

Starting with Hilsch, the characteristics of the vortex tube were built in the form \( \Delta T = f(\mu) \).

Fig. 3 shows a typical view of the characteristics of the insulated vortex tube at a given size, parameters \( T_1^* \) and \( P_1^* \), at the inlet and pressure \( P_2^* \) in the cooled stream.

As it can be seen from the characteristics, with increasing from zero the weight fraction of the cooled flow sharply increases the effect of its cooling and reaches a maximum at \( \mu = 0.25 \). With a further increase in \( \mu \), the cooling effect decreases and disappears at \( \mu = 1 \), i.e., when the throttle of the hot end of the pipe is completely closed and the entire flow exits through the diaphragm hole.

The heating of the hot stream, increasing with increasing \( \mu \), reaches a maximum value at \( \mu \) close to 1, and then drops sharply to zero when \( \mu \) approaches unity. If the cooling effect is known \( \Delta T_c \) cooled flow, it is easy to calculate the heating effect \( \Delta T_h \) hot flow, because in the absence of heat exchange with the environment, the energy emanating
from the vortex tube flows is equal to the energy of the input stream.

In the theory of the vortex effect, the pressure level does not play a role in the operation of the vortex tube, but the viscosity of the gas affects the rate of its flow from the nozzle to the friction against the walls and the process of vortex interaction.

Experimental studies show that a decrease in the overall pressure level while maintaining a constant degree of expansion leads to some decrease in temperature efficiency. This decrease is similar to the decrease in the efficiency of the aircraft compressor with increasing altitude and is about 1% for each kilometer of "altitude". The correction was tested to altitudes of about 13 km, to a cooled flow pressure of 1.67 MPa.

Fig. 4 shows a curve of relative temperature efficiency depending on the absolute pressure of the cooled flow. Here $\eta$ is the temperature efficiency taking into account the correction for the pressure level of the cooled flow. This curve can be approximated with sufficient accuracy by a polynomial of the second degree, based on experimental data:

$$\eta = 0.8325 + 0.2697p - 0.103p^2.$$  

(6)

The polynomial approximation can be used to describe values that alternately increase and decrease. It is advisable to use it to analyze a large data set of unstable magnitude. Polynomial approximations have a limitation: they cannot be applied outside the range of parameters in which they are obtained. Due to the fact that the calculations were performed for the absolute pressure and the coefficient determined in the range from 0 to 1, this condition is met.

The use of the effect of thermal separation of gases to control the cooling of friction surfaces is proposed in [8]. The method is to supply a cooled fraction of air during braking for thermoregulation of surfaces in the brake contact. An
improved method of improving the interaction conditions of the friction elements of the disc brake will stabilize the coefficient of adhesion of the friction surfaces of the friction elements.

3. Conclusions

The use of the energy separation effect is a promising direction for improving the efficiency of interaction of friction surfaces of railway brakes. The choice of optimal designs and geometric parameters of vortex tubes is carried out by conducting physical experiments. Along with physical experiments, the choice of optimal geometric parameters can be carried out using mathematical modeling in modern packages of computational hydrodynamics. The authors propose to use the effect of thermal separation of gases to control the cooling of friction surfaces. During braking, a cooled fraction of air is supplied to the brake contact to thermoregulate the surfaces. The improved method of improving the interaction conditions of the friction elements of the disc brake, which was proposed, will stabilize the coefficient of adhesion of the friction surfaces of the friction elements, and accordingly ensure better safety of railway transport and improve its environmental friendliness.

Acknowledgement

The study was carried out as part of the technical task of the research work DN-06-21 “Development of a resource-saving ecological method to increase the safety of railway transport by increasing the energy consumption of brake systems”.

References

Key Issues of e-ID UAS Integration

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Abstract

This paper is focused on the analysis of the applicable technologies of the e-ID for UAS and the identification of key barriers that need to be mitigated when the technologies are implemented into the airspace. The approach is focused on the system evaluation of airspace from the point of view of the possibility of integrating unmanned operations using U-space airspace. The use of U-space airspace in different parts of the current airspace classification entails different requirements for surveillance and anti-collision technologies. Current technologies are therefore evaluated against different airspace structures and obstacles are identified that prevent their use and the overall integration of unmanned aviation into airspace. The biggest obstacle found is a uniform reference height system, which does not yet exist. To implement it, a proposal has been created which, with the help of U-space service providers, will make it possible to ensure a uniform reference height for drones, thus helping to continue the integration.

KEY WORDS: Unmanned Aircraft; Unmanned Aircraft System; e-ID; remote identification; common altitude

1. Introduction

The integration of a new part of the operation into the existing environment always encounters obstacles. This also applies to the case of the development of drone operations [1], which must be integrated into the airspace already used by aviation pilots [2, 3]. To make this possible safely, it is necessary to use technology that has not yet been implemented and to overcome obstacles that have not yet existed.

Electronic identification (abbreviated as e-ID) is the ability of an unmanned aircraft (UA) to transmit in-flight identification data that can be received by other parties. The identification allows them to see the data about the UA and its operator on the mobile device. If the UA behaved illegally, some steps could be taken to stop it.

Within the e-ID, it is necessary to mention the so-called Network Identification Service. This is a service that will be provided within U-Space, which is created based on electronic identification. The data will be sent to the systems of U-Space service providers (USSP) [4].

To be able to carry out an e-ID transmission and use this transmission to ensure safe operation, obstacles to the implementation of the e-ID need to be identified. The following sections describe the system view of airspace and applicable technologies from the point of view of e-ID, propose a methodology for determining obstacles and their removal, and describe these obstacles and possible solutions. Finally, the feasibility of the solution is evaluated.

2. Methodology

For the purpose of identifying obstacles, an airspace model was created, into which the newly emerging U-Space was included, which is further described in Commission Implementing Regulation (EU) 2021/664 [12-13]. The airspace was divided into a total of 4 sections. These 4 sections are then divided into the two subsections, which belong to uncontrolled airspace (to illustrate specific airspace, the layout of the airspace of the Czech Republic was used, where uncontrolled airspace is up to 1000 ft Above Ground Level (AGL)) and two, which belong to controlled airspace (above 1000 ft AGL). Specifically, they are:

1. U-Space in uncontrolled airspace;
2. Uncontrolled airspace outside U-Space;
3. U-Space in a controlled airspace;
4. Controlled airspace outside U-Space.

In the airspace model, it is necessary to consider the control zones (CTR) and aerodrome traffic zones (ATZ). These determine further the size of the U-Space (or the interface between the responsibilities of air navigation service provider (ANSP) and USSP), within the defined geographical zones, and the requirements for UAS equipment. The proposed airspace model illustration is shown in Fig. 1. It can be seen that the existing airspace has been supplemented by the so-called "U-Space airspace", it is the space in which U-Space services will be provided. ANSP airspace is the existing airspace in which navigation services are provided.
Applicable technologies for e-ID were divided into two groups and then included in the newly created airspace. The first group is called Broadcast and includes technologies that use direct broadcasting. Thus, the connection is only between the receiver and the transmitter without any interface between them. The broadcast technologies are as follows:
1. Wi-Fi;
2. Bluetooth;
3. ADS-B;
4. FLARM.

The second group is called Network. There are technologies in which an interface is included between the receiver and the transmitter. The interface receives, processes, stores, and distributes the data. These are usually technologies that use IP transmission, where data is cached at the provider and only then sent to the receiver or receivers. This group includes:
1. LTE - Long Term Evolution;
2. 5G;
3. FLARM;
4. ADS-B.

Each of the proposed technologies has its pros and cons. This applies both to broadcast technologies, where barriers have been identified [5] for both Wi-Fi and Bluetooth, within ADS-B [6, 7], or for FLARM, as well as to Network technologies from a mobile signal perspective [8]. To ensure the correct operation, it is essential that unmanned aircraft can move safely in the defined area and can operate even in the event of a loss of signal [9, 10].

After selecting the applicable technologies for e-ID, and compiling the airspace model, these technologies were distributed to the newly divided airspace so that their properties matched the requirements of the corresponding airspace. For example, the airspace over 1000 ft in the Czech Republic is already a controlled area and for this reason, it is necessary to adapt the technology to this fact. Furthermore, it was necessary to consider the requirements for technologies that were outlined for operation in U-Space airspace [4]. After the theoretical deployment of technologies, it was possible to identify obstacles. The identification was performed from the point of view of data transmission and from the point of view of obtaining information for transmission. Subsequently, an optimal solution for these obstacles is proposed.

3. Results

The identified obstacles in the area of data transmission include congestion of the transmission band, the possibility of including a UA identification number, or the availability of data in a given locality (i.e. low coverage).

Among the identified obstacles in terms of obtaining information, the height measurement system was identified as the biggest issue. Legislation has not yet defined requirements for height measurement technology [11], so each manufacturer can choose his method. In this case, each system could operate with its own measurement starting point and accuracy. This will subsequently impact the possibility to use these measurements for traffic management, as two
UAs would each transmit a different altitude, even that they could be at the same height, in the risk of collision. The most commonly used measurement of flight height in commercial drones is the measurement from the point of take-off, as shown in Fig. 2.

![Diagram](image)

**Fig. 2** The difference of height measurement against actual flight level. Source: Authors

To unify the height measurement, a method was proposed, which is used to correct the input data from the UA and subsequent conversion to a common height. This correction is only possible in U-space airspace, where the Network identification service is provided. Upon receipt of the UA height information and other available data, which will be described below, the operator of this service could transfer the received data to a common altitude measurement system, ensuring that even if the two UAs transmit different altitude values, the relative height between them is known.

For the correct functionality of the conversion of heights to a common one, it is necessary to know the fragmentation of the terrain, how the height of the terrain changes compared to specific zero point. Furthermore, it is necessary to determine this zero point, which must be chosen as appropriately as possible. As a zero point, we can choose, for example, the sea level, which will also be in accordance with the "manned aviation" and will also allow the use of existing maps of altitudes of the areas. If the accuracy of these maps would be unsatisfactory, it is desirable to re-map this terrain with the required accuracy. As the last step, it is necessary to enter the detected elevation data on a map with exact geographical coordinates, so that it is possible to compare the corresponding change in elevation with the appropriate position in which the UA started. Lastly, it is necessary to have a central intermediary who will carry out this altitude conversion based on the terrain data in the area. This intermediary could just be a service provider in U-Space airspace, the so-called USSP.

If all the described data are specified, it is possible to perform a conversion from the measured height from the surface to a common system, which will tell us what height the UAs have from a single common zero point. If the UA1 drone measures its altitude from a take-off point of 20 m, which is 50 m from the selected zero point (e.g. sea level), then its recalculated altitude from the zero point is 70 m. The same principle is applied for another drone in the area marked as UA2. It measured its height from the take-off point with a value of 50 m, which is increased by 20 m compared to the zero point, then his recalculated height is also 70 m, which is the same value as for UA1. It follows that after the initial measurement of the heights of UA1 and UA2, it seemed that each was at a different height and there was no risk of a collision. After conversion to a common height, it can already be seen that they are in fact at the same flight height. If they continued to converge, a collision could occur. An illustration of the heights UA1 and UA2 can be seen in Fig. 3.

The result will be the altitude, which can be called "flight altitude". This altitude will be the same for all drones, no matter how high is the place from which the drone took off because it will always be changed by the value by which the altitude of the terrain has changed. After that, the USSP will only see the values of that flight altitude and will be able to suggest such adjustments that no collision will occur. The UA operator will see the altitude from the surface sent to him by the drone. However, this will not cause a problem due to the fact, that the necessary height changes for the evasive manoeuvre shown is the same for both, for height from the surface and for altitude. Thus, if the USSP proposes a change in height, it will depend solely on the magnitude of the change.

The introduction of such a correction system would allow control of the airspace during the operation of drones, as differences in terrain heights will be eliminated and all UAs will appear as if they were all taking off from a single location. This will ensure the possibility to control the airspace with drones, which will reduce the risk of a collision. This will also ensure that a new way of measuring altitude does not have to be sought for UA, as the current situation is that UA measures its height with a barometer from the take-off point.
4. Discussion

The results of this work are important especially for the further development of electronic identification for unmanned aircraft and increasing the numbers of drones simultaneously flying in the same airspace.

Defining individual parts of the airspace within unmanned aircraft operation will enable faster implementation of the proposed technologies, as it will allow determining the most suitable technologies for the given airspace. Each airspace places different demands on the operation and it is necessary to determine the individual technologies accordingly. The proposals in this paper are based on already functional elements, which are either needed to slightly adapt to the needs of the UA or to combine with another already established technology.

Thanks to the selection of technologies, the division of airspace, the classification of technologies into individual parts of airspace and the subsequent identification of obstacles and the proposal of solutions, will be possible to adapt these technologies more quickly to the growing UA traffic in the future. Based on the proposed solution to the biggest obstacle, it is possible to safely implement these technologies into the airspace and thus ensure sufficient safety of operations. This will enable the development of flights beyond the line of sight in the coming years, where a flawless system is a critical part.

5. Conclusions

The main goal of the paper was to identify the main obstacles in the implementation of e-ID for UAS based on the analysis of applicable technologies of the planned integration of UAS traffic into all parts of the airspace. To meet this goal, it was necessary to select the technologies that are most suitable for this case, then perform their basic sorting and create a system view of the airspace based on which the classification of individual technologies is determined so that their properties are used beneficially as much as possible. Thanks to this inclusion of technologies into the airspace, it was possible to find the most serious obstacles in the implementation of these technologies and to propose a solution that is most suitable for the given airspace.

Problems were identified in the transmission technology and in the data acquisition because the problem is not only about how the data are transmitted, but also it very much depends on the way the data are obtained, as they need to be usable in all situations and be futureproof.

The proposed solution to a major obstacle - the need for a uniform reference height - can help in the rapid integration of unmanned systems into airspace.

Although EASA seeks to interfere as little as possible with existing legislation and to create an isolated space for drones from normal airspace, it should be noted that this is not entirely possible and the necessary adjustments will be needed to fully exploit the potential of drones. If the findings of this article are to be used in some research on this topic, it is really appropriate, if not necessary, to carry out extensive simulations and practical tests, in highly congested conditions, as this is the situation that will be the biggest problem in the airspace in the coming years. It would also be appropriate to not segregate the UAS operations from existing airspace. The creation of two isolated systems is a step backwards in the development of drones.

Acknowledgement

This paper was supported by Department of Air Transport Faculty of Transportation Sciences Czech Technical University in Prague and the Grant Agency of the Czech Technical University in Prague, grant No. SGS21/135/OHK2/2T/16.
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4. EASA. Opinion No 01/2020: High-level regulatory framework for the U-space.
Experimental Testing of the Vehicle-driver Interaction by Eye-tracking Technology in Laboratory Conditions

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Abstract

The article deals with analysing the driver's activities and interactions while driving the vehicle in laboratory conditions. This experiment was performed on the truck simulator SNA – 211 REN located in University Science Park, University of Zilina. For obtaining exclusive data from the driver's point, we used eye-tracking technology (eye-tracking glasses), which identifies the driver's gaze on stimuli in a real or virtual environment. By analysing the raw data, we were able to find main procedures for how the driver interacts with the vehicle in various situations and the importance of controls situated in the vehicle cockpit dashboard. The final results from this analysis can primarily lead to a better understanding of the driver's control of the vehicle and secondary to an increase of ergonomics of the vehicle cockpit dashboard. All results from the experimental research can increase the road transport system's sustainability and safety.

KEY WORDS: driver-vehicle interaction; eye-tracking testing; car cockpit dashboard design

1. Introduction

In addition to the essential elements of human - vehicle enters the transport system environment. It is an extensive term under which we can include natural, non-human or only minimal influences (climatic conditions) and construction and technical equipment and transport-technical measures that result from human activity [15]. In the case of solving the mutual relations between the driver and the vehicle, we cannot neglect this factor, as when researching the interaction in laboratory conditions, it enters the issue as a virtual environment of a driving simulator.

Traffic safety can be defined as the protection of life, health and property in road traffic. It reflects the ability of the system to operate with an acceptable level of risk to the system environment and to the system itself. The traditional method of expressing traffic safety is traffic accidents [12]. A traffic accident can be defined as an adverse event in road traffic, such as an accident or collision that has occurred or started on the road, resulting in death, personal injury or property damage [2]. It is a disturbance of the balance between the system's three components - the environment, the vehicle, and man (human factor). Safety is a picture of the quality and maturity of roads, the transport environment, the experience of drivers and progress in implementing intelligent applications of science and research in practice, i.e. into vehicles and the traffic environment in which the driver operates [8]. The essential information underlining the importance of research into driver-vehicle interaction is that more than 90% of accidents are caused by driver failure. The exact ratio is unknown, as studies include different results ranging from 90 to 99% of human-caused accidents [14].

From the perspective of traffic psychology, we can express the driver's behaviour when driving the following Eq. (1) resp. function [11]:

\[ R = f(S - O), \]  

where \( R \) – driver behaviour (responding to stimuli); \( S \) – perceived and acting stimulants on the driver; \( O \) – personality
characteristics of the driver.

Driver behaviour takes place on two levels. On an unconscious level, i.e. automated activities of the driver, and at a level of consciousness, when the driver engages in automated activities consciously, according to changing driving conditions and stimuli, decides on the most appropriate correct choice of response [10]. Driving a motor vehicle is a demanding and complex activity requiring constant readiness and response of the organism to incoming stimuli. The driver's inattention is a common cause of accidents [5].

2. Used Methods and Techniques

2.1. Simulator Environment

The simplest way to define a driving simulator is a device that is used to simulate the driving of a road vehicle while imitating the natural environment in road traffic. Easy driving simulators are currently used as an effective tool for driver training [3]. Still, they are also a tool for various research on human-machine interaction and for solving many problems of this interaction and improving vehicle cabs and assistance systems [7]. Vehicle simulators are used for the entire chain of work associated with the development, production of cars and ensuring their reliable and safe operation. The designs of today's vehicle simulators are becoming more and more complex and contain more and more diverse electronic and information components. Research vehicle simulators with implemented advanced technologies are usually costly. This is due to the requirement for high-quality technical processing and the fact that vehicle simulator systems are not mass-produced but developed and built individually.

Our experimental measurements were performed on the SNA - 211 REN training driving simulator (Fig. 2), which is a detailed imitation of a Renault Magnum truck cab. From a design point of view, it is a stationary device without a moving or vibrating platform. The cab of this simulator is made as a structural model for the required type of vehicle (it is not the real truck cab). However, the interior equipment copies the real cab in terms of the layout of controls and indicators. The steering wheel characteristics are controlled by a servo motor, gear, pedals, handbrake, and by the setup of the steering wheel position, which are equipped with the power simulations of compressed air - analogous to the actual vehicle.

![Fig. 2 Training driving simulator SNA 211](image)

The picture is displayed on the set of three large-scale projection screens placed in front of the driver and at the same time to the rear views placed within the projection screen scope.

2.2. Eye-Tracking Technology

Eye-tracking is a sensor technology that captures the movement of the tested subject's eyes. It is often used to experiment with human behaviour in its interaction with machines and devices in the real or virtual world [1, 13]. The interaction can be driving a car or aeroplane, searching the web, reading, drawing, and so on. Eye-tracking is based on obtaining data on eye movement, resp. pupils [9]. This data is obtained by the Eye-tracker device, which consists of two main components: a light source that emits infrared light and is aimed at the eyes, and a camera that then captures infrared light reflections, including pupils' movements. The device must be connected to a computer or other device that stores the scanned data. We used SMI Eye Tracking 2 Wireless Eyetracking glasses (ETG) from SMI SensoMotoric Instruments (see Fig. 3) in the experiment. These glasses record human behaviour in real-time on a mobile device or computer. The sampling frequency of eye movement detection is up to 120 Hz, and the viewing range is 80 degrees horizontally and 60 degrees vertically. In addition to recording images at a resolution of 1280x960 pixels at 24fps or 960x780 pixels at 30fps, the glasses also use an integrated microphone that picks up ambient sound [6]. Behavioural and Gaze Analysis software was used for deeper analysis of the obtained data.
3. Objective and Methodology

The main objective of this article is to analyse the driver's activities and interactions in critical situations while driving the vehicle in laboratory conditions by using eye-tracking technology. We focused on two partial objectives: analyse driver reactions to the critical situation and driver interaction with vehicle cockpit dashboard in these conditions.

The experimental measurement was performed with the participation of four test subjects with a driver's license. Two entities had a driving license for motor vehicles up to 3.5 tonnes, and two a driving license for motor vehicles over 3.5 tonnes. This experiment aimed to determine the difference between prediction and reaction time in crisis situations and their use of vehicle controls. Each driver drove for at least 15 minutes, during which he was exposed to several obstacles. These obstacles consisted of:
- a falling tree directly on the road;
- a wildlife ongoing across the road;
- a tractor extending into the road.

We used a wearable ETG device for the measurements. With the help of these glasses, it was possible to observe what the test subject is looking at on the monitors in front of him or what devices he uses to drive the car. We also found out how long it takes for the test subject to respond to certain stimuli, how long it takes to look at the stimulus.

In Fig. 4, it is possible to see a red cross; this is the output of eye-tracking technology, which shows precisely where the driver is looking during the experiment. Thanks to this technology and the sound recorded by the microphone of the glasses, we compared the reaction time and the time of observing the obstacle. When evaluating the measurements, we used three measured data: the time of visibility of the obstacle, the time of observation of the obstacle by the driver, the time of the driver's reaction by braking. We also used eye-tracking technology to evaluate the visitor's attention by generating a heat map and defining the tested subject areas of interest (AOI) in the simulator.

4. Results and Discussion

We evaluated crisis situations based on four events: the appearance of an obstacle in driving, the observation of an obstacle by the driver, the start of the driver's reaction (braking) and finally, the end of braking and stopping the vehicle (Fig. 5).

![Fig. 5 Events and indicators of the experiment](image)

Table 1 shows the raw results of measuring how tested subjects responded to crisis situations. Subjects 1 and 2
have a driving license for group C (tracks) and subjects 3 and 4 for group B (passenger car). Ten selected crisis situations were evaluated for each tested subject, where two indicators were evaluated (obstacle observation time and reaction time).

<table>
<thead>
<tr>
<th>Crisis situation</th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.99</td>
<td>0.15</td>
<td>0.57</td>
<td>0.42</td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td>0.43</td>
<td>0.4</td>
<td>0.22</td>
</tr>
<tr>
<td>3</td>
<td>0.83</td>
<td>0.5</td>
<td>0.1</td>
<td>0.12</td>
</tr>
<tr>
<td>4</td>
<td>0.59</td>
<td>0.21</td>
<td>0.38</td>
<td>0.28</td>
</tr>
<tr>
<td>5</td>
<td>0.55</td>
<td>0.27</td>
<td>1.05</td>
<td>0.47</td>
</tr>
<tr>
<td>6</td>
<td>0.4</td>
<td>0.1</td>
<td>0.51</td>
<td>0.25</td>
</tr>
<tr>
<td>7</td>
<td>0.32</td>
<td>0.47</td>
<td>1.17</td>
<td>0.58</td>
</tr>
<tr>
<td>8</td>
<td>0.35</td>
<td>0.38</td>
<td>0.45</td>
<td>0.33</td>
</tr>
<tr>
<td>9</td>
<td>0.55</td>
<td>0.18</td>
<td>0.28</td>
<td>0.23</td>
</tr>
<tr>
<td>10</td>
<td>0.53</td>
<td>0.25</td>
<td>1.13</td>
<td>0.45</td>
</tr>
<tr>
<td>Average</td>
<td>0.563</td>
<td>0.294</td>
<td>0.604</td>
<td>0.335</td>
</tr>
</tbody>
</table>

By comparing the indicator: obstacle observation time, it is possible to identify differences between initial and final crisis situations. It is because the appearances of obstacles are repeated in regular intervals, so the driver can learn when and where to expect an obstacle of what type. E.g., the obstacle of a falling tree was repeated at the same turn, and at the exact moment, the wild boar was standing on the right side of the road, and at a particular moment, the wild boars were running from the left side of the road.

The length of the sighting time was also affected by the driver's distraction and concentration on the road. E.g., subject 2 had technical problems with the clutch, so he focused more on shifting gears than on the road.

![Fig. 6 Average value of indicators obstacle observation time and reaction time](image)

The average values of the reaction time indicator depended mainly on the driver's experience. It can be seen in Fig. 6 that the drivers with a driving license for tracks (subjects 1 and 2) had significantly better reaction time on obstacles than the drivers with a driving license for passenger cars (subjects 3 and 4). From the point of view of the indicator: obstacle observation time, it can be stated that drivers with a driving license for passenger cars achieved better values. It may be because these drivers have adapted better to the simulator environment.

The second part of our experimental measurement was devoted to how the driver's view is focused on the situation in front of the vehicle and the dashboard indicators. We identified two areas of interest: front windows and dashboard (see Fig. 7.) We analysed ten crisis situations that began by event: Obstacle appears and ended by Stop breaking and top vehicle event. We focused on KPI - dwell time, which represents the percentage of crisis situation time that the gaze of the tested subject was focused on a particular AOI. Table 2 presents the average values of dwell time for ten crisis situations.
Based on the eye-tracking analysis, we found that the tested subjects in 63% of the time of the crisis situation watched what was happening in front of the vehicle. In 24.7% of the time, they watched the vehicle's dashboard on average. The duration of the average fixation per area of interest was approximately the same, 0.347 (front windows) and 0.323 (dashboard) seconds. The importance of monitoring what is happening in front of the vehicle is highlighted by the average number of fixations per area of interest: 6.2 fixations (front windows) and 2.8 fixations (dashboard).

### Table 2

Results of eye-tracking analysis of AOIs

<table>
<thead>
<tr>
<th>Crisis situation</th>
<th>Duration of crisis situation [second]</th>
<th>AOI dwell time</th>
<th>Average fixation on AOI [second]</th>
<th>Number of fixations on AOI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Front windows</td>
<td>Dashboard</td>
<td>Out of AOI</td>
</tr>
<tr>
<td>1</td>
<td>4.18</td>
<td>64%</td>
<td>20.8%</td>
<td>15.2%</td>
</tr>
<tr>
<td>2</td>
<td>2.15</td>
<td>61.1%</td>
<td>25.5%</td>
<td>13.4%</td>
</tr>
<tr>
<td>3</td>
<td>4.26</td>
<td>60.5%</td>
<td>37.9%</td>
<td>1.6%</td>
</tr>
<tr>
<td>4</td>
<td>3.98</td>
<td>81.8%</td>
<td>13.5%</td>
<td>4.7%</td>
</tr>
<tr>
<td>5</td>
<td>3.43</td>
<td>73.6%</td>
<td>17.8%</td>
<td>8.6%</td>
</tr>
<tr>
<td>6</td>
<td>3.75</td>
<td>41.2%</td>
<td>22.8%</td>
<td>36.0%</td>
</tr>
<tr>
<td>7</td>
<td>3.65</td>
<td>73.6%</td>
<td>15.5%</td>
<td>10.9%</td>
</tr>
<tr>
<td>8</td>
<td>2.96</td>
<td>71.5%</td>
<td>21.2%</td>
<td>7.3%</td>
</tr>
<tr>
<td>9</td>
<td>2.94</td>
<td>48.1%</td>
<td>41.3%</td>
<td>10.6%</td>
</tr>
<tr>
<td>10</td>
<td>3.14</td>
<td>59.3%</td>
<td>30.7%</td>
<td>10.0%</td>
</tr>
<tr>
<td>Average</td>
<td>3.44</td>
<td>63%</td>
<td>24.7%</td>
<td>11.83%</td>
</tr>
</tbody>
</table>

A heat map represents the complex view of the interaction between human and vehicle. Eye-tracking heat maps visualize the most attractive components or segments of the research environment on how many times a particular section was looked at and for how long. A heat map shows a visual representation of aggregate tested subjects’ engagement. A warmer colour denotes higher engagement, and a cooler colour means lower visitor engagement.

**Fig. 8 Heat map and Focus map of the cockpit environment**

Another way how to present the complex data is a focus map. Focus maps visually “invert” heat maps to enable the visibility of the areas of viewer attention [4]. The areas shown on the focus map represent those parts of the cockpit environment that were seen by the test subjects (see Fig. 8). We can confirm that front windows and dashboard in the cockpit environment were highly visited during the experimental study.
5. Conclusions

The aim of this article was to perform and evaluate experimental testing of the driver-vehicle interaction in simulator conditions using eye-tracking technology. Despite the limitations associated with the COVID-19 pandemic (number of subjects tested), the proposed target was achieved. In the measurement, we focused on the driver-vehicle interaction in crisis situations. The measurement results point to two crucial facts - the importance of driver crisis management experience and the need for proper driver dashboard design. The importance of the dashboard and its ergonomic design is represented by AOI dwell time. The tested subjects paid attention to this area for a quarter of the duration of the crisis situation.

The number and length of fixings also underline the need for their ergonomic design on the components of the vehicle's cockpit. It is these indicators that point to the higher requirements for the cognitive functions of the tested subjects. We assume that the user-oriented design of the dashboard would lead to a reduction of attention to this part of the vehicle's cockpit and thus would transfer more attention to the area in front of the vehicle. The authors want to address this particular area in their future scientific work.

As the crisis situations were evaluated using eye-tracking technology and according to the sound recording from the camera placed on the ETG, it is possible that in some cases, there was a slight deviation in the measurements. This deviation may be of a maximum of five-hundredths of a second, which does not affect the conclusions obtained from the experimental measurements.

Acknowledgement

This publication was realised with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

References

All-purpose Interface Model Between Interlocking System and Line Block System

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Abstract

The paper is the result of the implementation of the project stage titled “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).

The interface between the interlocking system and the block system is a “place” prevailing on the PKP PLK S.A. network. Due to the significant impact on the safety of railway traffic and the large number of different technical solutions used on the railway network, standardization of this area will allow ensuring safety and functionality in the control subsystem. Standardization of selected interfaces of railway traffic control systems may be used in the implementation of the modernization of railway networks to a limited extent, e.g. modernization of a single route or a single station.

The paper presents the functional definition of the universal serial IXL-LB interface intended for use in computer railway traffic control devices. In accordance with the adopted assumptions of the project, the developed IXL-LB interface standard will make it possible to connect technical solutions of interlocking systems and block systems of various manufacturers and different types. Concepts of the general model of the interface between the interlocking system and block system are presented. For the purpose of modeling interfaces, a model of structures and data exchange between related systems was developed. The object model of railway traffic control devices presented in the work is only an example of an area of implementation of interface standards.

KEY WORDS: control command systems, digital interfaces, safety data transmission

1. Introduction

The rail market is becoming more open and the number of manufacturers of rail traffic control equipment and systems is growing rapidly. Currently, there is no comprehensive standardization, both in terms of requirements and specifications for the use of interfaces in rail traffic control systems. This problem is faced by both designers, contractors involved in the implementation of these systems and infrastructure managers. In order to fill the existing gap in this field, a project has been undertaken to develop a scope that can be used as an effective tool for organizing the use and interconnection of rail traffic control devices in a fully practical way.

The project described in this article, under the name of “Standardization of selected interfaces of railway traffic control equipment and systems” POIR.04.01.01-00-0005/17, has been created as part of the BRIK (Research and Development in Railway Infrastructure) program and has been co-financed both by the NCBiR (The National Centre for Research and Development), as well as the PKP Polskie Linie Kolejowe S.A. (PKP PLK - Polish State Railways) - which is a dominant operator of the railway in Poland.

The aim of the project was to develop the requirements and specifications for interfaces used in computer traffic control devices. For this purpose, research and tests were carried out, the results of which allow verifying the correctness of the adopted main research assumptions. The result of the work may be a guiding document, which would include standards, requirements and recommendations for the design and implementation of combining various types and different manufacturers of railway traffic control equipment and systems [10].

The article presents a functional definition of the universal serial IXL-LB interface intended for use in computerized railway traffic control devices. In accordance with the assumptions of the project, the developed IXL-LB interface standard will make it possible to connect technical solutions of interlocking systems and line blocks of various manufacturers and different types. Concepts of the general model of the interface between the dependence station devices and the line block are presented. For the purpose of modeling interfaces, a model of structures and data exchange between related systems was developed. The model of railway traffic control objects presented in the work is only a translation of the area of implementation of interface standards.
2. Interface Definition and Scope of Application

The concept of an interface is commonly used in normative documents and acts concerning the rail system, i.e. the Regulation on interoperability [3], the technical specification for interoperability of the rail system [2], the regulation on admitting certain railway structures, equipment and vehicles [4].

The term "interface" is commonly used in contexts relating to a wide variety of science (e.g. railways, IT, etc.) and may be confused with the term "linkage". A linkage is a system that uses device interfaces and additional intermediaries (hardware or software, standard or nonstandard). In the rail system, devices can cooperate with each other by means of interfaces or links. The issue of cooperation of computer devices and railway traffic control systems by means of a link is not the subject of this paper. The two examples presented below confirm how different the contexts of using the concept of interface can be.

The definition of "interfaces" in the CSM Regulation [1] defined as "all points of interaction during the life cycle of a system or subsystem, including maintenance and operation, where different subject of the rail industry work together to manage risks".

Whereas, the Directive on the legal protection of computer programs [5], in recital 10, uses the concept of "interface" as follows: The role of a computer program is to come into contact and interact with other computer system components and users. For this purpose, logical and, where appropriate, physical interconnection and interaction are required to allow all elements of software and hardware to function with the other software, hardware and users in all the forms of activity for which they are intended. The parts of the program that enable such interconnection and interaction between elements of software and hardware are generally known as "interfaces". This functional interconnection and interaction is generally known as "interoperability"; while "interoperability" itself can be defined as the ability to exchange information and make comprehensive use of the information already exchanged.

The above description concerns computer systems (or information technology devices) and could be used in the railway industry in relation to the scope and principles required for the correct cooperation of various computer systems of rail traffic control. However, as a definition it is too specific in its form, and in our case it is more helpful in defining an interface scope.

The above examples show the places of impact (interaction), the rules of conduct and the goal to be achieved as a result of the implementation of the interface definition.

2.1. Interface Definition in the Context of the Project

Bearing in mind the above-mentioned terms of "interface" and "linkage", as well as the aim of the project in the form of standardization of selected computer interfaces of railway traffic control systems and devices, the definition of "interface" has been formulated, taking into account some features of the interfaces already used on the PKP PLK S.A. railway network. (also European). Thus, the implementation of the interface cannot negatively affect its features defined in accordance with RAMS (Reliability, Availability, Maintainability and Safety) (PN EN 50126 [6] standard), and the specification of the data exchange protocol is to ensure the functional needs of the application area, such as system classes, level SIL safety integrity and security of access to data of cooperating traffic control systems (devices). The standardized interface is to ensure full compatibility of the systems and the elimination of systems or elements intermediating in their cooperation.

The definition of the interface adopted in project [9] says that it is: "the system of inputs and outputs of a given device (system, subsystem) together with the signals transmitted by them and the corresponding logic and sequences of the device's operation, enabling connection and cooperation between this device and another device ". This definition is complete, i.e. it defines the purpose of the interface and its elementary components related to the processing of process data (sequences of actions, data exchange protocol) and structure (inputs, outputs being the sources of data to be exchanged) and does not refer to technology.

2.2. Description of the Interface in the Context of the Project

The definition of the interface has been formulated at a certain level of generality, therefore, for the needs of the interface implementation, its basic components relating to:

- Technical means of transport (transmission) of data.
- The way of data exchange.
- A set of data used in information processing, adequate to the defined functionality of cooperating systems.

These components are a set of variables describing the current state of the device or process or their control, in particular commands (commands, etc.) ensuring the implementation of the functionality provided for the technical solution. The interface description enables a rational approach to the interface scope problem, which is important of ensuring the required level of security or acceptable risk (by the system user).

2.3 The Scope of the Interface in the Context of the Project

Defining the interface scope is important and requires a comprehensive approach, first of all to ensure the safe operation of the interface itself and the devices (systems, programs) connected with it, i.e. a technical solution intended
for operation on the railway network. The interface connects functionally autonomous systems (devices), providing such a system with the implementation of extended functionality in relation to the scope implemented by one system. From the point of view of ensuring security for the assumed scope of performed functions, it is one of the links in the data processing chain (inputs - outputs). Therefore, the standardization of the interface and its implementation by various manufacturers, i.e. the interface scope must be related to its definition and set of features interfering with the process of data transmission and processing, which allows for hierarchical structuring of threats in relation to the scope of the processed data. Data using a process or structural approach to a system, subsystem or the interface itself. The interface scope relates to the following considerations [9]:

- The scope of data exchanged by the interface used by individual systems for their needs, divided into safe and non-safe related.
- Identification of threats, the source of which may be hardware damage and software errors in the communication system and their impact on the operation of other programs in the system, especially those that generate important decisions for the protection of train traffic.
- Risk reduction by mitigating the effects of dangerous failures to the level acceptable by the system user (maintaining the required system performance, throughput, information transfer time).
- Ability to obtain quantitative values of RAMS (Reliability, Availability, Maintainability and Safety) parameters of a technical interface solution that meets the acceptable risk level, taking into account the operating and environmental conditions affecting the equipment and the link [11].
- Assignment of the SIL safety integrity level to the interface for the calculated quantitative hazard index target (according to PN EN 50129 [7]), and obligatory techniques and methods for this SIL in terms of software development (according to PN EN 50128 [8]).

The definition of the interface and its scope supplemented with a detailed and unequivocal description in order to implement the hardware and software implementation allows for a structural, hierarchical approach to the analysis and monitoring of threats, which is important during the product operation and maintenance phase.

3. General Model of the Interface, Structures and Data Exchange Between the Line Block and Station Devices

In this chapter, the specification of the interface model will be presented in the form of a description of the interface model, data structure model and data exchange, adopted in the interface standardization concept. The functional definition of the line block, from the point of view of completeness and keeping the universality of the solutions proposed below, assumed that the LB line block devices define the LB-IXL interlocking interface configuration, and dialogue station devices are their consumers.

3.1. Interface Model Specification

The theoretical general interface model is an machine that converts a set of input data into output data according to the scheme presented in Fig. 1.

![Fig. 1 Data flow in the general model](image)

The input data are:
- elements (objects);
- states of elements (objects);
- commands to elements (objects).

The output data are:
- elements (objects);
- states of elements (objects);
- commands to elements (objects).

Due to the direction of data processing, the machine can be distinguished:

a) processing data from free form to standard form – A;

b) converting from standard to free form - B.

Data in free form are sets of elements and states in a form appropriate for a given type of device (system). Standard data are sets of elements and states in a standardized form according to the rules defined within the project.
In the standard data model, the data stored in the database used by the machine were divided into [9]:

- constant (generic) - established for a given type of device / system, which include:
  - types of elements (objects);
  - functional features of individual types of elements (objects), i.e. bits; the bits can take different states at a given moment, i.e. the values "0" or "1";
  - types of orders for particular types of elements (objects).
- variables (application) - specific to a given interface application, which include:
  - specific elements (objects, e.g. individual external devices);
  - specific states of individual functional features (bits) of elements (objects);
  - specific orders to elements (objects).

Standard form data can be stored in a tabulated form, but two types of data processing tables should be distinguished [9]:

- translation table of types and functional features (bits) and orders to elements - a constant for a given type of device / system;
- element translation table - depending on the given interface application.

The translation of the elements into a form suitable for the data receiving system may be performed in only one machine. The data flow and translation interface model is shown in Fig. 2, while Fig. 3 shows the element type translation model.

3.2. LB-IXL Interface Model

At the beginning of the specification, the method of numbering line block and standardized nomenclature of interfaces to other devices and systems were defined. A way of distinguishing in the addressing of A and B channel devices and interface data receiving and transmitting ports was defined, LB line block - IXL interlocking system. Data exchange is carried out using the UDP IP4 protocol in both directions, and each device working in the network has a unique IP address. Line block communicates with other systems over a single transmission channel containing the agreed data from channel A, B and, if present, channel C. Line block transmits its states as broadcasts, but may be
configured to transmit states to more than one receiver. The data exchange between the line block and the external interlocking system is best illustrated as an internal state exchange. The length of the transmitted frame results from the configuration data. Receiving a frame of a different length than that saved in the configuration data results in the rejection of the telegram.

Below (Fig. 4) there are examples of the states of functional features (bits) of elements in the traffic control system and their imaging adopted in the interface simulator between the interlocking station devices and the LB-IXL line block.

![Fig. 4 A screenshot of the LB-IXL simulator elements states window (interface between interlocking station devices and the line block) [9]](image)

In the presented example (Fig. 4), the type of the object is the section behind the IT_SEM entry semaphore. This element is described by two functional features (bits):
- 0x1D Free
- 0x7A Occupied.

Each bit can take one of two states: "0" or "1". The section cannot be free and occupied at the same time, therefore only combinations of states can be considered correct:
- 0x1D Free = 1 and 0x7A Occupied = 0
- 0x1D Free = 0 and 0x7A Occupied = 1

Table 1 presents the list of possible states of the functional features (bits) of the IT_SEM element in the system:

<table>
<thead>
<tr>
<th>Element 1: IT_SEM</th>
<th>Bit 1: 0x1D Free</th>
<th>Bit 2: 0x7A Occupied</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&quot;1&quot;</td>
<td>&quot;0&quot;</td>
<td>the section is unoccupied</td>
</tr>
<tr>
<td></td>
<td>&quot;0&quot;</td>
<td>&quot;1&quot;</td>
<td>the section is occupied</td>
</tr>
<tr>
<td></td>
<td>&quot;0&quot;</td>
<td>&quot;0&quot;</td>
<td>incorrect state</td>
</tr>
<tr>
<td></td>
<td>&quot;1&quot;</td>
<td>&quot;1&quot;</td>
<td>incorrect state</td>
</tr>
</tbody>
</table>

The figure (Fig. 5) shows an example of the RESET_LOSI_SPC_OK command (axle counter reset) issued to the STC_L_TOR_SEM element (section after the entry semaphore).
The interface model described above was implemented in the test environment and was a tool for conducting tests aimed at confirming the assumptions adopted by the authors (functional specification) under simulation conditions. Positive test results will form the basis for carrying out tests in real operating conditions of railway traffic control devices at selected operational research area of PKP PLK S.A.

4. Conclusions

The solution presented in the article is a completely new approach to the problem of connecting devices and railway traffic control systems on the PKP PLK S.A. network, which will allow being combined into one coherent system. It will allow the exchange of information in an uninterrupted way between systems of different types and manufacturers without the need to modify these systems, and it will not require the use of additional intermediary elements.

The implementation of an open protocol on the Polish railway network that defines: the method of data exchange, physical and logical parameters of transmission links as well as data processing and security algorithms will reduce the implementation and operational problems of the systems and, consequently, lower implementation costs.

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Tourist Business – Driver of River Passenger Transport Development in Ukraine

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Abstract

Peculiarities of river passenger transport function in Ukraine with the help of the international experience for tourist business functioning needs are revealed. Based on a comparative analysis of river passenger traffic in European countries, it is proved that the development of tourism is a generator for demand within the end-to-end passenger traffic concept, and within Ukraine - also local passenger traffic use rivers and reservoirs potential. The structural potential of Ukrainian rivers for passenger transport in the tourism business is revealed and the following river transport models use are identified: updated role and alternative / supplement to other public transport types; updated role and tourist recreation development component; inland waterways use for expansion of residential areas (placement of floating structures on the water or on the lands of the water fund).

The modern concepts of the Ukrainian passenger river transport development in the terms of essential generation of tourist demand in competitive advantages and multiplicative effect of river tourism are actualized.

KEY WORDS: tourist business, river passenger transport, tourist vacation, potential of rivers, tourist demand, river passenger traffic.

1. Introduction

The modern trends of inclusive development and behavioral economy, globalization and competition have a dominant influence on the supply formation of river tourist transport services, thus affecting the economic growth and sustainable development of areas which are adjacent to river transport.

In practice, authors are of the opinion that the increase of river passenger traffic in Ukraine is possible when the territories which are adjacent to the rivers will complementary develop. The determining factors are the freight transportation and related industries intensification, as well as the development of the tourism sector. Investments in river infrastructure and supra-infrastructure will contribute to the river shipping routes restoration and the river ports operations. Furthermore, since in foreign markets the tourist segment plays a leading role in sea passenger transportation and is accepted as a component of the cargo segment, passenger seaports can become components of port transport and logistics clusters, which can subsequently be connected by river ports with the river-sea vessels “sea-river” participation. Main growth factors can be considered an increase in demand for cruise transportation, the implementation of the country’s tourism, recreational potential so on. This also testifies to the untapped potential of river ports as a component of expanding the tourist passenger transportation geography.

The river passenger tourism sector development is under the active influence of information and communication technologies and behavioral economics.

2. Methodology

The suggested study hypothesis by authors about the formation of river tourism multiplier effect which is based on the influence factors of the external and internal environment of river transport for the tourism sector needs.

As hypothesis of the basic level was presented as: the river passenger transport development is motivated by rational consumer behavior (according to which the main criteria for choosing a transport are cost and time) at the level of other passenger transport types in Ukraine.

During the study, the basic hypothesis was rejected: for objective reasons, river passenger transport (territorial accessibility which is limited by navigation, adverse weather conditions (drought), river shallowing, navigation period, etc.) cannot compete with road and rail transport. Consequently, river transport benefits should be identified by providing value parameters to the client. This enabled to identify lower-level hypotheses.

Hypothesis 1 (additional). It shows how the decision according to the basic hypothesis influenced the prospects for the river passenger transport assessment development:

a) external complementarity, namely, the freight river transport development will create favorable conditions, including infrastructure and supra-infrastructure for passenger river transport restoration; internal passenger formation
unified system transportation in Ukraine: online booking, support service, information board, etc. in the transportation system with of various types of transport involvement will have a positive impact on the demand for river transportation recreation, and consequently, on the river passenger transportation growth in the through passenger transportation system;

b) internal complementarity, namely, the provision of clear features of positioning river transport by activating the irrational consumer behavior on this transport associated with tourism, recreation, accommodation / recovery on ships-hotels / sanatoriums, receiving additional emotions, ecological recreation and other value parameters, which is considered a significant determinant of the river passenger transport development.

Concepts for the Ukrainian river passenger transport development were formed by generating tourist demand in various Ukraine territories. Analysis of potential generating tourist demand in Ukraine has proved the high hypothesis requirement for outing tours for Ukrainians.

The structural potential of Ukrainian rivers for passenger transportation in the tourism business was successfully revealed and such river transport models use were identified. 1. Renewed role and alternative / supplement to other public transport modes. 2. The renewed role and tourist recreation component development. 3. The inland waterways use for the residential areas expansion (floating structures location on the water or on the water fund lands).

3. Results

A. Literature Review

In the work the mechanism for cooperation between operators of urban passenger water transport with local authorities on the basis of public-private partnership (mechanism) is developed. The mechanism has been tested on the example of urban passenger transportation by water transport in Kyiv in two directions: the route transportation and the transportation by order. The provision of business profitability to private operators in the amount of 16-21% will provide the economical effect. The local budgets will receive additional income in the form of concession payments. A positive social effect is expected from the development of urban passenger water transport and transparency of relationships between private transport operators and local authorities.

Such prominent authors as Nezdoiyminov and Milashovska (2019) investigated the state of the Ukrainian water travel market functioning, which affects the development of the recreation and tourism in Ukraine sphere [9]. The directions for the development of the river travel and cruise tourism are proposed. A set of measures, which ensures the activation of tourist transportations by the river transport enterprises in water regions is proposed.

Modern processes of organizing tourist trips by waterways, socio-economic, environmental and cultural problems of river cruises were studied by Nasir, F. M. and Hanafiah, M. H. (Mohd Nasir and Hanafiyah, 2017) [8]. The cruise tourism influence on the economic development of territorial communities was analyzed by the authors T. McNeill, D. Wozniak (MacNeill, Wozniak, 2017) [7].

Authors Dradin, Jovičić, and Bošković (2010) investigated market trends in river cruises, impact of pricing policy on ensuring the competitiveness of tourism enterprises, supply and demand factors in potential segments in terms of travel safety, etc. [2].

The study of the spatial and geomorphological limitations of the geographical space in the ports functioning during river cruises was carried out by Tsotas, Niavis, and Sdrolias (2018) [11].

In study (Kaup, Lozowicka, 2018), in order to increase the competitiveness and attractiveness of inland waterway transport in relation to other types of transport, the results of a consumers survey about river transport services are presented. On their basis, two concepts of internal passenger transport (tourist and cruise transport) were formed for further use in the Oder River basin) [5].

Also, the service factors influence on the consumers satisfaction level of river transport services is considered as an important component of the passenger transport development, both in terms of planning the future water transport network (new routes and locations of terminals), and in relation to the growth in demand for river transport by increasing the level of service, global satisfaction with the river transport consumer value (Tanko et al., 2019) [10].

The work by (Nezdoiminov, Andreeva, 2017) investigated the state of Ukrainian passenger tourist traffic by water transport. The problems with water passenger transportation were identified as factors of influence on the development of the tourist flow in the regions of Ukraine. Economic instruments are proposed to ensure the development of the cruise tourism sector and the provision of services to tourists [14].

Such works as (Krykovskiy, Shandrivska, Shynkarenko, 2020) identify the main factors in the choice of river transport by consumers, which include the following: obtaining new emotions and additional aesthetic pleasure, the ability to combine a business trip with an excursion, environmental friendliness and safety of transport. This emphasized the need to develop river transport for the travel purpose, and then to activate such behavioral factors as the river transport choice, such as an interesting route, excursions while driving and the developed port infrastructure presence during stops. The effect of the tourist model introduction “3xE”, according to the authors, should be territories expansion in which tourism develops, and the creation of new tourist zones (attractions) [6].

The problems of studying the behavioral factors of the river transport choice by end users in Ukraine, the geography of tourist travel development and regular transport in Ukraine. Therefore, they became one of the directions of this research.

B. Comparative Country Analysis: Assessment of Tourist River Passenger Traffic

Worldwide dissemination of globalization and informatization testifies lower involvement of the tourists from EU countries in river tourist passenger flows, namely regarding the freight transport use of these countries on rivers and to
sea tourist passenger traffic. The EU countries peculiarities are that the internal water network is unevenly allocated over the territories of the countries, in some regions there are fully unnavigable inland waterways, in others there is a long network with a high density. For instance, a high density, over 200 km / 1000 km², is shown in eight regions of the Netherlands. In Berlin the network density is 190 km / 1000 km² and is formed mainly from canals, in Bremen the network density is 145 km / 1000 km², which consists of rivers. The regions of Hamburg and Schleswig-Holstein also have a dense network of 70 and 47 km / 1000 km² respectively, in both cases mainly consisting of rivers. Other regions with a dense network of inland waterways (km / 1000 km²) are in the Czech Republic (Prague: 65), Hungary (Budapest: 57) and France (Nord-Pas-de-Calais: 54, Ile-de-France: 53). The territory of Ukraine is characterized by an average density of river roads at the level of 3.52 km / 1000 km², which is significantly inferior to other countries. With the increasing density of the river network, the potential for attracting tourists by river transport is growing.

For example, in Poland there is a stable positive dynamics in the development of passenger traffic during 2014-2018. This means that there is a sufficient margin for the development of such business (Table 1).

Table 1

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The number of passengers carried, thousand</td>
<td>1038.2</td>
<td>1097.0</td>
<td>1277.6</td>
<td>1262.1</td>
<td>1395.3</td>
<td>1.34</td>
</tr>
<tr>
<td>2</td>
<td>Passenger turnover, thousand passengers km</td>
<td>12936.8</td>
<td>14161.0</td>
<td>16651.7</td>
<td>17765.3</td>
<td>18350.9</td>
<td>1.42</td>
</tr>
<tr>
<td>3</td>
<td>Average passenger transportation distance, km</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>14</td>
<td>13</td>
<td>1.08</td>
</tr>
<tr>
<td>4</td>
<td>Passenger rolling consistency, units</td>
<td>99</td>
<td>101</td>
<td>110</td>
<td>117</td>
<td>123</td>
<td>1.24</td>
</tr>
<tr>
<td>5</td>
<td>The number of passenger seats, units</td>
<td>8434</td>
<td>8698</td>
<td>9528</td>
<td>10322</td>
<td>10926</td>
<td>1.30</td>
</tr>
</tbody>
</table>

Source: systematized based on [4]

For international tourist passenger transportation by river transport, the following features are characterized:
- significant seasonal fluctuations in the demand for transportation, despite the efforts of travel companies to extend the navigation season during the winter period;
- change in the age category of the travelers: an increase in the share of consumers aged 26-40 by more than four times (up to 8.3% in 2018 against 2% in 2017);
- an increase in the share of German tourists aged 41-55 from 11.8% to 18.3%;
- higher rates of development of the premium tourist segment of passenger transportation relative to the luxury and ultra-luxury segments. For example, an increase in demand in the premium segment from 39.4% in 2017 to 45.6% in 2018 was fixed in Germany, while the market share of the luxury and ultra-luxury segment (together) drastically grew from 6.3% in 2017. up to 14.3% in 2018;
- the increase in demand in 2018 was set: by consumers from Asia, Russia, Scandinavia and Eastern Europe – growth by 41%, Great Britain and Ireland - by 31%, America – by 14.3% and Germany - 14.7% respectively.

C. Comparative analysis of passenger traffic on the Danube River

In the context of considering the concept of end-to-end transportation and Ukraine's participation in it, it is quite relevant to conduct a comparative analysis of the passenger transportation segment in countries that are located near the river Danube (Table 2).

Table 2

<table>
<thead>
<tr>
<th>Nr</th>
<th>Indicator</th>
<th>Total</th>
<th>Ukraine</th>
<th>Romania</th>
<th>Bulgaria</th>
<th>Hungary</th>
<th>Serbia</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Number of ships for passenger, units</td>
<td>194</td>
<td>6</td>
<td>6</td>
<td>14</td>
<td>102</td>
<td>12</td>
<td>54</td>
</tr>
<tr>
<td>2</td>
<td>Number of passenger seats on the ship, places</td>
<td>33321</td>
<td>1167</td>
<td>1296</td>
<td>1675</td>
<td>13980</td>
<td>1422</td>
<td>13781</td>
</tr>
<tr>
<td>3</td>
<td>Number of carried passengers within the country, thousand people</td>
<td>1390</td>
<td>4</td>
<td>133,5</td>
<td>5</td>
<td>1289</td>
<td>92</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>Number of transported passengers overseas, thousand people</td>
<td>129</td>
<td>11</td>
<td>-</td>
<td>89</td>
<td>0</td>
<td>29</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Passenger turnover (realized within the country), thousand passengers km</td>
<td>18273</td>
<td>219</td>
<td>0,5</td>
<td>-</td>
<td>16874</td>
<td>1180</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Passenger turnover (realized overseas), thousand passengers km</td>
<td>20523</td>
<td>12836</td>
<td>-</td>
<td>-</td>
<td>53</td>
<td>7634</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Average passenger transportation distance (within the country), km</td>
<td>13.15</td>
<td>54.75</td>
<td>0</td>
<td>-</td>
<td>13.1</td>
<td>12.83</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Average passenger transportation distance (realized overseas), km</td>
<td>159</td>
<td>1167</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>263.24</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: systematized based on [13]
An analysis of Table 1 showed that the largest number of vessels is in Hungary (102 vessels) and the Federal Republic of Germany (54 vessels), Ukraine and Romania have only 6 vessels, respectively. The greatest number of passenger seats on the ships is in Hungary (13980 seats), while Ukraine has the smallest number of passenger seats in ships - 1167 seats. The number of passengers carried in Ukraine is the smallest in comparison with all the analyzed countries: within the country are 4 thousand people; in foreign voyages are 11 thousand people. The table above shows that in Hungary, passenger transportation distance within the country is carried out over short distances - 13.1 km, but in Ukraine the average distance of transportation distance within the country is the largest - 54.75 km. A similar situation is observed when transporting passengers in foreign voyages - in Ukraine it is the longest (1167 km).

The analysis of the dynamic of the river traffic allows us to claim that by further stimulating of the development of tourism activities in the EU countries, the generation of the tourist demand, expanding of the transportation geography and organizational forms of activity are expected, including the involvement of various types of transport. By application of the method of integration of the transportation process, which is used in freight transport, the formation of an integrated demand for overland travel along with sea and river travel is expected. Due to expansion of the supply of passenger transportation on certain river areas on the part of interested stakeholders, an increase in demand for point (local) regular and tourist river passenger transportation is expected.

D. Analysis of the Ukrainian segment of river passenger transportation

The integration of the passenger transport of Ukraine along with the existing international transport corridors into interstate transport passenger flows testifies to lower involvement of Ukrainians into international and domestic water passenger flows relatively to the volume of passenger flows in the country (Table 3).

### Table 3

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The number of passengers carried, thousand</td>
<td>550.8</td>
<td>448.5</td>
<td>562.9</td>
<td>596.2</td>
<td>590.0</td>
<td>1.071</td>
</tr>
<tr>
<td>2 Number of trips per person, trips</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>3 Passenger turnover, thousand passengers/km, including:</td>
<td>8040.5</td>
<td>12554.1</td>
<td>19567.1</td>
<td>25511.7</td>
<td>24462.5</td>
<td>3.042</td>
</tr>
<tr>
<td>-international traffic</td>
<td>2682.1</td>
<td>7813.2</td>
<td>12836.0</td>
<td>17354.4</td>
<td>16501.3</td>
<td>6.152</td>
</tr>
<tr>
<td>-internal message</td>
<td>5358.4</td>
<td>4740.9</td>
<td>6731.1</td>
<td>8157.3</td>
<td>7961.2</td>
<td>1.486</td>
</tr>
<tr>
<td>4 Average passenger transportation distance, km.,including:</td>
<td>15</td>
<td>28</td>
<td>35</td>
<td>43</td>
<td>41</td>
<td>2.733</td>
</tr>
<tr>
<td>-in international traffic</td>
<td>1788</td>
<td>1132</td>
<td>1146</td>
<td>1181</td>
<td>1123</td>
<td>0.628</td>
</tr>
<tr>
<td>5 River vessels, units, including:</td>
<td>1321</td>
<td>1312</td>
<td>1401</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-passenger units</td>
<td>151</td>
<td>151</td>
<td>166</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6 Density of shipping lanes, km of lanes per 1 thousand km² of territory</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>7 Passenger traffic intensity, mln.pass.km per 1 km of track length</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>8 Exploitation length of river waterways, thousand km</td>
<td>1.6</td>
<td>1.6</td>
<td>2.1</td>
<td>1.9</td>
<td>1.9</td>
<td>1.188</td>
</tr>
</tbody>
</table>

Source: Systematized based on [12]

According to the analysis above, the number of passengers carried in 2019 reached up to 590 thousand people and 107.1% of 2015. Number of trips per person per year for the period 2015 - 2019 hasn't changed either. By the growth of the transport work of this transport in 2015 - 2019. (the rate of growth for this period counted up to 304.2% in 2019 or 24462.5 thousand pass-km), the average distance of passenger carried increased from 15 to 41 km. An improvement in the transport work of this transport in 2015 - 2019. (the rate of growth for this period counted up to 304.2% in 2019 or 107.1% of 2015. Number of trips per person per year for the period 2015 - 2019 hasn't changed either. By the growth of tourism business enabled it to identify next.

E. Study of the structural potential of the rivers of Ukraine by their use for passenger transportation in the tourism business

The study of the structural potential of the rivers of Ukraine by their use for passenger transportation in the tourism business enabled it to identify next.

1. On the Dniester River, the potential implementation for the end-to-end passenger transportation development using river transport is quite possible in the following river sections:
   - upstream of the Dniester (Moldova) to Vadul-lui-Voda, under conditions of (potentially) deepening of the river bed and deepening of the fairway along the entire length of the Dniester from Dubossary HPP to the Black Sea in order to use additional navigable capacities of small displacement, especially in conditions of Ukrainian control of the upper and lower reaches of the river;
   - downstream (Ukraine) to the Black Sea resorts of Serhiivka and Zatoka on ships of small displacement; on ships of the "river-sea" type calling at the seaport of Odessa. Decrease in passenger traffic at the terminal of the Odessa port for the period 2011 - 2020 from 122 ship calls to 22 (potentially) and its use at the level of 3.5% do not contribute to
the development of this direction of transportation;

- Dniester estuary for passenger transportation by motor ship along the route Belgorod-Dnestrovsky - Ovidiopol - Zatoka;
- on ships of the "river - sea" type calling at the seaport of Constanta (Romania);
- on ships of the "river - sea" type calling at the seaport of Varna, (Bulgaria);
- on ships of the "river - sea" type with a call at the seaport of Istanbul, (Turkey) with the prospect of its transformation into a special cruise port - a logistics hub for cruise liners. The port's potential passenger traffic is expected to be 2.5-3 million cruise ship passengers. The port infrastructure will allow 8 cruise ships to dock at the same time, the total length of the docks will be 3 thousand meters, 30 thousand square meters. meters of space will be allocated for the stay of passengers, 120,000 sq. m will be allocated for sea terminals;
- on ships of the "river - sea" type calling at the seaport of Novorossiysk (RF). In the conditions of the Russian Federation conducting a hybrid war on the territory of Ukraine, the development of this direction of passenger transportation is not expected.

2. The Danube River and its navigable tributaries. The efficient multimodal terminals construction in river ports along the Danube, which is designed to effectively combine inland waterways, railways and highways, on the one hand, and the Danube-Black Sea deepwater project implementation on the other, are factors in promoting river passenger transport. However, the indicated transformation processes in the Danube delta caused a runoff redistribution between the Kiliysky and Tulchinsky branches of the river, which led to a shallowing of the Kiliysky branch, water loss in the Ukrainian part of the Danube at the level of 40 cubic km per year, the impossibility of year-round navigation. The location in the Danube basin of 9 EU countries (Austria, Bulgaria, Czech Republic, Germany, Hungary, Romania, Slovakia, Slovenia and Croatia), Serbia and four regions of Ukraine (Odessa, Chernivtsi, Transcarpathian and Ivano-Frankivsk regions) should also be considered as a source of demand formation for river transport and a factor in promoting international cross-border cooperation in the development of tourism, and then transport and information infrastructure of the region. The modern river cruises development on the Danube, which is carried out by PJSC "Ukrainian Danube Shipping Company". During navigation 2016, 48 flights were carried out and more than 7 thousand Europeans were transported; in 2018 - 100 cruises were carried out and more than 12 thousand Europeans were transported. The international tourist route organization from Romania - "Izmail - Tulcea" and "Reni - Galati" by the motor ship "Synevyr" and the opening of local routes in the cities of Izmail, Reni, Vilkovo are seen as promising. The attempt of Ukrainian transport agencies to engage the segment with elder people was failed because of their low solvency. Therefore, the Ukrainian river cruise segment could potentially consist of foreign tourists traveling to the Ukrainian delta of Danube and Izmail.

3. Development of river navigation on the rivers Pripyat, Southern Bug. Dnieper is permanently related to the implementation of the E40 project, which should connect the Baltic and Black seas along the route Gdansk (RP) - Warsaw (RP) - Brest (Belarus) - Mozyr (Belarus) - Kyiv (Ukraine) - Kherson (Ukraine) with a path length of about 2250 km. The potential of river transportation can be unlocked because of the transportation from the Black Sea ports up the Dnieper. A significant driver of passenger traffic growth on the river. The Dnieper is a supplement in the transit of goods from Belarus, which has its own river fleet (potentially, as well as Turkey, Georgia). Along with the increase in freight traffic on this section, it is advisable to pay attention to the development of the tourism business using river transport.

2020 witnessed such an element-wise development of the tourist river segment in certain sections of the Dnieper and the river Pripyat: a river tourist route is organised. Dnieper and river Pripyat on the route Kyiv - Mozyr - Kyiv using the vessel "Rassvet", which belongs to the State Enterprise "Administration of river ports" and inspection of the Chernobyl nuclear power plant; in Kyiv, the pleasure tourist motor ship "RIVEREST-4" is used; in the city of Mykolaiv, passenger transportation by river transport is organized on the line "Cabotage ml - Malaya Korenikha", which can be used as part of walking tourist trips etc. Regular water passenger transportation along the Dnieper and the Southern Bug is carried out along the routes "Golaya Pristan - Kherson - New Kakhovka", "Mykolaiv - Kinburnska spit - Ochakov", "Voznesensk - Kovalyka - New Odessa - Mykolaiv", there are walking routes in Mykolaiv and Kherson. Individual pleasure trips can be possible.

Moreover, the following point (local) passenger regular and tourist services along the Dnieper are subject to potential repairing, such as Kyiv-Kaniv, Kaniv-Cherkassy, Cherkassy-Chigiryn, Cherkassy-Kremenchug, Dnipro-Zapirizhia, Zapirizhia-Nikopol and other passenger services between Zhytomyr, Poltava, Dnipro, Donetsk and Zaporizhya regions along with the existing crossings in Kherson, Zapirizhia and Mykolaiv regions etc. The potential of passenger traffic can reveal the use for the purpose of passenger transportation and reservoirs: Dnistrovsky, Dniprovsky, Kremenchugsky, Kakhovsky, Kyivsky, Dniproderzhynsky, Kanivsky.

However, the implementation of these local transportations provides the river infrastructure and supra-infrastructure development for servicing passengers: (railway stations, berths, access roads, service and recreation establishments, inland waterways, including high-speed ones, etc.). For instance, river passenger traffic in the capital is limited due to the lack of sufficient places for disembarkation and embarkation in Kyiv (except for two equipped berths for the river station ships: on Poshtova street and near the Dnieper metro station). In Obolon district, Kyiv, there are restrictions on the ships passage. On the left bank of the Dnieper there are no places for disembarking and embarking passengers. The bottleneck remains the connections issue with other modes of transport (trolleybus, road, railway station). A similar situation is observed in Cherkasy, Kherson, Dnipro, Zapirizhia, Kremenchug and Mykolaiv, along with the uncompetitive pricing policy, the prerequisites for an increase in demand for river passenger transport are not formed, which should be the basis for the river transport resumption.
F. Concept for Ukrainian passenger river transport development in the context of generating tourist demand

Ukrainian river passenger transport by generating tourist demand should be considered as:

- as a supplement to the citywide, suburban and intercity transport network, as a tourist network. For example, potentially as part of the urban transport infrastructure in the city of Zaporizha, the commissioning of river pleasure trams between the urban-type settlement Strizhavka, and urban-type settlement Sabavir, river passenger transportation by high-speed hydrofoil boats "Nibulon Express" on the Dnieper and Southern Bug rivers (since 2017) has been restored, the services of which were used in 2017-2019 more than 75 thousand passengers;
- the complementary development factor of related and tangential industries: in shipbuilding: production of low-tonnage river craft for urban communication (Zaporizhia, plant "Analog") and recreational activities (Mykolaiv, shipping company "NIBULON"); ship repair industry; public food, etc.), stimulates employment and economic activity in the region, contributes to the tourism development in the structure of the gross regional product of the riverside regions;
- factor in the development of interregional cooperation due to the development of interregional tourist routes;
- a factor in solving environmental and the port regions economic problems through the use of electric motors on watercraft;
- a component in the forming end-to-end tourist traffic system (for land, sea and river travel) by generating tourist demand, expanding the transportation geography and tourist activity organizational forms.

As for social inclusion: it is proposed to widely involve the population in the use of the benefits that river tourist transport brings due to the general use of physical and social space, (due to territorial proximity to water bodies), involvement and participation of end users in decision-making regarding strategies and resources that are focused on target segments of river transport tourists, the use of value parameters to attract consumers and the river transport performance parameters.

The potential for generating tourist demand in Ukraine is demonstrated by its dynamics during the period 2000-2018, which indicates an increase in the total number of organized tourists who were provided with services in Ukraine during the period 2000-2019 (3.044 times more) According to the total number of tourists the travel quantity had been increasing during 2000-2019 mostly by outbound tourists. It means that foreign tours are in demand among Ukrainians, considering the begin of visa-free regime in 2017. The number of domestic tourists in the period 2000 - 2019 decreased significantly from 1,350,774 to 520,391 people (the growth rate for this period was 0.385). As a conclusion, there is a high demand for outbound tours for Ukrainians. The low need in travelling in Ukraine can be increased due to the tours marketing promotion, in particular, aimed at through travel by various transport modes by solvent target segments. The identification of these segments (both macro and micro) by features and the travel assortment proposals development for each of them requires a special study. A dedicated niche in end-to-end travel in the tourism business is occupied by river passenger transportation.

The value-based approach to the river transportation offer and the behavioral consumers characteristics should be determined based on the results of marketing research of target segments and identification of the passenger profile. The level of service, the ability to access hard-to-reach regions relative to other modes of transport (for example, on the Kinburn Spit, the extreme northwestern part of the Kinburn Peninsula between the Black Sea and the Dnieper-Bug Estuary), spatial and geomorphological restrictions and other factors can create a set of stable value preferences for river passengers.

The development concepts of the territories adjacent to the river transportation are considered. The authors of this study have formed such models of the use of river transport.

1. Renewed role and alternative / supplement to other modes of public transport.
2. The renewed role and component of the development of tourist recreation.
3. The use of inland waterways for the residential areas expansion (placement of floating structures on the water or on the lands of the water fund).

Let's consider these models in more detail:

1. Renewed role and as an alternative / supplement to other modes of public transport.

The goal is to increase the throughput and public transport productivity, unload road transport; to reduce the environmental load, to position river transport as a hub in the system of point (local) passenger river transportation and as a hub in through transportation with the land transport participation.

Competitive advantages: price competition of river transport due to the lower cost of transportation (for cruise transportation with high passenger capacity), safety of movement relative to other types of transportation, substitutional alternative in case of limited access to ground infrastructure.

According to this model of using river transport, it is advisable to single out:

a) route (regular) transportation:
   • urban: ferry crossings across the river (point, local transportation) and urban linear ferry systems (linear transportation);
   • suburban scheduled services: linear routes along water bodies and ferry crossings connecting the suburbs with city centers;
   • intercity ferry transportation: distance linear regular transportation, including ferry, linear transportation by hydrofoils, and the like;

b) transportation to order.

2. Renewed role and as an alternative / supplement to tourist recreation.
Purpose: meeting all the needs of the end users of river transport for recreation, comfort and service.

Competitive advantages: experience of using different from other types of transport, subject to spatial and geomorphological restrictions; service factors as an important element in the added value of travel.

According to the second model of using river transport, we have identified:

a) city river transportation, including water tram;

b) one-day cruises;

c) multi-day sightseeing cruises, including river rafting and swimming.

Positioning of tourist transportation of passengers from a marketing standpoint: the passengers tourist transportation should be considered as socially important services for the passengers transportation, in order to improve the quality of service up to the European level, including relatively comfort. It is expected that the provision of such services will be carried out on a contractual basis with the application of compulsory financial compensation to carriers and in compliance with the legislation on public procurement (in accordance with the draft law "On socially important services").

3. Use of inland waterways to expand residential areas.

The use of the provisions of the geographical analysis of the spatial evolution of urban settlement systems and urbanization processes, which form the basis of geo-urban studies, enable outline the latest trends in the globalization of the role of cities in the foci of adjacent territories. According to one of them, it is highly recommended to highlight the trend of transformation of the network of urban settlements into settlement systems, including attraction of territories adjacent to rivers into the sphere of influence of cities. It is also worth to note that the existing alternative concept of the formation of a settlement system based on the extraction of territories adjacent to rivers from the sphere of cities influence (secluded settlements), but these are isolated cases. At the same time, the spatial and geomorphological limitations of the territories adjacent to the rivers determine the specificity of such residential settlements.

Objective: To meet the growing demand for alternative housing.

Competitive advantages: price competition due to the absence of the need to purchase a land plot for housing; high mobility and self-expression.

According to the third model of using river transport, we have identified:

a) lacement of floating structures on the water:
   - placement of residential barges on the water;
   - arrangement of a floating craft for living quarters (for example, floating craft in Italy, France, Holland);
   - floating houses as an option for permanent housing (a town of 600 houses on the water near Amsterdam; floating houses in London on the Thames, placing most of the capital of one of the states of India on Lake Dal) for the location of hotels, entertainment complexes, restaurants, offices in them, and etc.

b) placement of floating structures on the lands of the water fund:
   - structures on piles in the water;
   - structures that are located on the shore near the water.

4. Conclusions

While researching, the basic hypothesis about the development of river passenger transport in Ukraine for the expense of stimulating rational consumer behavior, on a level with other types of passenger transport, was rejected. On the other hand, a hypothesis was put forward and tested about the complementary development of Ukrainian river transport, which is due to external and internal factors: the development of river freight transport, the formation of an end-to-end system of domestic passenger transportation based on an integral tourist offer (through and local traffic), which considers inland navigation as an important link in the tourist offer; appeal to the irrational behavior of the consumer of river transport; the participation of local authorities in positioning river passenger tourist transportation as socially important services for the transportation of passengers is an important component of tourism development and creates favorable conditions for the provision of a wide range of tourist services.

The representativeness of the results of the study about Ukrainian river passenger transport is proven by a comparative analysis of the segment of passenger transport by river transport on the example of countries that are located on the route of the Danube River. The analysis showed that in the context of further stimulating the development of tourism activities in the EU countries, it is expected to generate tourism demand, expand the geography of transportation and organizational forms of activity, including with the involvement of various types of transport. In the context of the application of the method of integration of the transportation process, the formation of an integrated demand for overland travel along with sea and river travel is expected. Despite the expansion of the supply of passenger transportation on certain river sections on the part of interested stakeholders, an increase in demand for point (local) regular and touristical river passenger transportation is expected.

As a summary, the current stage of development of Ukrainian river passenger transport requires urgent reform, reorganization and search for effective ways to restore passenger traffic, including for the needs of the tourism business. In particular, the processes of transformation of river passenger transportation require the implementation of the following means: the construction of regional route systems for passenger transportation by river and other modes of transport with the support of information and telecommunication technologies, the development of models for coordination of the operation of all modes of transport in the port regions, the study of patterns of formation of demand for river passenger transportation and determination of the capacity of the Ukrainian the passenger transportation market, assessment of its
main segments, including for the needs of tourism; increasing the efficiency of monitoring passenger traffic in river transport in the context of the development of information and communication technologies.

References


Public Financial Support to Aviation During the COVID-19 in the Baltic Countries

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Abstract

The paper analyses government financial support (state aid) arrangements to the aviation sector in the Baltic countries due to the COVID-19 pandemic situation. The support schemes include three main features. First, the design of public support schemes grounds on a standardized Keynesian framework of stimulation measures during economic recessions. Second, state aid is a rather sensitive issue in the European Union context. Support schemes are generally banned and strictly regulated even in the global pandemic situation. Third, stimulation measures depend on countries' capabilities to support their flag carriers. Which has a direct impact on the post-COVID-19 competition situation in the region. The paper focuses on comparative analyses of the scope of state aid in the COVID-19 situation in the Baltic Sea Region. In the frames of research is given an overview of stimulative instruments proposed by international aviation organizations. As a conclusion will be discussed motives to support aviation and stimulation schemes particularities.

KEYWORDS: Aviation; COVID-19; Baltic countries; EU state aid

1. Introduction

The aviation sector is one of the most suffered economic sectors during the COVID-19 pandemic period and following economic recession. The majority of economic indicators demonstrate a dramatic fall in aviation activities in 2020-2021 to compare with earlier years. By IATA, the aviation companies lost 118 billion dollars of revenues in a single year [9]. By the Airports Council International [3], the European airports’ revenues in 2020 were €30 billion lower than in 2019 or dropped more than 60% annually [3].

Aviation is a strategic industry, which often keeps together all economy’s fabric. The aviation sector itself employs 11.5 million persons worldwide and additionally induces a total of 87.7 million jobs [5]. The EU aviation sector supports almost 10 million jobs and €672 billion in European Union economic activity. That makes 4.2% of all EU jobs and 4.2% of its total GDP amount [6, p.3].

The aviation industry has also a large multiplier effect on job creation and provides an extensive economic boost to the whole economy [5]. Therefore, aviation stability and intensity is a crucial element to keep going many sectors of the national economies.

The current paper focuses on Baltic Sea Region countries' supportive measures (state aid) to air operators, particularly in the Baltic countries (Estonia, Latvia, Lithuania). To start with, there will be introduced Baltic countries air passenger turnover and flight intensity. For the Baltic countries, the efficient functioning of air connectivity is a vital issue. They are geographically located at the European Union peripheral borderline. The intensity of mainland infrastructure networks, connecting them to the European core, is still limited and underdeveloped. Aviation in those countries operates in rather tough conditions - air accessibility with major European destinations is an essential issue, but due to the limited size of passengers, it is difficult to gain scale economies and cost-efficiency. Such a situation puts the countries indeed in an unfavorable situation.

In the second part, the paper highlights a set of fiscal measures practiced, which governments have used to help their national air operators. Despite the several components of the air transportation system (e.g. air operators, airports, GH, MRO, others), our paper focuses on national flag air carriers only.

There is also an important issue that should be mentioned. In frames of the European Union, supporting particular air operators (or airports) is strictly regulated. The EU’s core principle is to maintain market competitiveness and avoid favorable treatment of own “national champions”, which may distort competition. For the air transport applies provisions of the Treaty on the Functioning of the EU), which in general, bans state aid to the economic establishments, if international competition may be harmed [20].

However, to avoid situations where regulatory requirements opposing economic (also human or social) necessity, the laws define circumstances in which state aid is allowed and do not contradict with TFEU. State aid to aviation (among others) may be provided “to stabilize the economy, prevent unemployment waves and provide immediate relief” [15]. The regulation logic comes from understanding that the collapse of flight activity may lead to further troubles, which dangers society’s vitality. COVID-19 pandemic is such an extraordinary situation, there EU recognizes the need for temporal relaxation of state aid strict requirements (see Section 3).

The third part of the paper is followed a specific set of state aid in the Baltic states in comparison with other countries in the region.
2. Baltic Aviation in General

As the Baltic countries' economic scope is limited in the European context and they locate outside of major vacation destinations, the air traveler’s capacity is relatively narrow. Despite the geographical closeness of the countries and proximity of population size and living standard, the countries aviation situation is somewhat different.

The biggest aviation center in the Baltic is Latvia (Table 1). Riga airport serviced almost 8 million passengers in 2019, which is double the amount compared with Estonia. During the COVID-19 pandemic situation, the aviation sector in the Baltic countries has declined dramatically. Passenger turnover decreased more than 70 percent and the number of served flights drop more than a half. Similarly with the global aviation situation, to survive troubling periods the Baltic aviation sector requires well-timed and targeted support from the governments.

<table>
<thead>
<tr>
<th>Baltic airports turnover</th>
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</thead>
<tbody>
<tr>
<td><strong>Number of commercial airports</strong></td>
</tr>
<tr>
<td>Estonia⁴</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Latvia⁵</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Lithuania⁶</td>
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<td></td>
</tr>
</tbody>
</table>

Sources: [10, 17, 18, 19]

The situation with legacy air carriers over the Baltic countries is different (Table 2). In the traditional sense, the national air operator (Air Baltic) exists only in Latvia, where the company mainly services passengers via Riga’s hub. Latvian airBaltic is the biggest air operator in the region, which mostly presents characteristics of classical national air companies.

Estonia established its national air operator Estonian Air in 1991. In 2015 the company was found guilty of receiving unlawful state aid and was forced to make repayments [22]. Instead, the Estonian government decided to liquidate the company and founded a new establishment – Nordica Aviation Group. Within the group operates air carrier Regional Jet, which flies under the brand name Xfly.

Lithuania does not have currently a national air carrier (from 2015). Lithuania recognizes a need for reestablishing a new public air carrier, but until now not yet succeeded [1].

<table>
<thead>
<tr>
<th>Baltic countries air operators</th>
</tr>
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<tbody>
<tr>
<td><strong>Country</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Estonia</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Latvia</td>
</tr>
</tbody>
</table>

Source: [2, 14]

As Table 2 demonstrates, both Estonian and Latvian air companies have suffered economic losses also before the pre-COVID-19 period.

During the last decade, airBaltic (AB) has pursued a strategy of fast expansion and aggressively obtaining a market share in the Baltic Sea Region countries. To implement the strategic goals AB moved towards a business model, which is classified as a low-cost carrier business model (LCC). The characteristics of the model are - use of limited types of aircraft (one-two types only), limited (free) services on board, and flying between destinations, which provide necessary passenger volume for their fleet. The strategy is to increase passenger capacity via cheaper flight tickets, charging highly
on-board services, and cut efficiently operational costs. About half of the AB operational cost is related to fuel and maintenance; another half is not controlled by the company (e.g. taxes and GH services) [2]. Therefore, Air Baltic is switching only on the use of the single type of Airbus 220-300 aircraft and discontinuing the use of Boeing and Bombardier planes. To finance its strategic expansion, the AB has increased borrowing and has tried to attract private investors as the government capital injections are limited by the EU regulations. Unfortunately attracting new private investors hasn’t been successful yet.

In contrast, Estonian Nordica operates mainly in the routes outside Estonia or provides “whitetail” services to the different European carriers. The company has made operational losses since the beginning six years ago. At the same time, the Estonian government considers Regional Jet still as a strategically important enterprise and continues to support its activities and keep it publicly owned.

It is important to take into account the market failure in the European air transport market, where airlines primarily prefer aircraft with 180 or more seats due to the low Cost of Available Seat Kilometer (CASK) [13]. While Latvia built the hub with to help of its national company, Estonia considers it strategically important to have relatively smaller aircraft with 70-120 seats to provide air connections. Lithuania mainly expects low-cost airlines (LCC) to provide the necessary market volume.

3. Public Supportive Schemes in the European Union Context

General global economic fall and particularly dramatic reduction of aviation operations put the sector into very harsh conditions. Keynesian economic logic expects governments’ intervention to help the aviation industry in the situation of economic shock. Governments’ have to design instruments and supportive schemes, which are addressing the core problem and effectively allow the aviation sector to recover.

However, in the frames of the EU regulatory environment supporting national aviation enterprises is a delicate issue. European Union regulations do not allow straightforward support and subsidizing the country’s own “national champions”. Even at the country level, aviation traffic should take place in a competitive environment, and providing exclusive support to national companies is not tolerable. In frames of EU, direct state aid to particular air operators (e.g. national legacy carrier) is considered as a distortion of fair competition and therefore, generally banned. On certain occasions, state aid may be tolerated, but EU Commission should give its acceptance in every single case. Otherwise, public support to domestic companies may harm competition and put different companies into unequal positions. There are recent cases in Central and Eastern Europe, where air companies went to bankruptcy after being accused of unsuit state aid (Hungarian MALEV and Estonian Air) [21].

In the devastating COVID-19 crisis, various international aviation organizations invite EU Commission and the Member States to “put place a targeted European Aviation Relief Programme covering the period until the recovery of air traffic” [6]. Aviation representatives argue that the recovery of the European aviation sector will require substantial and fast public support. Aviation Round Table argues that “most airlines would not have been able to survive this crisis without public support” and such help is fully justified and needed to protect employment and aviation sector operations. Logically, such a position requires the modification (loosening) of EU regulations on state aid to aviation.

There are emphasized several criteria for public support on aviation. First, the help should be fast and comprehensive. In the short term, it is important to provide the aviation ecosystem with the necessary funding to keep operating and restore air connectivity [6]. Such type of measures is related to providing financial liquidity, cost relief, and support on maintaining jobs. However, despite the more tolerable attitude from the EU regulators, each state aid package should be notified and agreed upon by the EU Commission.

Second, it is an important issue to maintain a connection between state aid, job protection, and sustainable business models [6]. That is, state aid should not only provide short-term necessary financial help but support long-term economic competitiveness. COVID-19 should not increase companies' long-term dependency on state donations. That is a real risk for the Baltic countries, their national air companies have operated in most of the periods on negative profits level. Fiscally powerful countries can provide much larger support (in absolute terms) to their aviation than smaller Member States. As an outcome, already dominating big national companies are maintaining their favorable positions and market distortions are deepening through government intervention. State aid allows rearranging market shares within the region. The outcome might be narrowing air connectivity in the Baltic region.

Third, the ACI’s proposal is a recommendation to the countries “temporarily and in a non-distortive manner suspend tax payments and/or social security contributions” [6]. Therefore, in addition to the direct funding to airports and air operators is proposed to provide relief through taxation instruments. In reality, it means declining of cost for various operators (airport cost, parking, other operational costs) and stimulates them to intensify operations.

4. Fiscal Instruments of State Aid

To compensate for the losses and revitalize aviation, most countries have designed supporting schemes for airlines. The International Air Transport Association (IATA) provides an overview of various fiscal measures, which have been practiced worldwide [8]. As the table demonstrates, the measures can be divided into two groups – the funds which are given as non-repayable relief (non-reimbursable) to the sector. Such measures include wage subsidies, capital injections to equity, and decreasing taxes on inputs. Such kind of public support covers about 40% of all state aid.

Another 60% of public support covers various instruments, which air companies have to pay back(reimburse) to
the issuer of funds (usually a government-controlled agency). 47% of all aid schemes are various loans and loan guarantees.

13% cover public help is transferred in form of decreased corporate and consumption taxes. Cross the countries the supportive instruments vary significantly.

Table 3

Government aid to aviation, billion US dollars, 2020

<table>
<thead>
<tr>
<th>Form of government aid</th>
<th>Amount</th>
<th>%</th>
<th>Reimbursable/deferral only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loans</td>
<td>58</td>
<td>33.5%</td>
<td></td>
</tr>
<tr>
<td>Loan guarantees</td>
<td>24</td>
<td>13.9%</td>
<td>Reimbursable/deferral only</td>
</tr>
<tr>
<td>Wage subsidies</td>
<td>46</td>
<td>26.6%</td>
<td>Non-reimbursable/discount</td>
</tr>
<tr>
<td>Cash injections/equity financing</td>
<td>23</td>
<td>13.3%</td>
<td>Non-reimbursable/discount</td>
</tr>
<tr>
<td>Corporate taxes</td>
<td>12</td>
<td>6.9%</td>
<td>Reimbursable/deferral only</td>
</tr>
<tr>
<td>Ticket taxes</td>
<td>10</td>
<td>5.8%</td>
<td>Reimbursable/deferral only</td>
</tr>
<tr>
<td>Fuel taxes</td>
<td>1</td>
<td>0.00%</td>
<td>Non-reimbursable/discount</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>173</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: [8] and authors calculations

The structure of public support demonstrates the logic and perspectives of support schemes. About half of the state aid is given in the form of loans and loan guarantees. One-fourth of public support is provided as non-reimbursable cash flows to maintain aviation jobs during acute health crises. Direct capital injections cover only 13% of total state aid. Therefore, the countries avoiding the takeover of air companies (or increasing public share in the companies), but provide temporary and fast relief (liquidity) in the shock situation. By providing loans, the governments demonstrate their faith in companies’ recovery; issuing loan guarantees the governments are building a bridge between air companies and private capital markets. The governments injecting confidence into aviation and beliefs of fast recovery. As a logical outcome, the aviation sector's total debt has increased more than one-third during just one COVID-19 year [8].

As will be demonstrated below, the Baltic countries' public support pattern is different – the countries mainly used public funds to inject new capital into the companies, not so much provide short-term liquidity to the companies.

5. Baltic Aviation Support in the Regional Context

During the COVID-19 pandemic, the Baltic Sea Region air operators had to cope with the sharply contracting travelers’ market.

Table 4

State aid to aviation at the Baltic Sea region countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Flag carrier</th>
<th>State aid instruments</th>
<th>Revenue and Earnings (EBIT), 2019, million</th>
<th>State aid package compared to revenue, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estonia</td>
<td>Nordica Aviation Group</td>
<td>€30M injection to stock capital</td>
<td>219.7</td>
<td>13.6%</td>
</tr>
<tr>
<td>Latvia</td>
<td>Air Baltic</td>
<td>€36.1M loan &amp; €250M equity financing</td>
<td>503.3 (26.6)</td>
<td>56.8%</td>
</tr>
<tr>
<td>Sweden</td>
<td>SAS</td>
<td>€455M loan guarantee</td>
<td>Group 4.6B (79.4)</td>
<td>9.8%</td>
</tr>
<tr>
<td></td>
<td>+ 20 more operating in local lines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>SAS</td>
<td>€137 M credit facility</td>
<td>Group 4.6B (79.4)</td>
<td>2.9%</td>
</tr>
<tr>
<td>Norway</td>
<td>Norwegian</td>
<td>$533M hybrid loan guarantee</td>
<td>Group 4.6B (79.4)</td>
<td>11.6%</td>
</tr>
<tr>
<td>Germany</td>
<td>Lufthansa</td>
<td>€9 B state aid</td>
<td>€36,4B (1.6B)</td>
<td>24.7%</td>
</tr>
<tr>
<td>Finland</td>
<td>Finnair</td>
<td>€286M on recapitalization &amp; €600M loan granted to Finnair pension fund</td>
<td>€3,1B (93.0)</td>
<td>28.6%</td>
</tr>
<tr>
<td>Poland</td>
<td>LOT</td>
<td>€400M loan &amp; €250M capital injection</td>
<td>€1.65B (20.6)</td>
<td>39.4%</td>
</tr>
</tbody>
</table>

Source: [23-29]
This immediately put air operators into the situation of shockingly decreasing revenue flows and complete close of many destination countries. The companies had to react immediately – closing and rearranging routes, withdrawing financial (leasing) activities, and cut the number of employees.

To provide help to the aviation sector, the governments designed various state aid packages to support national air operators. Table 4 provides an overview of Baltic Sea Region countries’ state aid measures. Despite there are several instruments to support aviation, the Baltic Sea Region countries mostly opted for two major mechanisms – they provided loan instruments and made direct capital injections to air the carriers. Other instruments, listed in Table 3, were in minor use. Therefore, the main focus has been the provision of short-term financial liquidity to air companies.

Table 4 is assessed state also aid proportion. All the countries with distinctive national air carriers did support those companies. German national air carrier Lufthansa has received as much as 9 billion of state aid, which is about 25% of the company’s turnover in 2019 [12]. SAS “countries” all together supported the aviation group about the same percentage proportion. Finland’s support to its national air carrier cover more than one-third of its earnings a year before [7]. Polish LOT state aid reached up to 40% of the 2019 turnover [11].

Proportionally the highest state support was given to AirBaltic, which reached up to 57% of AB turnover. The Latvian government has actively funded national air carriers to help its survival and maintaining market share in the region [2].

Estonian government support to national operator Nordica was the lowest among the Baltic Sea region countries and covered only 10% of turnover in 2019. Nordica’s role in Estonian aviation market is considered to be minor. However, Estonian government’s support confirms its interest to keep the national air carrier and current “window” is a good opportunity to inject capital into the company.

To conclude - richer and economically more powerful Baltic Sea Region countries capability to support own aviation is much higher (in absolute terms) than Eastern-European countries do. In relative terms, Latvia and Poland supported their companies more than other Baltic Sea Region countries.

6. Conclusions and Further Discussion

Until the crises, the EU Commission has taken a strong attitude towards state aid to the countries air operators and often accused countries of breaching the international competition. In the current crisis, the EU has loosened requirements for providing needed financial donations to national aviation. In the COVID-19-pandemic situation, most European countries provided financial support to their national air carriers.

As concluding words, here are raised two issues for further discussions and studies.

First, there is an expected reallocation of market shares among air operators, which is facilitated by the state aid schemes.

Second, state aid schemes strengthen publicly owned air carriers’ position over privately owned LCC companies (e.g. Ryanair vs KLM). [16].

Specifically, the countries are not equal by the capabilities to provide various support to their “national aviation champions”. The opportunity to provide state aid favors bigger and richer countries’ companies. The Baltic countries’ capability to support their national companies is lower than bigger European countries could provide. That may lead to strengthening market positions of financially more capable (i.e. richer countries) air companies.

Another close issue is related to reshuffling competitive positions among air operators is - who does receive government support and those who don’t. Logically, the companies who are receiving public support are in better positions compared to air companies, which are operating only on their revenue flows. If the government supports its national flag carrier operators, the other companies are put into an unfavorable position. For example, Europe-wide air operator Ryanair accuses Estonian Nordica of receiving financial aid, which is, by opinion, incompatible with EU requirements [4,16]. The same complaint has been targeted against Finnair and SAS, Ryanair has already won the complaint against the Netherlands carrier AF-KLM and Portuguese TAP over illegal state aid and EU Commission suspends out-payments to the companies until further clearance of the situation [4].

To conclude, state aid is a multifaceted phenomenon, which will have a significant impact on the post-pandemic airline positions in the Baltic Sea Region.

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Hazard Sources’ Identification During Unmanned Medical Transport Flight

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Abstract

Unmanned Aerial Vehicles (UAV) have got significant values that make them appropriate for medical transport. These are independence on traffic, road infrastructure and in case of automatic flight on operator availability. Its’ velocity, size and weight are their great advantage over classic and even helicopter ambulances. The risk assessment of these operations is the key factor in their conducting. The hazard sources not applicable to the other means of medical transport must be taken into consideration. The flight should be thoroughly planned and takes into account hazards connected with air traffic, weather, people and infrastructure on the ground, airspace structure, current legal frame and the characteristic of the aircraft itself. Although, it is not yet practice to transport patients by UAV. Many others can be transported e.g. blood, organs, samples. They are however biological substances considered dangerous goods. They require special affect and attention. Thus, hazard sources identification is the key factor to be conducted before a flight.

KEY WORDS: Unmanned Aerial Vehicles, risk of hazards, hazard sources, medical flights

1. Introduction

Unmanned Aerial Vehicles (UAV) also called drones are wildly used in many economical branches. Apart form well known recreational and military purposes there are used commercially more often.

The UAVs are commonly equipped with cameras, which allow their use in the film industry, agriculture or surveying, as well as in crisis situations. They can help in assessing the consequences of natural disasters and planning rescue operations, but above all, they are increasingly used in various types of rescue operations. It is estimated that the use of drones in the upcoming years will significantly increase in most sectors. The analysts are forecasting that the increase will reach up to 7% annually, to almost USD 4 billion in 2021 (from the current 8.5 to 12) [20]. The transport system as a complex organizational and technical system can be considered in many aspects. The most important of them, however, is the safety of transport operations. In terms of the system, the state of air traffic safety is such a state of the system in which its elements do not threaten each other and strive to neutralize threats, if they appear anyway [22].

Unmanned Aerial Vehicle Operations are divided into two categories, in terms of risk assessment, open and specific. UAV operations in the "open" category enable low-risk flights. They do not require a prior permit to fly with CAA (Civil Aviation Authority). Operations in the "open" category may only be performed within the Visual Line of Sight (VLOS) and at a distance of no more than 120 meters from the nearest point of the earth's surface, with drones not exceeding 25 kg. The "special" category is intended for medium risk operations, which flight parameters exceed the "open" category. When performing operations in the "special" category, registration of all UAS operators is required, regardless of the weight of the drone used [13, 25]. There are three options for obtaining a permit for such a flight [25]:

1. STS (Standard Scenario). The statement on a standard scenario operation. Two standard scenarios published by EASA will become applicable from December 2, 2021 and the concern VLOS and Beyond Visual Line of Sight (BVLOS) flights in a sparsely populated environment. These are not compatible with medical sample transport requirements. There are nine national scenarios available so far in Poland [3, 10].

2. Authorization for the operation. It is necessary to conduct a risk assessment of the planned operation in accordance with the SORA (Specific Operations Risk Assessment) methodology and submit, together with the application, the risk assessment and all risk mitigation measure and compliance with operational safety objectives to the Civil Aviation Authority.

3. LUC certificate. The operator shall demonstrate that is able to independently assess the risk of every operation itself.

Risk assessment requires the recognition of the analysis area and carrying out the hazard sources identification processes. The article presents formal procedures for identifying hazard sources (HS) and hazard recognition (H), using a properly constructed checklist of questions about the presence of hazards in the given area of analysis. A transport system consisting in the transport of medical materials by unmanned aerial vehicles was selected as the area of analysis. Each transport system consists of the subsystems [1]:

- technical (infrastructure and UVA);
- organizational (organization of transport);
2. The Possibility of Using Unmanned Aerial Vehicles in Medical Transport

2.1. Properties of Unmanned Transport

The efficient operation of medical services depends to a large extent on time, speed of reaction and information flow. Regardless of the needs of blood, serum, drugs or even medical equipment, UAVs are able to reach their destination faster than with traditional transportation methods. An example of the transport of medical materials using UAV is shown in the Fig. 1.

Fig. 1 Medical drone shipment [5]

The Swedish Karolinska Institute has carried out research to deliver a defibrillator to the scene of the accident. In rural areas 10 km from Stockholm, the average UAV flight time was 5 minutes and 21 seconds. Whereas in real emergencies an ambulance would cover the same distance in about 22 minutes [23]. In Poland, in December 2020, long-distance test flights were carried out to demonstrate the possibility of delivering medical materials in a controlled space in Warsaw (Fig.2). From the safety perspective, this makes it much easier to secure this flight by PANS (State Air Navigation Services Agency) because every traffic taking place in the CTR space is known and remains in the communication of the Airport Control Service. PANS has designated the R (Restricted) area in the NOTAM message to secure the flight. The route has already run in both types of space. The flights were performed by a 14-kilo vertical take-off plane moving at speeds of 10-30 m / s at a maximum altitude of 120 m AGL [4]. While flying through a separate air corridor and with a maximum speed of up to 90 km / h, the drone delivered medical packages on average half faster than by road transport [20].

Fig. 2 Medical flight in Warsaw airspace [2]

The opening hours of the laboratories in the hospitals differ from institution to institution. The road transport in rush hours is ineffective, thus the need of infrastructure free mean of transport which can overreach the problem of road transport. The ordinary helicopter is not cheap to use and needs at least 1.5 times more space than its biggest dimension. UAVs are here to serve. They are relatively inexpensive, unmanned, stable in flight, ecological and reliable as the test in [8, 16] shows.

According to the CAA in UK [7] the most occurrences including drones included to Mandatory Occurrence Reports happened from 0 to 2.5 kft above the ground. This indicates that the higher altitude values are safer although there is more risk of mid-air collision.

2.2. Medical Flights Risk Assessment

First step in risk assessment algorithm is to describe the field of analysis. The field may be divided into three parts after SHELL model. These are: Software, Hardware, Environment and Liveware (operator), Liveware (other).

The second step of risk assessment algorithm is to perform an identification of hazards in defined area. It can be done, among others, by creating a checklist with specific questions referring to the given situation. The algorithm for constructing the checklist is shown in Figs. 3 and 4.
Following methods can be used to identify safety hazards [26]:
- Flight Operations Data Analysis (FODA);
- Flight Reports;
- Maintenance Reports;
- Safety (& Quality) Audits / Assessments;
- Voluntary reporting of Incident/accidents/near misses;
- Mandatory accident reporting to the competent authority;
- Brainstorm acc. to Failure Mode Effects Analysis (FMEA);
- Surveys.

When publishing zones, PANSA uses additional horizontal protection from the nominal route and vertical protection from the flight height. When publishing zones, PANSA uses additional horizontal protection from the nominal route and vertical protection from the flight height [27].

Medical flight has already taken place e.g. in USA, Switzerland and Poland [6, 9, 19].

3. Medical Flights Hazard Sources Checklist

The methods listed in section 2.2 can be used in order to obtain information on the hazard sources. One of the most formalized procedures for identifying hazard sources in the areas of analysis are checklists. When developing checklists, one should take into account information about sources of already activated hazards. As medical flights are
only in the initial stage of development, a checklist will be developed for hazard sources that, according to the authors, may be activated during an aircraft operation. Moreover, when compiling the lists, the type of the source should be taken into consideration. According to [28], the sources may be of a personal, technical, environmental and organizational nature.

It is assumed that the flight takes place in Polish airspace. The check list for the selected area of analysis is presented in Table 1. Generating hazard sources is considered in the areas divided into human, technical, organizational and environmental factors [15, 17, 21, 24].

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Is it possible that the weather forecast wasn’t checked?</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Is there a possibility that the third parties would like to take over the cargo?</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>Is it possible that the operator didn’t programmed the drone appropriately?</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>Is the flight path repeatable?</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Does the coordinator of the flight know UAV’s technical data and characteristic?</td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>Is the person collecting the parcel properly trained?</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Is it certain that the UAV is equipped in a transponder?</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Are there more than one fail systems in the UAV?</td>
<td></td>
</tr>
<tr>
<td>2.3</td>
<td>Are there dedicated propeller guards?</td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>Is every crucial element doubled?</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>Is there a possibility of a sudden drone’s failure?</td>
<td></td>
</tr>
<tr>
<td>2.6</td>
<td>Is the landing place properly prepared for landing?</td>
<td></td>
</tr>
<tr>
<td>2.7</td>
<td>Is there enough space for landing near the hospital/laboratory?</td>
<td></td>
</tr>
<tr>
<td>2.8</td>
<td>Is the drone equipped with FLARM system?</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>Is there a possibility that the battery will be damaged during flight?</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Does the flight take place over highly populated areas?</td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>Are there reservoirs en route?</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>Are there intensive magnetic fields en route?</td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td>Is the solar activity significant?</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Are there some meteorological precipitation?</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Is the arrival point beyond visual line of sight?</td>
<td></td>
</tr>
<tr>
<td>4.2</td>
<td>Is it possible that the flight doesn’t take place from the aerodrome?</td>
<td></td>
</tr>
<tr>
<td>4.3</td>
<td>Can there be another unmanned aerial vehicle flying nearby?</td>
<td></td>
</tr>
<tr>
<td>4.4</td>
<td>Is it certain that vertical separation provided in the flight area?</td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td>Is there a necessity to report every flight to the CAA?</td>
<td></td>
</tr>
<tr>
<td>4.6</td>
<td>Is there a possibility, that the flight isn’t coordinated with PANSA?</td>
<td></td>
</tr>
<tr>
<td>4.7</td>
<td>Does the enterprise have the LUC certificate?</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>Are there alternate landing places en route?</td>
<td></td>
</tr>
<tr>
<td>4.9</td>
<td>Is the airspace controlled (class C, D)?</td>
<td></td>
</tr>
</tbody>
</table>

Table 1

Hazard sources identification checklist

Declared answers to questions from the check list allows to recognize the hazard sources in the area of analyses. On the basis of such prepared checklists, hazards are recognized through the procedure of grouping the hazard sources. HS grouping consists in creating lists (groups) of sources whose presence and joint activity in the analysis domain is seen as the state of this domain leading to the UE. The creation of the HS group takes place through their indication (e.g. separation from the HS list) and mental association according to a certain principle of joint activity [11, 12]. An example of the characterized risk is presented in Table 2.
Table 2

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Can there be another unmanned aerial vehicle flying nearby?</td>
<td>YES</td>
</tr>
<tr>
<td>20</td>
<td>How are the airspace elements arranged?</td>
<td>YES</td>
</tr>
</tbody>
</table>

Hazard recognition

Hazard 1: The possibility of mid-air collision with another UAV

The guidelines for grouping HS are as follows:
- Striving for a minimum number of HS in the group;
- A group of hazard sources may be composed of one source;
- One HS can exist in many groups;
- In the HS group, there are no deficiencies in the elements related to risk reduction measures;
- In the HS group, no damage to safety system components should be taken into account.

According to the analysis the most hazard sources can be identified in the field of technical and organizational hazard sources (Fig. 5). The personal ones, connected with human factor are the second significant value. The environmental issues are the least numerous group. It is due to the fact that the contemporary drones are increasingly weather resistant.

4. Conclusion

The purpose of identifying the hazard sources is to constantly improve the areas of human activity. On the basis of the identified HS, appropriate risk measures (technical or organizational) can be selected, which reduce the probability of the EU occurring in the analyzed area. The article presents formal procedures for identifying sources of threats and threats, using a properly constructed checklist of questions about the occurrence of threats.

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Evaluation of Methods for Passenger Counting in Public Transport

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Abstract

This article tried to contribute Automatic Passenger Counting (APC) in the public transport system that is rapidly developing and collecting a lot of interest. Passenger counting is an important issue not only in public transport, and it is widely being used in the malls, public events, and many other places for the purpose of data collection, analyzing, marketing, and planning as well.

Currently, most developed and developing countries are starting to pay attention to the concept of the Sustainable Public Transport System. This is a very huge and complex system; hence APC forms small pieces but is necessary. The basic method that is commonly used is IC card information. However, it cannot give satisfying results to consumers due to fare dodgers and human unconscious actions. In addition, there is a manual counting method that was being used in the first but not reliable method.

Even, most suggested methods are showing high-performance results of their methods, they still have unresolved tasks. By analyzing the studied methods through their historical development, we generally categorized all methods and suggested indicators to evaluate them. Moreover, we concluded the evaluation with the suggested method.

KEY WORDS: passenger counting methods, public transport, evaluation of methods, sustainable public transport system

1. Introduction

Along with the widely concerning Sustainable Urban Transport system, APC (Automated Passenger Counting System) might be the tiny part but its significant part is rapidly developing. From the 1970s until now, there have been tons of research done related to this area. Not only the Public Transport system, passenger counting in cars for emergency use, public spots such as malls, exhibition halls for the purpose of future service improvement, management as well APC is gathering the people’s interests.

According to the article [1], the size of the market of the “people counting system” is expected to grow from USD 818 million in 2020 to USD 1,333 million by 2025. Not only for public transportation, but there is also a growing need for other public places such as hospitals, sports centers, and marketplaces due to safety requirements during COVID-19. The following companies were considered as a key market player in this field: HELLA Aglaia Mobile Vision GmbH (Germany), Infrared Integrated Solutions (IRISYS) (UK), which are the two manufacturers currently in use technologies for “Rīgas satiksme” public transportation in Riga, as well as RetailNext (US), ShopperTrak (US), V-Count (Turkey), Eurotech (Italy), Axiomatic Technology (UK), CountWise (US), Dilax Intelcom GmbH (Germany), and IEE S.A. (Luxembourg).

As has mentioned above, there are various kinds of methods to make statistics of passengers at different places through its historical development. And many challenges have arisen following it. Even, there are a lot of methods suggested to use as people counting, and all of these methods intend to solve the particular problem, and it is still a problem that what indicators should we focus on when we are trying to improve the methods is not clear. Each method has its own advantages and disadvantages, and it depends on circumstances. Therefore, evaluating the methods with appropriate indicators is also a necessary task in this field.

In this paper, we describe what kinds of methods are commonly used in which area and situations, for what purposes as well. Furthermore, we intend to make study directions clear due to identifying measurements of passenger counting methods. After measurement items are decided, we can evaluate methods that represent each type. By doing this evaluation, it will be feasible to determine which method is suitable for what kind of situation as well to improve which method for special circumstances what can be the main challenges to concentrate on.

First, we will mention the method that has been used in real life how it works, second of all what kinds of research directions have been done in order to improve. By analyzing the methods, we will suggest the main challenges and their priority. After that, by using these problems, we will evaluate the methods. Because there are lots of methods and it is not
possible to test them all in the same condition, in this research, we will suggest results that are derived from only theoretically evaluating them and aim of this research is to contribute to the future development of APC system in the public transport system.

2. Real-Life Methods

Along with the demand for passenger counting, there are a lot of devices that are different by price, usage, functionality as well as comprehensive services that exist in the market. We chose and explained some most commonly used devices with their performance and features.

The first one is a video turnstile device which is produced by a “Retail sensing” manufacturer from the UK. This sensor and related services are being used in 23 countries of the European Union as well as the US and other countries. This sensor counts passengers with 98% accuracy. Fig. 1 shows the main part of the device, it consists of two parts. One is called VT part for passenger counting, and it has an input port to get the video stream from the installed surveillance camera, another one is called a logger part for saving the counted data to send it to the server by using the IoT. Also, it has contact with bus events such as door opening to limit the computing time.

![Fig. 1 Retail Sensing device](image1)

The second one is the China Reamol Bus People Counter System from “Auto Watchdog Electronics Co., Ltd”. As shown in Fig. 2., it has its own camera to record video to detect the people’s head and count passengers in two directions onboarding and alighting direction. Even though, head detecting method has several disadvantages such as occlusion and illumination, the algorithm used in this device isn’t affected by all of these, and the accuracy rate is the same as the previous device 98%.

![Fig. 2 China Reamol Bus People Counting device](image2)

The next one is not such a new technology, but it is used widely in bus passenger counting. Differences from the two methods mentioned before, it is an autonomous device, not a complex counting system. The model of the equipment is HPC086 (Fig. 3), and it consists of infrared sensors, processor unit, GPRS module, and gate control switch. The daily average accuracy percent is more than 90, vulnerable to changes in temperature and humidity. And the advantage is the low cost.

![Fig. 3 HPC086 Bus Passenger Counter](image3)

Iris - infrared and intelligent sensor which is expert in automated passenger counting is shown in Fig. 4. Manufacturer of iris has been supplying this field for 25 years [16]. “Rigas satiksme” from Latvia is one of the European countries which has public transport vehicles equipped with an iris sensor for passenger counting. IRMA, which is the main product, counting sensors work with 3D image streaming. The basis is the distance measurement according to the time-of-flight principle (TOF). In a time of flight (TOF) system, the distance between the target and the camera is measured on a pixel level, based on a reflected beam of light usually originating from a modulated light source.
The last example of a real-life product is HELLA Aglaia People Sensor [17] (Fig. 5). This sensor is one of two methods currently used at the newest public transport vehicles by “Rīgas satiksme” in Riga City, and another one is explained previously.

It utilizes 3D image processing algorithms to analyze the flow of people. Due to its executing object detection on 3D images acquired from sensors, distinguishing if the object is a real human being or just an object with a human shape, and if it is a human, it has an ability to detect its age as well.

3. Evaluation of Methods for Passenger Counting in Public Transport

Through the most related study, methods can be categorized in three categories by its used techniques for counting, which are based on physical sensors, based on computer vision, and combining these two technologies. Moreover, by analyzing the methods, we clarified a list of challenges that needed to be met with the requirements. This list will be the main indicators of our evaluation of the methods.

1. Cost: This indicator has quite a high priority because we are considering public transport. In other places such as malls or dormitory entrances, only one or two devices are required to be installed, but in public transport quantity of required equipment and its maintenance cost will be multiplied by at least a few hundred.
   1.1. Installation cost. Cost of devices and their deployment.
   1.2. Calculation cost. Memory, CPU, electricity usage that is consumed for computation.
   1.3. Maintenance cost (stability): In order to reach the goal of sufficient data that can provide the development of a Sustainable Transport System, the system needs to be kept for a long period. Maintenance cost to secure the stability of the system this indicator item cannot be missed.

2. Accuracy rate: Most methods show near to 100% accuracy rate when counting passenger form is queued, and all passengers have the same appearance.
   2.1. Density: In order to use the system in real-life experiments, the system has to keep the accuracy rate high even if passengers are crowded, with high passing through speed as well abreast formation.
   2.2. Occlusion: For the same reason that mentioned the previous indicator, passenger’s appearance such as hat, suitcases derive occlusion problems.

3. Compatibility: The system has to be compatible with different environments.
   3.1. Illumination: It has to show the same result in daytime lightning and nighttime.
   3.2. Temperature: It has to be vulnerable to all weather changes in a whole year.

4. Functionality: Functionalities in order to support further usage of the gathered data from devices.
   4.1. Flow detection: Detects the passenger flow direction.
   4.2. Real-time: Real-time data gathering and passing it to the specific source.

(These indicators will be used as their numbers, such as 1.2 … 3.1 in the remaining part)

As mentioned in [2, 6, 9, 10] thermophile sensor, ToF camera, Wi-Fi technologies, pressure sensor and light sensor [2]. Thermopile sensors are fabricated with silicon MEMS (micro electro-mechanical systems) technology, and monitor the temperature difference between the cold junction and the hot junction, which latter is heated by the infrared radiation [2]. In a time of flight (TOF) system, the distance between the target and the camera is measured on a pixel level, based on a reflected beam of light usually originating from a modulated light source [5]. While Wi-Fi-enabled devices get into the Wi-Fi area, it sends a probe request that contains the device’s information, such as mac addresses. By installing the sensor that listens for probe requests, it is feasible to measure the count of passengers going through between the sensors. The author of [9] presented the method that studies the characteristic of thenar pressure when the human body gets on or down the stairs under the public transportation environment and applies it to the passenger flow count. In addition, this method can distinguish the direction that the passengers get the bus on or off, which made up for the insufficiency of
pressure sensor technology. The author of [10] introduced the method that uses the light-sensitive wireless sensor with a directional light source.

As it is mentioned in [3-5, 7, 13-15] by using the different algorithms of image processing to passenger counting and flow direction detecting on captures from the video which is installed above the doorways of the bus. Passenger counting with computer vision process consists of four main parts, which are object detection from frame, segmentation, flow detection, and counting. Most methods follow these steps but using various algorithms, programs, and libraries to execute these tasks. One research study [3, 5] offered to use surveillance camera data to count the passenger statistics due to there being no extra installation cost (1.1). Also, as it is mentioned in [4], Photogrammetry on video cameras which are located at the bus stop can be the alternative to reduce the installation cost (1.1) due to the number of bus stops being less than bus quantities. According to the paper [4] photogrammetry is the science of obtaining reliable information about the properties of surfaces and objects without physical contact with the objects and measuring and interpreting this information. There are many studies done in order to improve detection algorithms, such as using machine learning [5], CNN, and other image processing algorithms [7].

Moreover, the methods combining the computer vision with physical sensors were introduced by [8, 11, 12]. The main computing process is based on image processing but using the sensors additionally saves the source. For instance, as in [10], when the prototype is started, the GPS sensor begins to track the location at certain predefined intervals. The prototype system processes the results obtained from the camera when the GPS coordinates are in the range of predefined targets. One research study used a sound sensor to handle the sound of the door opening and closing. In addition, another research [12] suggested using a Kinect device that has a variety of sensors: a video camera, an IR depth camera, four microphones, and a 3-axis accelerometer.

Table shows which methods have an advantage or enough evaluation on which indicator by checking.

<table>
<thead>
<tr>
<th>Evaluation indicators</th>
<th>Method type</th>
<th>Based on physical sensors</th>
<th>Based on computer vision</th>
<th>Combining the image processing with physical sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Installation cost</td>
<td>X</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Calculation cost</td>
<td>✓</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Maintenance cost</td>
<td>X</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>Accuracy rate</td>
<td>Density</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Occlusion</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Compatibility</td>
<td>Illumination</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Functionality</td>
<td>Flow direction</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Real-time</td>
<td>X</td>
<td>✓</td>
<td>X</td>
</tr>
</tbody>
</table>

4. Discussion

In this research study, we suggested evaluation indicators for passenger counting in the public transport system and evaluated several methods by using these indicators. All methods can show perfect results in their own ideal case, but not all of them can be enough for these requirements. We hope that this conclusion and the suggested result of the evaluation can contribute to the future improvement of this field. The current COVID-19 pandemic situation increased the demand and priority of passenger counting, especially its significance in the sustainable development of public transportation. The passenger counting technologies with high efficiency can serve as providing information for passengers as well, which means it influences comfort and reliable parts of public transportation and citizens interact.

5. Conclusions

The information used to make a result of this evaluation is obtained from existing surveys, and it evaluates the methods by their characteristics and used technologies overall. In order to implement a more detailed and optimized evaluation, we need to test all these methods in the same circumstances and environments. In a further improvement of
this task, we need to get experimental results of at least one represented method from each category. Therefore, the current pandemic situation shows methods must be adaptive for extreme public situations affecting a wide range such as epidemics, natural disasters, civil war, social protest, or possibly war. Due to that reason, evaluation of its effectiveness also should consider its adaptive features. In addition, most of the mentioned methods used body temperature of the image of the passenger, which is biometrics of the human body. These methods are continuously collecting citizen’s personal means privacy-violation risks have to be under consideration as well, in future evaluations.

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/4/20/658 “Adapting the public transport system to the COVID-19 challenge, ensuring its sustainability”).

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Smart Ports’ Influence on Coastal Sustainability

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Abstract

Nowadays, ports are actively seeking ways to improve their safety and operational activity. An essential driver in this context is digitalisation. Since seaports are also key actors for the sustainable development of coastal regions, it is important that they transform into smart port ecosystems. Hence, the automation and digitisation of ports’ operations are important not only for the ports themselves, but also for the regions and countries hosting regional port ecosystems. Studies on the digitalisation level of ports bear the potential to detect optimal ways for increasing safety, security and visibility in terms of the digital transformation, as well as attracting passengers and freight flows, which in turn positively affects not only the ports, but particularly also the sustainable development of coastal regions. Therefore, the paper presents the results of a conducted assessment of small and medium-sized ports’ digitalisation level as well as introduces ways and recommendations how to improve the level of digitisation on the path towards becoming a smarter port ecosystem. The research builds upon key insights from the still ongoing INTERREG South Baltic Programme 2014–2020. Thereby, the research utilises collected primary data concerning ports located in the Baltic, North and Mediterranean Sea Regions. Thus, the study bases on well-grounded theoretical and practical findings in the maritime science field in the nexus of digital transformation.

KEY WORDS: smart port; port digitalisation; digitalisation level; port ecosystem

1. Introduction

Small and medium-sized ports are important for the sustainable development of regions and even countries, because they represent essential parts of the local and regional economy [1-5]. Hence, a smart regional development is directly linked to (port) logistics performance improvements [6-8]. Concerning small and medium-sized ports, recent studies noticed that they face big challenges in comparison to their larger counterparts due to limited financial resources and the lack of suitable human capital [9, 10]. Especially the latter two pitfalls represent grave problematic aspects regarding the digital transformation – i.e. smart port development. The main objective behind the smart port concept is to reach the highest digitalisation status [11], which – in turn – is expected to have a powerful influence on regions’ sustainability, due to arising radical spill-over effects emanating from ports’ strong interrelationships to other key industries.

Next to this, regional sustainability areas are immediately affected by ports’ potential to – for instance – attract passengers and cargo flows, favour regional labour market via the creation of additional working places, as well as encourage tourism plus education and research in transport and logistics [12-14]. The digitisation in terms of smart logistics operations is not only important for ports, but also for the corresponding regions and countries that strongly depend on the regional port ecosystems [15-18]. In this context, studies on the digitalisation level of ports bear the potential to detect optimal ways for increasing safety, security and visibility in terms of the digital transformation, as well as for attracting passengers and freight flows, which in turn positively affects not only ports, but particularly also the sustainable development of coastal regions [19-22].

In line with this, the current paper aims to present the findings of a performed assessment of small and medium-sized ports’ digitisation level as well as to introduce ways and recommendations how to improve the level of digitisation on the path towards becoming a smarter port ecosystem. The study builds upon key insights from the still ongoing
Connect2SmallPorts project, which is part-financed by the INTERREG South Baltic Programme 2014–2020. Thereby, the research bases on collected primary data that refers to ports located in the Baltic, North and Mediterranean Sea Regions. Therefore, the study sets upon well-grounded theoretical and practical findings concerning the maritime transport science field in connection with the digital transformation. In accordance with recent studies [9, 23, 24], the results of the present examination show that the digital efforts in small and medium-sized ports cover differ and thus, are dispersed, whereby the digital transformation is important for both, ports and their regions.

The paper is structured as follow: In the second section, the theoretical background is outlined, whereas in the third part of the article, the applied methodology is set out. Afterwards the main findings are highlighted. The paper ends with some conclusions.

2. Theoretical Background

Seaports – regardless their size – are essential parts of cities as well as surrounding local industries, and as such, attract tourism in form of passengers as well as are responsible for in- and out-going cargo for settled enterprises [15, 19]. Accordingly, also small and medium-sized ports have a great influence on the sustainability of their regions [2, 16, 25].

For describing small and medium-sized ports, only a limited number of factors is necessary. By taking Europe as an example, small and medium-sized ports [26-28]:
- are no core ports in the sense of the Trans-European Transport Network (TEN-T);
- handle less than 10 million tonnes of cargo per year;
- are specialized or non-specialized ports (also known as universal ports);
- are mainly municipality ports;
- face limits regarding capacities and expansion possibilities.

Smart small and medium-sized ports – in certain ways – are similar to smart organisations, since the main operations are managed through a single centre, too, which also [9, 17, 20]:
- regulates information concerning shipping operations and navigation;
- determines the optimal flow of cargo to, within and from the port;
- optimally distributes port equipment for ship handling activities;
- effectively employs marketing;
- efficiently regulates the access of passengers and cargo to or from terminals.

Nowadays, port processes and operations shall be as much as possible automated and digitalised, but on the other hand must be economically useful and sustainable. Therefore, the crux of the matter for small and medium-sized ports is to identify and initiate sustainable measures and investments in order to reach the processual smart port status.

The main areas of port digitalisation are usually [22, 27]:
- digitalisation of the management functions;
- digitalisation of port’ or terminals’ operations and port service;
- safe navigation;
- control of real (actual) depths in the port;
- emergency situation management in port;
- port control institutions;
- legal documents validation in the port (port rules, navigational regulations, etc.);
- port dues and tariffs;
- ships in the port;
- ETA and ATA of the ships;
- cargo in port;
- passenger entrance to the port;
- service companies in port and its activities;
- port statistics;
- port annual reports;
- port development programmes (sustainability and digitalisation strategies);
- port promotion materials (video, audio etc.), etc.

In contrast, the main objectives or tasks of the digitalisation in ports are commonly to:
- improve environmental and safety;
- make the best choice on best practice applications;
- increase transport efficiency;
- reach the final digitalisation level, which is associated by the smart port stage.

Generally, this implies the detection of operational areas in which digitisation is needed. As a suitable tool, digitisation audits can assist such endeavours and at the same time shall point out the effectiveness of the digitalisation case-by-case actions. On the other hand, if such digital audits are conducted additionally on a bigger scale, this allows for comparative assessments of ports’ level of digitisation in the course of a benchmarking, which in turn allows for the derivation of best practices. [9, 16, 18, 20, 22-24]. For evaluating the effectiveness of ports’ digitalisation progress some indicators are needed. An innovative tool that hosts a set of suitable indicators is the digital readiness index for ports
(DRIP), which can be used as well for an evaluation of ports’ digital transformation and benchmarking purposes [23, 24]. Within this so-called DRIP, the five main pillars – which accumulates numerous digital performance indicators and port performance indicators (PPIs) – refer to [ibid.]:

1. Management – associated indicators deal with port’s digitalisation strategy and openness to implement new digital solutions;
2. Human Capital – associated indicators determine employees’ knowledge, skills and capabilities;
3. Functionality (IT) – associated indicators evaluate the functionality and effectiveness of IT systems and efficiency of processes;
4. Technology – associated indicators refer to used enabling technologies and digital solutions;
5. Information – associated indicators measure the degree of knowledge procurement sources.

3. Methodology

According to the DRIP model, the final DRIP score is calculated based on the results of examined pillars for which different weighting factors apply [23, 24]: (1) Management = 20%, (2) Human Capital = 20%, (3) Functionality (IT) = 25%, (4) Technology = 30%, (5) Information = 5%. For the benchmarking, the ports in the sample had been grouped according to different characteristics, such as the achieved DRIP score, port classification in the sense of the TEN-T (i.e. core ports, comprehensive ports, Non-TEN-T ports), but also according to other useful determinants such as cargo turnover and port location (country) [8, 15]. However, the benchmarking results presented in the present study showcases basically ports’ digital auditing results. Moreover, ports are specified depending on their achieved DRIP score, importance in logistics chains and cargo turnovers. This is necessary because different ports have varying possibilities and resources for implementing digitalisation programmes. In respect of the mentioned features, it will be possible to figure out which digitalisation level is typical for certain port characteristics. In order to respect the confidentiality of data provided by the audited ports, the port’s names were anonymised.

In the frame of the benchmarking, it is good practice to test the quality of accurateness concerning port auditing results. For such a purpose, it is appropriate to use the maximum distribution method [23]. Mathematical conditions for the auditing and benchmarking base on random factors. Therefore, interviews were conducted with responsible top-level managers for IT implementations, who have a great overview on digitalisation information in the port and actively participate in the digitisation progresses in the port or terminals. However, in case of data with big random factors it is possible use the Normal (Gaussian) principal [13].

Applied method in the present study targets on the DRIP scoring band analysis. To calculate the size of the random error or the DRIP scoring band, dispersion and/or “maximal distribution”, mathematical methods can be used. It was set that the size of the random error (\( e \) or \( \Delta t_p \)) in the dispersion method is comparable with dispersion (\( \sigma_y^2 \)) [13, 26, 29]. The dispersion method was implemented to evaluate the DRIP scoring band and can be expressed as follow [29, 30]:

\[
\sigma_y^2 = \frac{1}{n-1} \sum (t_i - t_y)^2 ,
\]

where \( n \) – the number of the measurements (audited ports); \( t_i \) – particular measurement results (ports’ DRIP score); \( t_y \) – mathematical expectation of the average DRIP scores, which can be calculated as follows:

\[
t_y = \frac{\sum t_i}{n} .
\]

Finally, the DRIP scoring band (\( \Delta t_p \)) with determined probability (e.g. 63-68%) can be presented as follow:

\[
e = \Delta t_p = \pm \sqrt{\sigma_y^2} .
\]

The DRIP scoring band \( t_p \) is calculated as follow:

\[
t_p = t_y \pm \Delta t_p .
\]

Similarly, the DRIP scoring band can be calculated using the maximum distribution method. In the frame of the present research, it can be expressed as follow [3, 30]:

\[
t_p = t_y \pm P \cdot \Delta t_t \cdot k ,
\]
where $P^{'}$ – probability coefficient (according to the literature, it is recommended that in case of a probability of 63-68%, the probability coefficient should be equal 1; in case of a probability of 95%, the probability coefficient should be equal 2; and in case of a probability of 99.7%, the probability coefficient should be equal 3); $\Delta t$ – difference between maximum and minimum DRIP score results; $k_{t}$ – coefficient, which depends on the number of measurements (the number of processed data) (if the number of data is 3, this coefficient will be 0.55; if the number of data is 4, this coefficient will be 0.47; and similarly, if the number of data is 5, this coefficient will be 0.43; 6 $\leq$ 0.395; 7 $\leq$ 0.37; 8 $\leq$ 0.351; 9 $\leq$ 0.337; 10 $\leq$ 0.329; 11 $\leq$ 0.325; 12 $\leq$ 0.322; etc.; the minimum value of the coefficient is 0.315, if the number of collected data is greater than 15).

4. Results

Within a first step, the digital auditing results of a large range of the ports from the Baltic, North and Mediterranean Sea were contrasted. Building upon the detailed digital auditing results, the corresponding DRIP scores as well as DRIP filtration results were calculated for 30 ports. However, first, the cargo turnover and corresponding DRIP scores for large, medium-sized and small ports are showcased in Fig. 1.

According to Fig. 1, the strong relationship between cargo turnover and DRIP score becomes apparent, whereby a detailed analysis of corresponding indicators and pillars revealed that the main reasons for this detected circumstance can be traced back to the lack of financial and human resources in medium-sized and small ports.

Nevertheless, smart ports indicator results can be linked to regions’ smart systems elements – especially concerning environmental and safety factors. Next to this, it should be noted that the achieved DRIP score by ports depends on the individual, who participated in implementation and evaluation process. This has a big influence on the accuracy of the received DRIP scoring results. Consequently, for the accuracy evaluation of the DRIP scoring results, dispersion and maximum distribution methods were used. The corresponding results are highlighted in Table and Fig. 2, whereby a selection was made, which culminated in a focus on small ports from BSR.

| Table Calculated and filtrated DRIP scoring results for small ports located in BSR |
|-------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Ports | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Filtrated DRIP |
| DRIP  | 2.54 | 2.55 | 3.08 | 3.37 | 3.43 | 3.47 | 3.90 | 3.91 | 3.99 | 4.03 |
| Filtrated DRIP | 2.65 | 2.66 | 3.05 | 3.35 | 3.42 | 3.46 | 3.88 | 3.89 | 3.92 | 3.98 |

The analysis of the DRIP scoring accuracy shows a great fluctuation. Thereby, the calculated mathematical expectation DRIP score is 3.456, the DRIP score band is 0.506 and the accuracy of the DRIP score results is 14.7%. From the received results, it can be derived that according to the DRIP assessment, some smaller ports are close to score up to 4.5 (cf. possible DRIP score spread: 1.0 to 6.0), which implies that it is possible to link or use ports’ high digitalisation level with respective regions’ and cities’ operation, safety and security systems, as well as to promote the creation of joint regional or urban smart systems.
5. Conclusions

The implementation of digital solutions to improve small and medium-sized ports’ operations and management is essential for their sustainable development, but also for achieving the visions of both smart ports and smart regions likewise.

However, the study turned out that the digitalisation level of small and medium-sized ports is much lower, compared to the level observed in the case of investigated large ports. On average small ports’ DRIP scores ranged from 2.54 up to 4.02, medium-sized ports’ DRIP scores ranged from 2.92 up to 4.32, and large ports’ DRIP scores ranged from 3.15 up to 4.90.

Moreover, the accuracy of evaluation results differs regarding ports importance: core ports up to 18.0%, comprehensive ports up to 10.8%, and Non-TEN-T ports up to 15.5%. Furthermore, the accuracy of evaluation results differs regarding cargo turnover: large ports up to 15.3%, medium-sized ports up to 9.8%, and small ports up to 16.4%.

Nevertheless, overall, it could be derived that the digitalisation level of small and medium-size ports is about 30% less in comparison to large ports. Nevertheless, it can be concluded that an increasing digitalisation level in small and medium-sized ports can stimulate their activities and increase port service options and smart port development progress, which in turn will promote the creation of regional or urban smart systems.

The DRIP model used as a methodological concept to evaluate the port digitalisation level and smart port development progress appear to be a suitable tool, since it builds upon 5 pillars and 38 indicators that are well-defined. Nevertheless, also other than these 38 indicators could have a decisive influence on the development of smart ports, which in turn allows if necessary to reconsider the model and to include further or other indicators in the frame of future studies. On the other hand, for the present study, this represents a methodological limitation, due to the lack of other substitutable tools to the DRIP model, since the DRIP model is still unique and the first of its kind. Hence, currently there do not exist other digital readiness indexes or maturity models for ports in the scientific literature and in practice.

References


Estimation of the Residual Resource of a Dumping Wagon for Transportation of Bulky Cargo after Long-term Operation

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Abstract

The problem of the formation of a shortage of specialized rolling stock on the territory of the Republic of Belarus and the ways of solving this problem are considered. The analysis of the specifics of the operation of dumping wagons. An approach to assessing the residual life of dumping wagon after long-term operation is proposed, taking into account the main physical and mechanical characteristics of the metal and the specificity of the operational loads of a wagon of this type. The article describes the zones of the upper and lower frame of a dumping wagon, established by means of technical diagnostics, which are more prone to the formation of defects. The calculation of the bearing metal structure of a dumping wagon was carried out taking into account the real physical state of the metal structure of the body of the selected typical representative, which is in the worst technical condition. The picture of stress fields distribution in the body structure of a dumping wagon is presented. The zones from which the metal samples were cut out were established for in-depth study of the chemical composition and mechanical characteristics of steel. Based on the results of the studies carried out, a methodology for assessing the residual resource has been developed.

KEY WORDS: estimation of the residual resource, dumping wagon, dumper, technical diagnostics, resource

1. Introduction

Nowadays the railways of the Commonwealth of Independent States (CIS) and the Baltic countries have a significant number of freight rolling stock units whose service life is approaching or exceeding the one established by the manufacturer.

The technical documentation for each model of the wagon establishes its designed service life – the calendar duration of operation. When reaching it the operation of the wagon must be stopped regardless of its technical condition. Decommissioning a wagon after exceeding the designed service life is primarily based on the condition of safe train traffic.

Due to the deficit of specialized-type rolling stock, and the technical and economic complexity of updating it after the standard service life, the Council of Railway Transport of the CIS and Baltic countries decided to partially abandon the regulated standard service life for those units of rolling stock whose individual resource allows their continued operation [1].

Many years of experience in examining the technical condition of wagons after long-term operation by employees of the Belarusian State University of Transport show that the service life specified in the technical conditions is often far from the limit, this is due both to the safety factor in the design and to the specification of operating a particular type of wagon.

It is worth noting that the problem of assessing the residual resource of wagons that exceeded a standard service life is significant not only for the Republic of Belarus, but also for other countries [2-5].

On the Belarusian Railways, for the transportation of bulky and lumpy goods, dumping wagons equipped with a mechanical unloading device became widespread. For dumping wagon of models 31-638, 31-656, 31-661, the standard service life is 22 years and a significant proportion of wagons have exceeded it. It should be noted that the operation specifications of wagons of the mentioned types differ from the operating conditions of freight wagons. Often, these wagons have a low intensity of operation, and, consequently, less impact of longitudinal impact forces (determining the resource of a wagon), there is also a seasonal prevalence in operation.

To ensure traffic safety, rolling stock having a service life above the standard requires additional control. The existing schemes for extending the service life of wagons are based mainly on the pattern of distribution of the stress-strain state, on the basis of which an estimation of the residual life is performed. In our opinion, changes in the basic physical and mechanical characteristics of the metal (tensile strength, endurance, hardness, etc.) and the specification of operational loads of this wagon should be taken into account. Changes in the physical and mechanical characteristics can only be shown by appropriate tests, for which it is necessary to select typical samples of renewable models of wagons, the construction material of which will become the object of profound research.

Assessment of the technical condition of the load-bearing structure of dumping wagons operated over one and a half service life demonstrates the feasibility of conducting research in the field of developing a procedure for predicting their residual life after long-term operation, provided they are maintained in further safe operation [6].
2. Methods

The proposed approach to assessing the residual life of dumping wagon presented in Fig. 1.

At the first stage, the design features of the dumping wagon were studied and on the base of the design documentation the nominal thickness of all elements was determined. The analysis of the specification of wagon operation of this type showed that wagons often move along the same route over short distances. There is also a seasonal prevalence in operation [7].

At the second stage, employees of the Belarusian State University of Transport examined 311 dumping wagons in the period from 2018 to 2020. Of the total number of wagons examined, 96% was found to be in satisfactory technical condition. Examination of the technical condition by non-destructive testing methods (visual inspection and ultrasonic thickness measurement) revealed a number of zones subjected to the formation of defects:

- lower frame: connection unit for the spinal beam and the pivot bracket, connection unit for the spinal beam and the cylinder bracket, the zones of the thrust angle bars, the fastening zone of the hanged equipment;

- upper frame: nodes for connecting longitudinal side and transverse beams, nodes for connecting pivot and cylinder beams with supports (support zones), welded joints of the frame's supporting elements, corrosion damage, places of application of external loads.

During the third stage of work, a three-dimensional finite element model of a dumping wagon was developed. The model envisages the possibility of differentiated accounting of the worst situations of metal structure degradation, established according to the results of a technical condition survey. As a result of the strength calculation, taking into account the real physical state of the metal structure of the worst type representative, it was found that the strength under all design conditions satisfies the requirements [8-11]. Fig. 2 shows the distribution of stress fields in the metal structures of the upper and lower frames of the wagon.

Fig. 1 Methodology for assessing the technical condition of a dumping wagon after long-term operation

Fig. 2 Results of virtual research
After analyzing the stress-strain state of the metal structures of the dumping wagon, taking into account the results of the design survey, sticker schemes for strain metric sensors were developed. The selected wagon sample with the worst technical condition and local corrosion wear, reaching 17% of the nominal thickness value, was subjected to control tests, including loading modes characteristic of the operational specification.

The results of the virtual calculations and full-scale tests demonstrate a fairly complete picture of the stress-strain state of the wagon structure, but considering their long-term operation, it is necessary to have information on the actual values of the physical and mechanical characteristics of the material the wagon is made of. Based on the obtained results, the zones from which metal samples were cut out were determined for profound research. The samples were cut out to determine: the chemical composition of steel, mechanical characteristics, hardness, percussive toughness, and the main characteristics of mechanical fatigue resistance. The results of the analysis of the chemical composition of the steel from which the spinal beam is made are presented in Table.

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinal beam material</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>09G2S [10]</td>
<td>0,095</td>
<td>1,467</td>
<td>0,023</td>
<td>0,028</td>
<td>0,018</td>
<td>0,023</td>
<td>0,049</td>
<td>0,189</td>
<td>0,001</td>
</tr>
<tr>
<td></td>
<td>± 0,02</td>
<td>± 0,10</td>
<td>± 0,05</td>
<td>± 0,005</td>
<td>± 0,005</td>
<td>± 0,05</td>
<td>± 0,05</td>
<td>± 0,05</td>
<td>+0,02</td>
</tr>
<tr>
<td>13Mn6 [11]</td>
<td>0,012</td>
<td>1,30–1,70</td>
<td>0,30</td>
<td>0,035</td>
<td>0,30</td>
<td>0,04</td>
<td>0,30</td>
<td>0,001</td>
<td></td>
</tr>
</tbody>
</table>

Comparative analysis of the chemical composition of the metal under study indicates that the elements of the spinal beam are made of steel, the chemical composition of which corresponds to the structural low-alloy steel grade 09G2S (used in the CIS) and 13Mn6 (used in Europe).

The initial data for determining the residual life were the actual mechanical properties of the material of the dumping wagon after long-term operation and the results of experimental field studies of the stress state of the metal structure.

3. Results

According to the methodology developed due to the results of the studies, the assessment of the residual life of the wagon, claimed to extend the service life, with a technical condition that is different from the technical condition of a typical representative that has passed a set of tests should be performed as follows. A set of strength calculations is carried out on the load-bearing structure of the dumping wagon, taking into account the actual values of the thickness of structural elements obtained as a result of technical examination by non-destructive testing methods (visual inspection and ultrasonic thickness measurement).

Based on the experimental test data of a typical representative (denoted by the index ”e”) and the calculated values obtained (denoted by the index ”p”), the predicted calculation and experimental dependence of dynamic tense changes (denoted by the index ”pe”) in \(i\)-th control point of wagon design depending on \(j\)-th technical condition (metal thickness \(t_i\)) for \(k\)-th specific load mode are determined. So tense volume for residual life calculation for \(k\)-th load mode at \(n\)-cargo condition (tense mode level) and \(j+1\) technical condition in \(i\)-th control point can be defined in formula:

\[
\left(\sigma^{i+1}_{j+1}\right)^{pn}_{k_i} = 1 + \left[\frac{\sigma^{i+1}_{j+1} - \sigma^i_{j+1}}{\sigma^i_{j+1}}\right]^{p} \left(\sigma^i_{j+1}\right)^{pn}_{k_i},
\]

The resulting data volume is actually a set of the dependencies of \(\sigma^i_{j+1} = f(\delta^i_{j+1}, t_i)\), moreover, as an additional exogenous variable, along with the values of the mechanical characteristics of the material, seasonal prevalence of operation, etc. a coefficient \(\sigma/\) that takes into account wear (thinning) of the supporting structure at the \(i\)-th control point appears.

Thus, for any \(j\)-th technical condition, it is possible to estimate the resource of the \(i\)-th control area based on the expression

\[
T_p = N_0 \sum_k K_k \sum_j \left(\left(\sigma^{i+1}_{j+1}\right)^{pn}_{k_i}\right)^m \cdot p^n_{j+1},
\]

where
where $\sigma_{a,N}$ – fatigue limit (in amplitude) for the control zone with a symmetric cycle and steady-state loading mode with the base number of cycles $N_0 = 10^7$, which is determined taking into account the actual material endurance limit after long-term operation and the coefficient of endurance limit reduction in the selected control zone; $[n]$ – minimum allowable safety factor for fatigue resistance for the selected service life, $[n] = 1.8$; $K_k$ – coefficient linking the total number of cycles of dynamic stresses with the estimated total service life for the $k$-th loading mode; $m$ – exponent in the equation of the fatigue curve; $p_i^k$ – the probability (frequency) of the action of the amplitude level $\sigma_{a, \omega}$ in the $i$-th interval of the $k$-th loading mode.

Based on the processing and analysis of the results, taking into account current regulatory documents and the nature of the goods transported, a decision is made on the further suitability or unsuitability of the wagon for operation.

4. Conclusions

Based on the results of the technical condition examination of the supporting metal structures of the dumping wagon bodies with the expired standard operating life, an insignificant percentage of their rejection was determined, which indicates the presence of a residual resource of the structure and the possibility of its determination. Based on this, a procedure is proposed for predicting the residual life of dumping wagons after long-term operation, which envisages the establishment of the actual technical condition of the wagon; physical and mechanical characteristics of the material; a series of virtual and full-scale tests of metal structures; determination of residual life based on the results.

The conformity of the supporting metal structure of the dumping wagon after long-term operation and the expiration of the standard service life to the current regulatory requirements have been determined. Correspondence was found on the basis of virtual and experimental studies of the stress-strain state of the wagon body structure taking into account its degradation.

Studies were carried out to determine the chemical composition and physical-mechanical properties of the structural material of the load-bearing elements of the body of a dumping wagon after long-term operation.

Based on the results of experimental data, the residual life of the supporting structure of the dumping wagon after its standard service life has been estimated.

A methodology for assessing the individual resource of a dumping wagon after a standard service life has been proposed.

References

Justification of Technological Parameters of Transport Infrastructure when Construction of Specialized Terminals in Sea Ports

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Abstract

The article shows the need to apply a differentiated approach to calculations for the selection of technological parameters of transport infrastructure in seaports. The methodology for the creation and detailed development of mathematical models for the design and construction of grain terminals has been substantiated. It is proposed to consider ensuring the established level of reliability of servicing freight traffic as an indicator of the efficiency of the port infrastructure. The paper substantiates the need for further improvement of the infrastructure of such production systems, which are characterized by deep integration into the international logistics network.

KEY WORDS: mathematical modelling, specialized terminals, transport infrastructure, warehouse, economic indicators, transportation and technology processes.

1. Introduction

Comprehensive studies of the efficiency of servicing material flows in seaports require a differentiated approach to mathematical modelling of production processes [1]. The creation and detailed development of mathematical models must necessarily be associated with the need to take into account a large set of random factors that affect the current and final results of the entire production system [2]. From this point of view, the use of vehicles for moving agricultural goods should be considered as a single technological process, formed from the individual components of the system [3]. In this case, an indicator of the efficiency of the transport and warehouse system is considered to ensure the established level of reliability of servicing freight traffic, which consists in moving a certain volume of final agricultural products for a certain period [4]. It is clear that such a system must be simultaneously determined by such a level of economic indicators of the work performed that will satisfy both the performers of transport and warehouse operations and their customers at different levels of market economy relations [5].

Optimization of logistics costs when servicing freight flows of agro-industrial production involves the creation of mathematical models with a deterministic nature of technical and technological indicators. In this case, the theoretical prerequisite for performing the relevant calculations is the assumption that the numerical values of the influencing parameters of the transport and warehouse system should be clearly defined [6]. However, mathematical modelling of the process of servicing such traffic flows should take into account the random nature of the current values of individual infrastructural elements [7]. The formation of the infrastructure of terminal systems for servicing agroindustrial cargo flows in a number of cases is considered using the basic provisions of the theory of optimization of material resources [8]. Application of the proposed methodology for moving such products allows for multivariate calculations to determine the resulting indicators of generalized logistics costs, taking into account the influence of individual interrelated factors [9]. At the same time, modelling of the production process takes into account the peculiarities of servicing agro-industrial cargo by various types of rolling stock, the intensity of using the existing infrastructure in the terminal system, as well as the prospects for using the production capacities of individual enterprises and transhipment facilities [10].

2. Calculation of Technological Parameters of Transport Infrastructure During the Construction of Port Grain Terminals

The use of the theoretical provisions of the linear programming method makes it possible to determine the necessary technical and technological parameters of the infrastructure of the transport and warehouse system, provided that the minimum value of the generalized logistics costs is achieved \( W_{\text{opt}} \). But the results obtained make it possible to determine the numerical values of the terminal infrastructure of the system, provided that all the initial parameters of such a formation are clearly defined values. However, in the conditions of market relations, the values of a number of infrastructural indicators are of a random nature. Therefore, to make final decisions in such cases, methods of stochastic programming are used.
The main purpose of using stochastic models and methods to optimize the production process in terminal systems is to take into account the entire range of changes in possible values of infrastructure parameters. The reasons for this behaviour of the input information in the economic and mathematical models of the production direction are explained both by the distribution of agricultural cargo flows in space and time, and by the technical state of individual elements of the system, as well as by the influence of weather and climatic conditions on the characteristics of the transportation process in the agro-industrial complex. The practical application of stochastic models in the process of forming the infrastructure of production systems makes it possible not only to ensure the appropriate reliability and a certain accuracy of current calculations, but also to solve a number of production problems, the implementation of which using only deterministic models becomes almost impossible.

Vrahoyuchy speciality of the vakonannya and the growth of the exchange of export transport of grain vantages, especially the respect for organizing the invoice of trade deliveries of the vantages through the sea trade ports. The established tendencies to the increase in export and transit of the designated products through the territory of the state have improved the scientific prospects for the development of technological and structural ambushes for improving transport safety.

Carrying out analyzes allowed for the development of visnovoks about those that are profitable and sea ports for the clever organization of trade, efficient distribution of vantage flows and economic robots for healthy operations in transport. The results of the function of motor transport enterprises, like those of the state structures, play a vital role in the process of the advance accumulation of grain vantages at the enterprises of the elevator and warehouse state gifts. In such a setting, the food service is like the servants who live in the fields in that, in the process of transporting grain, the products have preserved their cobs of power. With the most up-to-date, there is a growing list of on-board vehicles and hobby vehicles.

In the world of increasing the amount of support for the accumulated delivery of grain vantages, and, as a matter of fact, for the acceleration of the tasks of transport services, with a change in the flow of automobiles, the transportation of more urgently needed transport services. To this, for transport universities, an important characteristic is the recognition of the terms accumulated and the processing of the export party of vantages. They are sensitive to the vague nature of the vantage for the processing and the unavailability of the vantage for the processing of grain vantage flows, transport universities are responsible for the need for the storage needs of the warehouse.

The values of the way of keeping stocks in a short period of time, when collecting vantages in warehouses of additional stocks of additional permutations, and the accumulation of grain on wheels to bring a part of the wagons for the turnover. In addition, because of the preservation of the need for the processing of grain vantages, the practice of servicing the significant vantage flows is included in the operation at the territory of the port of port elevators and special grain processing complexes.

Given the peculiarities of the implementation and growth of exports of grain cargo, special attention should be paid to the organization of foreign trade supplies of these goods through sea trade ports. The established tendencies to increase the export and transit of these products through the territory of the state outlined the scientific prospects for the development of technological and structural principles for improving the transport of grain cargo under the condition of railway transport and seaports.

The analysis allows us to conclude that railroads and seaports, provided a clear organization of trade, even distribution of freight flows and coordinated operation of these modes of transport are able to carry out foreign trade operations with significant annual volumes. The results of the functioning of motor transport enterprises, as separate economic structures, play a crucial role in the process of preliminary accumulation of grain cargo at the enterprises of elevator and warehousing. In this formulation of the question, the quality of customer service is that in the process of transportation of grain products retain their original properties. To this end, the issue of using on-board cars and hopper trains becomes relevant.

Decision-making based on the results of the analysis of the random nature of production processes in terminal systems significantly depends on the target basis and information structure of mathematical models. Therefore, the problem of rational distribution of material resources in terms of stochastic programming is formulated as follows: determine the vector \( X = (x_1, x_2, ..., x_n) \), at which the results of the function, in addition to the controlled parameters \( X \), also depend on some random variables \( \omega = (\omega_1, \omega_2, ..., \omega_n) \), for which components:

\[
\begin{align*}
\max (\min) F &= f(X, \omega), \\
q_i(X, \omega) &\leq 0 (i = 1, m), \\
X &\geq 0, \ \omega \in \Omega,
\end{align*}
\]  

(1)

where \( \Omega \) — a set of influencing factors \( \omega \).

To solve the problem of improving the efficiency of functioning and improving the infrastructure of the terminal system on the example of servicing freight flows of the export and transit directions, provided the basic characteristics of the random parameters \( \omega \) are known, the objective function can be the minimization of the mathematical expectation of the generalized \( W_{ob} \) of logistics costs. Depending on the possibility of obtaining and taking into account information about the stochasticity of the functions \( f(X, \omega) \), \( q_i(X, \omega) \), the condition for setting mathematical programming problems
should be the presence of the corresponding coefficients of the objective function and deterministic constraints. Under such conditions, the vector $X$ is a random variable of the mathematical model, and therefore a function of $\omega - X(\omega)$. And the optimization of the objective function is interpreted as the minimization of the mathematical expectation of the generalized $W_{\omega o}$ of logistics costs.

Mathematical modeling of transport and warehouse services for agro-industrial cargo flows takes into account the random nature of economic and technological indicators that characterize production processes in port terminals. Methods for solving stochastic programming problems provide for the construction of functions $f(X, \omega)$ and $g_i(X, \omega) \leq 0, \ i = \overline{1,m}$ on the basis of information regarding the parameter $\omega$ with the subsequent transition to a deterministic analogue of the problem. Limitations in stochastic economic and mathematical models of such production systems are determined both due to the random nature of technological processes of moving agro-industrial goods, and as a result of the impact of the peculiarities of performing maintenance of these cargo flows. In problems with a random nature of the quantities $\omega$, the constraints are specified as

$$g(X, \omega) \leq 0.$$  \hspace{1cm} (2)

The impossibility and sometimes inappropriateness of the requirement that the found solution satisfies condition (2) for any realizations of random parameters $\omega \in \Omega$ forces us to apply less stringent parameters of constraints. In particular, instead of unconditionally fulfilling the initial requirements, it is allowed to fail to fulfill the conditions with a certain probability:

$$P\{g(X, \omega) > 0\} \leq \gamma.$$  \hspace{1cm} (3)

Then, if $f(X, \omega)$ is a function that determines the efficiency of the plan for given $X$ and $\omega$, then the problem of creating an optimal deterministic plan $X$ with random parameters $\omega$ is formulated as

$$(\max) \min Mf(X, \omega)$$  \hspace{1cm} (4)

under the terms

$$P\{g(X, \omega) \leq 0\} \geq 1 - \gamma ;$$  \hspace{1cm} (5)

$$X \geq 0, \omega \in \Omega.$$  \hspace{1cm} (6)

Thus, in order to efficiently allocate material resources, it is necessary to maximize the average expected efficiency of their optimization. A prerequisite for this is that the limitations of the corresponding resources and ensuring the reliable operation of the infrastructural elements of the production system are met with a probability of $1 - \gamma$. For practical use, a mixed system of restrictions is expedient, that is, one part of the restrictions can be fulfilled on average, and the other with a certain probability.

To create a set of measures to improve the infrastructure of terminal systems based on the known characteristics of the probability distribution of random parameters, a one-stage stochastic programming model is used for mathematical modeling of transportation processes. For production formations of export orientation, the specified problem is formulated in the following setting: to determine the plan $X$ of the infrastructure support of the transport and warehouse system, for which the objective function of minimizing the generalized $W_{\omega o}$ of logistics costs with appropriate restrictions has the form:

$$\min M\left\{\sum_{j=1}^{n} c_j(\omega)x_j\right\},$$  \hspace{1cm} (7)

$$P\left\{\sum_{j=1}^{n} a_j(\omega)x_j \leq b_j(\omega)\right\} \geq p_i(i = \overline{1,m}),$$  \hspace{1cm} (8)

$$x_j \geq 0, \omega \in \Omega\left\{j = \overline{1,n}\right\}.$$  \hspace{1cm} (9)

Under such conditions, the algorithm for the implementation of the mathematical model of the optimal distribution of material resources provides for the use of well-known methods of the theory of linear programming. The intensity of using the infrastructure of production systems for individual transportation schemes is characterized by a matrix of coefficients, and the vector of limiting infrastructure resources determines the features of using the material and technical base of the transport and warehouse system. First of all, the numerical values of the infrastructural restrictions of the combined consignment of goods take into account the possibility of parallel accumulation of other grain consignments and crops. This possibility was taken into account by the vector of restrictions for such indicators as
the capacity of linear elevators for the shipment of grain $U$, the design capacity of the grain terminal for handling railroad cars $D$ and the capacity of the port elevator $H$. The restrictions on the capacity of the customs-licensed warehouse $M$ provides for the use of the corresponding elevator and warehouse enterprises for the needs of the processing industry, and the availability of grain resources in the farms $Q$ takes into account the limited possibilities of using vehicles $E$ in the specified region.

The productivity of the designed and built grain terminals for handling railroad cars $D$ is one of the influential factors in ensuring the reliability of transhipment operations. This factor becomes especially significant in the context of the creation of an export consignment with a large volume of railroad traffic. Using the example of the functioning of the Odessa Commercial Sea Port, an increase in the throughput of the grain terminal $D$ from 30 to 110 railway cars per day and an increase in the capacity of the port elevator $H$ from 5 thousand tons to 25 thousand tons reduce the sum of the generalized logistics costs $W_{ob}$ by 19.2%. This tendency is explained by a decrease in the specific weight of the ship's loading according to the direct option and an increase in the volume of grain cargo traffic, the maintenance of which requires the use of the capacity of the port elevator. And according to the conditions of ensuring the productivity of the grain terminal $D \geq 70$ wagons / day, it becomes expedient to reload grain from railway wagons onto ships by using ship loading machines. This scheme is used especially intensively under the condition of insufficient free capacities $H$ in the port elevator.

A differentiated analysis of the reliability of servicing grain cargo flows and the efficiency of transportation indicated the need to diversify existing routes and use the existing infrastructure of the terminal system. Further development of the range of transportation services and an increase in the throughput of the main transport hubs contributes to the further development of export and transit transportation of grain cargo between countries. And since the sea trade ports of Ukraine are natural transhipment points of the route network, the decisive factors for the effective use of individual infrastructural elements in most cases can be the provision of not only transportation, but also logistics services.

Of great importance in the structure of production systems for servicing transit and export cargo flows is the performance $Z$ of the port terminal's ship loading machines. The performed multivariate calculations indicate the influence of the normally distributed random value of the productivity $Z$ of ship loading machines on the throughput of direct grain loading mechanisms $G$ and the useful capacity of the port elevator $H$ (Fig. 1).

![Fig. 1 Dependence of the productivity of direct loading mechanisms (-----) and the capacity of the port elevator (-----) on the reliability of the ship loading machines, subject to their design capacity, t / day: 1 - 1500; 2 - 2500; 3 - 3500; 4 - 4500; 4 - 4500](image)

Thus, an increase in the reliability of the transhipment complex $p(Z)$ from 0.75 to 0.95, provided the coefficient of variation of the indicated indicator $\sigma_Z = 25\%$, makes it possible to reduce the volume of loading according to the direct option by 5.8% for $Z = 1500$ t/day, by 22.1% – for $Z = 3500$ t/day and 84.8% – for $Z = 5500$ t/day. The rapid decrease in the intensity of the use of mechanisms for direct loading of vessel $G$ is explained, first of all, by a decrease in the volume of grain movement according to the direct option and a corresponding increase in traffic using port elevators and ship loading machines. The expediency of the indicated redistribution of grain cargo traffic is based on the relatively lower cost of logistics services $C$ of the last two technological schemes.

At the same time, increasing the reliability of the functioning of ship loading machines $p(Z)$ requires an increase in the capacity $H$ of the port elevator. An increase in the $p(Z)$ index from 0.75 to 0.95 requires additional free elevator capacities $H$ from 1.8 thousand tons for $m_Z = 1500$ t / day to 3.9 thousand tons for $m_Z = 5500$ t/day. The need to increase the volume of preliminary accumulation of grain cargo in the transport hub, provided that the power of the ship loading machines $Z$ is increased, is dictated by the more intensive use of the corresponding technological scheme.
However, the proposed measures are associated with solving the issues of the technical state of system elements, the organizational structure and the efficiency of using transport and technological processes, as well as the regulatory framework. The creation of such production systems opens up new prospects for the formation of a regional logistics network.

Further improvement of such systems is characterized by deeper integration into the international logistics network. Improving infrastructure in the design and construction of new grain terminals is an essential condition for attracting additional grain cargo flows. In order to increase the throughput and efficiency of transportation capabilities, operators of the logistics market need to strengthen marketing work with promising customers of warehouse services by offering high-quality marketing products, using flexible management of the production process and access to available infrastructure facilities.

3. Conclusions

Based on the results of the calculations, the main directions of scientific research are determined in order to develop methods for organizing and managing the system of centralized transportation of grain crops. Creation of organizational bases for transport service of export and transit of grain crops allows to provide increase in throughput of transport system, improvement of its competitiveness for grain cargoes. Systematic management of interconnected processes of grain transportation in the involved production structures in full compliance with all incoming and outgoing operations in their sequence in time and space allows to coordinate the work of different modes of transport in a single logistics service system. And the consistent improvement of export monitoring and sound management decisions with the involvement of centralized management with a high level of information and control improves the system of delivery and processing of grain cargo flows through the operational management of all components of a single transport system.

The use of modern mathematical models in the design and construction of grain terminals, taking into account market relations, opens up new potential in the creation of infrastructure support. The advantages and prospects of creating a regional network of logistics centers are associated with solving certain problems within the framework of a joint strategy for the systemic development of transport hubs. The studies carried out to substantiate the parameters of the transport infrastructure in the design and construction of grain terminals are aimed at the effective functioning of these facilities in the economic complex of the country.

References

Pedestrian Vehicle Accidents and Design of a Test System for the Needs of Forensic Science

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Abstract

Traffic accidents between vehicles and vulnerable road users have fatal consequences in most cases. Despite the development of active and passive vehicle safety and significant progress in the use of autonomous systems, there is still a need to pay increased attention to these accidents. Investigating such accidents is not an easy task and in most cases and it is a very time-consuming process, both in terms of time and in terms of the technique needed to perform deep investigation and potential verification of the accident scenario. The affordable and technically achievable test system which would be able to perform and reproduce accident scenarios is a kind of solution that will help forensic engineers to understand the physic of accidents in more detail.

KEY WORDS: pedestrian, traffic accident, testing, vehicle

1. Introduction

Even though the current trend of increasing the active safety of vehicles and the advent of autonomous vehicles is obvious and unstoppable, it is necessary to realize that transport as we know it today will be with us for at least 20 years [1]. An overall change and progress to the next level will only take place if people switch to use purely autonomous vehicles whose interaction with each other, as well as with other road users, is known, verified and safe. Last but not least, the quality of transport infrastructure and availability of robust legislation are key aspects which will influence the standard usage of autonomous vehicles on higher level. As we are still very far from the described situation, it is still necessary to pay great attention to the traffic accidents and especially accidents of vehicles with vulnerable road users (pedestrians).

Each accident and especially interaction between vehicle and vulnerable road users (e.g. pedestrian) is an accidental and very complex action. The detailed and authentic reconstruction is very difficult and, in most cases, impossible. To clarify complicated traffic accidents, forensic science use historical data of accidents from the past or from simulated crash tests. A crash tests is a specific act which represents essentially controlled and planned interaction between test vehicle and pedestrian dummy, the objective of which is to help to identify or verify certain essentials concerning the condition of individual participants in a traffic accident in particular stage of the accident. The crash test of a vehicle with a pedestrian dummy is particularly specific, because it is very difficult to simulate the real behavior of a pedestrian (e.g. stopping, accelerating, reversing, etc.) just before collision and the realistic movement of human body afterwards.

2. Trend in the Numbers of Accidents and Fatalities in the EU

In 2010, the EU set a target (European Commission, 2010) to halve the number of road fatalities by 2020, with respect to their level in 2010. Figure 1 explores to which extent this target has been met and compares the EU target (dark blue line) to the present observed number (light blue line) across the 27 EU Member States [2].

Fig. 1 shows that between 2010 and 2014 the number of observed road fatalities was close to or even below the target. However, during the five subsequent years, the number of road fatalities stabilized between 24,400 and 22,700. As a consequence, in 2019 the observed number of fatalities exceeded the target by almost 8,000. The observed trend suggests that the EU target for 2020 will not be met. However, significant progress has been made: in 2019, the number of fatalities was 58% lower than in 2000 and 23% lower than in 2010 [2].

In 2016, 5,320 pedestrians were killed in road accidents in the EU (excluding Lithuania and Slovakia), which is 21% of all road fatalities. During the decade 2007-2016, in the European Union, pedestrian fatalities were reduced by 36%, while the total number of fatalities was reduced by almost 41%. Fig. 2 shows the trend of the number of pedestrian fatalities over the period 2007-2016 in comparison with the respective trend of total road fatalities over the same period [3].
Despite of significant reduction of pedestrian fatalities in last decades, constantly increasing number of vehicles in all over the world will never allow to completely eliminate pedestrian fatalities. The further investigation and development of deep knowledge which will help to understand the interaction of vehicle and pedestrian, is an essential requirement to achieve further reduction of all road fatalities.

3. Analysis of Pedestrian Movement before Interaction with the Vehicle

The video analysis performed on 398 traffic accidents (interaction between vehicle and pedestrian) provides relevant outcome related to behavior of pedestrian just before interaction with vehicle.

Fig. 3 shows the graph which represents 398 analyzed traffic accidents, only 42% of pedestrians did not change their movement before collision and continued with constant speed and direction during entire action. The pedestrians did not register incoming vehicle neither by peripheral vision nor through their hearing (e.g. rolling tires, engine sound, brake sound, etc.), thus they did not react by changing their movement. The Pedestrians, who increased their speed in the same direction in which they walked before the collision represent 12% of monitored cases [4].

In all cases where the pedestrian does not react or increases his speed it is possible to apply time prevention of a traffic accident. If the pedestrian does not react to the incoming vehicle, a possible reaction by increasing the pedestrian’s speed does not affect the result of the simulated prevention, or it will affect it positively [4].

The next representative group of pedestrians were those who stopped just before the collision. These pedestrians represent 22% of the total number of monitored traffic accidents. If the pedestrian stops just before the moment of a collision, it significantly affects the calculation of the time prevention of a traffic accident with a pedestrian. Stopping a pedestrian increases the time when the pedestrian stays in the corridor of the vehicle's movement (to infinity) and thus makes the time prevention of an accident unusable. 10% of pedestrians out of the total number responded to the incoming vehicle by slowing down their movement. 8% of pedestrians responded by tripping to the incoming vehicle. Bouncing, reversing, and jumping represents a group where none of them exceeded 4% out of the total number of monitored accidents [4].
4. Conceptual Design of the Test Equipment

Calculating impact speeds of vehicle-pedestrian collisions is a common task in traffic accident analysis. For the solution of this task, it is necessary to know boundary conditions (geometric and material) for vehicle and pedestrian safety [6]. The technical assistants in the vehicle have also a huge impact on the potential accident. The possibility to simulate a realistic crash tests (vehicle vs. pedestrian) will bring positive outcome also for better and detailed understanding of functionality and reliability of advance driver assistance systems (ADAS).

The most important condition related to the development of new test equipment is to provide a possibility to perform a most realistic test in terms of the behavior of the pedestrian dummy (speed, direction of the movement) before the interaction with the vehicle.

4.1. The Analysis of the Current State

Table shows the overview of existing mechanisms and their comparison based on defined key criteria. The criteria were defined based on conditions that need to be controlled during the entire test (speed of dummy) and requirements that should fulfill adequate robustness and mobility with a combination of the cost.

<table>
<thead>
<tr>
<th>Name of the mechanism</th>
<th>Brand</th>
<th>Crash test [Yes/No]</th>
<th>ADAS testing [Yes/No]</th>
<th>Max dummy speed [km/h]</th>
<th>Dummy type</th>
<th>Robustness</th>
<th>Estimated price [k Eur]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft pedestrian target (SPT)</td>
<td>AB Dynamics</td>
<td>No</td>
<td>Yes</td>
<td>40</td>
<td>soft</td>
<td>medium</td>
<td>150</td>
</tr>
<tr>
<td>Soft pedestrian target – one pulling rope (SPT)</td>
<td>AB Dynamics</td>
<td>No</td>
<td>Yes</td>
<td>40</td>
<td>soft</td>
<td>medium</td>
<td>150</td>
</tr>
<tr>
<td>6 D manipulator</td>
<td>Messring</td>
<td>No</td>
<td>Yes</td>
<td>-</td>
<td>soft</td>
<td>high</td>
<td>500</td>
</tr>
<tr>
<td>“Steve” – walking dummy</td>
<td>Toyota</td>
<td>No</td>
<td>Yes</td>
<td>-</td>
<td>soft</td>
<td>medium</td>
<td>50</td>
</tr>
<tr>
<td>LaunchPad technology</td>
<td>AB Dynamics</td>
<td>No</td>
<td>Yes</td>
<td>50</td>
<td>soft</td>
<td>medium</td>
<td>150</td>
</tr>
<tr>
<td>UFO</td>
<td>Humanetics</td>
<td>Yes</td>
<td>Yes</td>
<td>80</td>
<td>Soft/hard</td>
<td>high</td>
<td>450</td>
</tr>
<tr>
<td>4active SB/XB</td>
<td>4active</td>
<td>No</td>
<td>Yes</td>
<td>25/40</td>
<td>soft</td>
<td>medium</td>
<td>150</td>
</tr>
</tbody>
</table>

As the figure above shows, most of the existing mechanisms do not offer possibility to perform crash test with pedestrian dummy which represents human body in terms of size, weight, and body construction. All mentioned attributes have significant impact on process of the accident and result as well.

4.2. Definition of Main Objectives for the New Testing Mechanism

The criteria for the new mechanism were determined based on the analysis of the current state and the needs of forensics science, which are important for the relevant investigation of accidents between pedestrians and vehicles.

Technical objectives:
- Possibility to perform the test with a static dummy.
- Possibility to perform the test with a moving dummy (representing the real human body).
- Possibility to test advanced driver assistance systems (ADAS) with the soft dummy.
- Ensuring the repeatability of each test.
- At the moment of contact of the vehicle with the dummy, this must not be in the contact with any guiding elements of the mechanism.
- Ensuring the repeatability of each test.
- If there is a risk of contact between vehicle and dummy (soft) during the autonomous emergency braking test, the dummy must be released from the guiding mechanism to avoid damage to the vehicle, dummy or mechanism. Otherwise, it must remain connected to the mechanism.
- The mechanism must ensure variability regarding the definition of the pedestrian movement towards the vehicle (side impact - various angles, front impact, rear impact).
- Mechanism has to ensure ‘just in time’ release of pedestrian dummy to secure direct contact between the road surface and the feet of a pedestrian dummy (In case of crash test vehicle vs. pedestrian dummy).
- Possibility to change the speed and direction of the movement just before the collision of the pedestrian dummy with the vehicle.
- Easy and fast assembly of the mechanism.
- Economic (operational) objectives:
  - The total cost should not exceed 15000 € (development, material, testing) without pedestrian dummy.
  - The cost of operating the mechanism. The assumption in this particular case is expenses for electricity consumption and operation of the equipment. The assembly, disassembly and operation should be handled by two operators.
  - The device should be made of as many series-produced components as possible.

4.3. The Basic Concept of the New Testing Mechanism

The analysis of the current state and definition of main objectives are key attributes that define clear requirements regarding the new testing mechanism. As was mentioned above, the new mechanism will be dedicated for the implementation of crash tests (vehicle vs. pedestrian dummy) and testing of advanced driver assistance systems (ADAS).

The basic of the developed mechanism (see Fig. 4) is that it consists of at least one supporting structure (1) composed of at least one transverse beam and a pair of uprights and guide cage with an electric drive (2) being part of it. The movement of the cage (2) is ensured by an electric drive and gear rack, which is firmly connected with the supporting structure (1). The connection and possible release of the pedestrian dummy with the cage are realized by spring hook, which is controlled by an electromagnet. The cage movement and the activation of the solenoid are controlled by one synchronization unit (7) with analog and digital inputs for peripherals and thus allows to set the sequence of movement for the whole crash test run (e.g. direction and speed of movement) [5].

![Fig. 4 The basic concept of the new testing mechanism (1 – aluminium structure, 2 – guide cage, 3 – tensometer, 4 – light gates, 5 – vehicle, 6 – pedestrian dummy, 7 – synchronization unit)](image)

Fig. 4 shows the concept which uses light guides and tensometer like peripherals inputs. The light gate initiates the movement of the pedestrian dummy and at the same time can be used to calculate (verify) the impact speed.
Tensometer ensures timely release of the manikin from the guide mechanism. The synchronization unit is mainly used for reliable control of the test.

5. Conclusions

A prerequisite for the practical benefits of the testing mechanism should be its use to obtain information from simulations and reconstructions of crash tests, such as pedestrian dummy ejection and its orientation, size and type of vehicle damage, track lengths and others. The valuable advantage of such testing is the possibility of producing audiovisual material, the analysis of which can provide data and information. The information obtained in this way can be used in the future to clarify the technical cause of an accidents, particularly in conjunction with advanced reconstruction techniques (as presented i.e. in [7] and [8]) and to educate forensics experts. The verification of the reliability of advanced driver assistance systems can help to establish a database that can provide a comprehensive view on active safety.

Acknowledgments

The article was created with the support of the University of Žilina grant system for the project: “Guiding system design to perform impact tests (vehicle–pedestrian) and for testing the active and passive safety of vehicles”.

This paper is based on utility model registered in the Czech Republic –“Vodící mechanismus pro realizaci nárazových zkoušek vozidlo – chodec a na testování aktivní a pasivní bezpečnosti vozidel” (No.: 33 728).

The publication was partially supported 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 program 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 the Ministry of Education, Science, Research and Sport of the Slovak Republic.

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Conditions for the Use of Optimal Energy-saving Driving Cycles of Trucks on Highways

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Abstract

The research is devoted to the choice of the sequence of control modes of road freight vehicles. The selection criterion is to achieve the most energy-efficient truck driving. The restriction concerns the timely arrival at the final point of the route. The research is based on a theoretical model of optimal control of a road object movement using the principle of maximum. It was assumed that road conditions which cause definite rolling resistance are known for the achievable forecast horizon. At the level of modern telecommunication technologies, the probable forecast of road and traffic conditions reaches 800 m of the highway. The condition of absence of dissipation of energy of movement because of forced braking is observed. In contrast to known studies, it is considered that transport conditions can also be variable. Free movement of the car can be interrupted by obstacles on the highway. In this case, the pre-selected cycle, consisting of the phases of acceleration and free rolling, should be replaced by a shorter one. The new cycle should reduce the speed to the required place and time when there is a hindrance on the road. It has been found that the sum of the properties of all cycles can be no worse than the properties of one unobstructed cycle. It is shown that the horizon and the accuracy of forecasting road and traffic conditions should be sufficient to ensure that the shortest optimal control cycle with the required phase trajectory is placed in a real time frame. The study was conducted for both horizontal sections of the highway and for a hilly road on the example of the section of the highway E-471.

KEY WORDS: driving cycles, energy saving, forecasting horizon, highway, road condition, traffic

1. Introduction

Saving energy and reducing pollution in road transport are among the most pressing problems of our time. One way to solve them is to use automated vehicle control systems that operate within intelligent transport systems (ITS). The use of a minimum of energy resources for road transport is possible if one successfully uses the road and transport conditions and does not dissipate energy for to slowing down or braking. However, the random nature of the traffic flow on the transport network makes it difficult to follow this control method. Telemetry tools, which are developing rapidly in recent years, do not yet provide a proper basis for the implementation of ITS too [1]. After all, as the forecasting horizon increases, the error in estimating road obstacles increases too. To improve the efficiency of forecasting, a network of interacting on-board telemetry systems is used. However, the number of vehicles connected to such a network is extremely small, which makes it impossible to perform its functions [1, 2, 6, 9]. However, the cyclic operation of both internal combustion engines and electric motors, as well as hybrid power plants in transport cycles is of great interest to researchers as a means of reducing fuel consumption and reducing environmental pollution [1, 4, 5, 8, 19]. Thus, a study [1] of cyclic operation of a motor vehicle engine is presented in order to research the use of a hierarchical model-forecast control to minimize fuel consumption in a heavy truck, which is connected to the automated mode and connected to the onboard system. The authors pursued the goal of reducing fuel consumption in both urban and road transport cycles. The presented truck control scheme optimizes several functionalities of the chassis and power unit. These functions include: vehicle routing, adjustable intersections, optimization of phase trajectories, platooning, prediction of optimal gear shifting and torque generation at the request of the engine. The results suggest that reducing fuel consumption by 15-20% or more is potentially achievable, especially in urban areas. However, the authors of the article note a great contradiction between long-distance and highway cycles. Therefore, the possibility of jointly forming the working cycles of vehicles by optimizing the speed trajectory and the optimal schedule is insufficiently studied. Also, the article does not consider the temporal aspect of the transport task, which often contradicts the energy saving regime.

Recently, the interest of researchers has grown significantly in self-driving vehicles, as they remove the obstacle to achieving the minimum energy consumption, which is the driver, as the most inertial link of the system Driver-Car-Road-Environment [4, 7]. This applies especially to electric cars use, a charge which is sometimes not enough to traffic on the highway routes. In particular, article [7] presents a way to meet the requirements of efficient and comfortable driving for a self-driving car while driving on difficult routes. The idea is that for efficient driving, the following requirements must be met: 1) to follow the required phase trajectory (usually generated by the route planner), as accurately as possible, with the least deviation; 2) get to the destination as soon as possible; 3) comply with the requirements for driving comfort, which can be assessed by acceleration and deceleration (± 0.2 g m/s²); 4) adhere to
the dynamics of the vehicle (restrictions). However, the authors did not take into account that the formulated conditions are contradictory and this should be taken into account in the optimization problems.

In the papers of other authors [3, 5, 9-12] the possibility of achieving energy savings through the use of autonomous vehicles is questioned due to the need to adhere to driving safety. Instead, adaptive eco-driving strategies are proposed, based on modified cruise control systems, which serve as a driver and sometimes correct his actions. All of these systems use traffic forecasting to develop optimal controls. According to researchers the goal function is a minimum of dynamic maneuvers of the car, which are the causes of excessive fuel consumption. Optimization of this goal function within the Model Predictive-Control algorithm, allows the controller to generate steering commands, throttle control (throttle / brake), which meets the above requirements and limitations. Article [3], for example, presents a controller designed and implemented to effectively control an autonomous vehicle for maneuvering a pre-calculated complex phase trajectory obtained from a route planner. In this work, the baseline scenario of adaptive cruise control was compared to the case of achieving a 2.5% improvement in fuel saving of the fleet by improving rolling resistance and improving tire pressure maintenance.

The studies of optimal driving cycles of electric vehicles are of great interest in particular electric cars use the dynamics of the vehicle (restrictions). However, the authors did not take into account that the formulated conditions are contradictory and this should be taken into account in the optimization problems.

In [8, 10] it was proved that a loaded electric car with a DC traction motor with sequential excitation will move along the horizontal section of the highway, minimizing battery power consumption, only when the current in its supply circuit is formed by a periodic or quasi-periodic law. However, models that describe the most energy-efficient motion often have no solution, or their solution is unstable and strongly depends on the boundary conditions of the model. These models are mostly nonlinear. The only successful approach to their identification and solution is dynamic programming [1, 4, 12]. However, the question remains as to how far away from the optimal driving cycle of the vehicle in the detection of unexpected obstacles and how to restructure the next driving program within the forecast horizon.

In [8, 10] indicated that the main energy consumption of the vehicle to overcome the rolling resistance and the dynamic modes. However, the model of vehicle driving deliberately includes energy consumption for braking (dissipation). In each case, the driving of a heavy vehicle on such highways in free rolling mode will not exceed the allowable safe speed if the initial free rolling speed was chosen correctly [9, 11, 13]. Thus, the model of vehicle movement, built on the principle of minimum energy consumption, should not include braking force. However, non-braking control is possible when the driver or crew is sufficiently informed of the energy-efficient traffic cycle without hindrance. Then the choice of the optimal cycle can be implemented without hindrance.

2. The Method of Synthesis of Optimal Energy Savings Cycle with Restrictions

2.1. Formulation of the Purpose and Tasks of Research

The purpose of these studies is to establish the compliance of the choice of traffic program with the conditions of traffic safety and maximum energy savings of a heavy vehicle on the highway long-distance route. In previous works, we present the results of the study of the influence of the forecast horizon on the achievement of the optimal energy-saving cycle [14]. The truck driving in the main traffic flow on intercity route was studied. We consider the truck as a subject of the ITS. The car driving is carried out under the control of the onboard automated system and supervision of the driver. The on-board system of the car is connected to the ITS of V2V + V2I type [15]. Thus, the cruise control of the truck can be provided with the necessary input data for a sufficiently long length of the highway. However, any forecast of traffic conditions is not reliable. Therefore, unexpected changes may occur in the vehicle program, which, however, should not impair the purpose of the transport task. In each case, the vehicle control program must meet the optimality criteria with time constraints.

In this study, in contrast to the known models [1, 8, 18, 19], we accepted the hypothesis that when driving on a given route under known road and transport conditions, the energy of the truck power unit will not be spent on deceleration. Braking of the vehicle occurs by spending kinetic energy for rolling resistance of the movement. It is also taken into account that positive work can be performed not only by the driving force $P_d(t)$, but also by the horizontal component of the gravitational force $P_g(x)$ on the slopes of the highway. The content of the task is to select such modes of the truck driving on the highway, which allow to one to arrive from the starting point to the end point of a given route with minimal energy consumption while accurately scheduling. The truck must pass the specified section of the highway no more than the specified time. If we take into account the length of the main route, the truck can be considered on it as a material point. This task arises as optimizing then. The optimization criterion is written as follows:

$$E = \int_{t_0}^{T} \left( P_k(t) - P(x) \right) dx dt \to \min,$$

where $t_0$, $T$ — cycle start and end time, sec.; $x$ — coordinate, or the distance traveled by the car, m.

The restrictions of these studies apply to both fixed ends of the phase trajectory of the truck. Minimum and maximum speeds are restricted as well. The start time, start speed, and end time and end speed are set. During the truck movement on each forecasted section there can be some hindrances, therefore the truck should reduce speed to the minimum allowed on the highway. Additional hindrances that arise unpredictably are also additional limitations of the
task. In practice, the traffic driving program \( S \) on long-distance routes with known road conditions is much shorter than the length of the route of the car \( S_{nm} \). The optimal traffic cycle of vehicle, according to expression (1) depends on \( S \). Therefore, if their hindrance appears then such a cycle must be reviewed and changed. In this case the integral in expression (1) has fixed left and right boundaries. According to the principle of Pontryagin optimality [16] as well as algorithms of dynamic Bellman optimization [17] the route can be divided into set of sections so that the general traffic control program \( u(t), x = 0... S_{nm} \), consisting of partial optimal programs \( u(x), j = x_{c0}... S_{i} \), was optimal too. The solution of such a local problem was found by the methods of variational calculus. In particular, the mentioned principle of Pontryagin's maximum was used. The reduction of the initial problem of vehicle control optimization to the final-dimensional problem of mathematical programming was applied:

\[
\sum_{i=0}^{N} (u' \pm f_w^i)((t_{i+1}-t_i)x_2^i) \rightarrow \min,
\]

where \( u \) – the relative value of control, which means the ratio of the driving force of the truck to its total mass, N / kg; \( i \) – the index of the section of the route, which was divided \( S_{ni} \); with a system of conjugate equations:

\[
\begin{align*}
\frac{x_2^{i+1} - x_2^i}{t_{i+1}-t_i} &= u' - f'_w \pm f'_w x_1^i - f_w x_2^i - f_w \left(x_2^i\right)^2, \\
x_2^{i+1} &= x_2^i \frac{t_{i+1}-t_i}{t_{i+1}-t_i}.
\end{align*}
\]

\( x_2^0 = V_0; \ x_2^N = 0; \ x_2^i \leq V_{max}, i = 0,1,...N; \ u' \leq u_{max}; \ x_2^N \geq S, \)

where do we get

\[
x_2^{i+1} = \left(u' \pm f'_w \right) \left(x_2^i - f_w \left(x_2^i\right)^2\right) \left(t_{i+1}-t_i\right) + x_2^i,
\]

and

\[
x_2^{i+1} = x_2^{i+1} \left(t_{i+1}-t_i\right) + x_2^i,
\]

where \( f_w, f_w \) – constants, which reflect relative rolling resistance, which depends, respectively, on the road profile and air resistance.

The new problem relates to mathematical programming, the variables of which are \( x_2^i, i = 1,...N \) and \( u_i, i = 0,...N-1 \). In order for the on-board vehicle control system to ensure optimal control of the vehicle, it must be provided with the necessary optimal amount of input data. The input data flow of road and traffic conditions on highways is huge. Therefore, the optimization of the vehicle speed forecasting horizon on the intercity highway has been performed. The model is based on discrete moments of the traffic control process. It was found that the total amount of information increases with distance expanding of the traffic scanning process. The share of reliable information is reduced. It was found that the dependence of the indicators of the quality of vehicle traffic control on the size of the forecast horizon is piecewise continuous. In each continuous section, the dependence has the optimal value of the horizon. The next task of research now involves the implementation of optimization under different conditions of information support of traffic.

2.2. Application of Theoretical Models

The theoretical model (2) - (5) formulated above is used to develop real energy-saving cycles for road conditions on the example of the long-distance road route L’viv-Stryi (Ukraine) on the road E-471. The condition of the road surface, relief, plan and profile of the route are taken into account. Based on this, the route resistance profile of the route is constructed, a fragment of which \( f_w(t) \) is shown in Fig. 1. Using computer tools to solve the problem of mathematical nonlinear programming, we found the optimal control laws for the following initial conditions: the minimum cycle speed \( V_{min} = 15 \text{ m/s} \); coefficient of relative rolling resistance \( f_r = 0.0015 \); coefficient of relative air resistance \( f_w = 0.0015 \); the maximum allowed speed \( V_{max} = 35 \text{ m/s} \). The forecast horizon is 760 m, which is due to the possibility of modern telemetry. The optimal phase trajectory for unimpeded traffic is shown in Fig. 2. The laws of optimal energy-saving control, which correspond to different numbers of sudden hindrances on sections of the route, are shown in Fig. 3. The phase trajectories corresponding to these laws are shown in Fig. 4. The optimal control is an oscillating mode, on a straight hilly section of the road, i.e. one in which the driving force (drive of power units) of the car increases to achieve the nominal mode. After reaching this mode, the drive is turned off or switched to partial and the vehicle speed is reduced to a minimum - 15 m / s. Note that the acceleration of the car is carried out at the theoretically possible maximum value of the relative driving force \( u_{max} = 5.2 \text{ N/kg} \). The ratio of acceleration duration to cycle duration is 0.28. In real conditions, this can be realized only with certain dynamic characteristics of a vehicle. The section of free
rolling to the minimum speed is 232 m. The duration of the optimal cycle is 32 s, i.e. the average speed is 23.75 m / s.

The same laws of traffic and the corresponding phase trajectories have been obtained on a straight horizontal road, i.e. when $f_k = \text{const}$, but for this case the amount of energy to ensure the cycle is much more smaller. The speed of the truck varies here in the range of 15.9 … 32 m / s (see Fig. 2). On a hill, the car will be drove on a pulse mode with a restriction: acceleration-movement at a constant speed - free rolling. Here its speed does not fluctuate significantly, because there is an accumulation of kinetic energy, which is spent on the descent. Next, on the horizontal section (Fig. 5 and 6), the vehicle must again be drove in pulse mode without restriction. Total energy consumption per unit of total weight of the truck - 1,025 kW • h. / kg.

Fig. 1 Fragment of the road profile E-471
Fig. 2 The optimal phase trajectory of the truck at a 100% reliable horizon on a hilly section of the road of 760 m
Fig. 3 The relative value of the driving force in accordance with the optimal control of the drive, with different numbers of hindrances on a hilly section of the road
Fig. 4 Optimal phase trajectories of the truck with different numbers of hindrances on a hilly section of the road
Fig. 5 Optimal phase trajectories of the truck with different number of hindrances on a horizontal straight road
Fig. 6 The relative value of the driving force in accordance with the optimal control of the drive, with different number of hindrances on a horizontal straight road

The method of constructing a model of optimization refers routes of arbitrary length and longitudinal profile. It also does not depend on the type of rolling stock and category of roads. Using the principle of optimality in dynamic systems, this technique can be used even if the exact conditions of movement for the car along the entire route are not known.

2.3. Experimental Verification of Models

In order to verify the theoretical statements based on the conceptual model (1), experiments were performed. Experimental studies were conducted on the suburban road E-471 in the L’viv region in the direction of L’viv-Stryi, which has a dry flat and hilly road surface, which is in good technical condition. According to the parameters, this road
The sections of the road on which the research was carried out, laid on hilly terrain, has no intersections with other roads, pedestrian crossings, areas with limited visibility, bridges, narrowings. The research was conducted at the time of the lowest traffic intensity (Sunday, 8:00-9:00), which did not reach 5 cars / hour. The visibility of intersections with other roads, pedestrian crossings, areas with limited visibility, bridges, narrowings. The research was conducted on a truck train consisting of a DAF XF 105 tractor unit, engine capacity 12.9 l, 2018. with a total mileage of 70 thousand km. + Cogel Cargo SN 24 semitrailer. The car and the semitrailer were in good condition. The truck train was without cargo. There were two people in the car: the driver and the passenger. Measurement of cycle duration was performed using an electronic stopwatch and controlled by a DOD GSE 550 video recorder, which also determined the instantaneous speed and distance traveled. Engine performance was recorded in real time using a Scannomatic device connected via a diagnostic connector and a DB25 adapter to a PC, and the appropriate software. The change of indicators over time was recorded, namely track fuel consumption, instantaneous vehicle speed, crankshaft speed. The following modes of traffic were used: 1) acceleration from the initial speed, respectively, 15, 20, 25 m / sec. to, respectively, 25, 30 and 35 m / sec. with the minimum acceleration (minimum admissible speed of rotation of the engine v. at the given speed) on direct transfer of transmission; then - free rolling with the transmission off until the initial speed is reached; 2) the same cycles of acceleration - free rolling, but with the maximum acceleration (a rail of a fuel nose - as much as possible open); 3) steady traffic with an average speed of 21.1 m / s, the engine is running in partial mode (the fuel pump rail is not fully open). Each experiment was repeated three times in the forward and reverse directions of the road. Appropriate oscillograms have been recorded. The experiments were performed at different maximum achievable speeds, but the length of the truck train way traveled was constant - 760 ± 6 m. The data of the recorded waveform files were digitized. After that, tabular data was processed using Excel spreadsheets and the obtained cycles were compared with homogeneous ones at the average technical speed on a given section of the road. As a result, it was proved that the best practical results are consistent with the simulation under the condition of the most intensive acceleration to the highest possible of the maximum speeds (35 m/s - in this case). An example of experimental data, which achieved the maximum expected effect of fuel economy with acceleration of 15-20 m / s., is given in Table. As it can be seen from the Table experiments № 1, 2, 3 show that the cyclic waving driving of the truck is more economical in terms of fuel consumption than the mode of steady one, which is shown in experiments №4. The greatest savings are observed in those oscillating modes where the maximum speed does not significantly exceed the speed of free rolling. However, comparing the ratio of acceleration duration / cycle duration, we can see that for the most economical mode №3 it is the largest. This means that high acceleration is a negative factor in the vehicle's energy efficiency, taking into account the facts known from practice.

<table>
<thead>
<tr>
<th>№ experiment</th>
<th>Maximum speed, m/s</th>
<th>Minimum speed, m/sec.</th>
<th>Mileage, m</th>
<th>The ratio of acceleration time / cycle duration</th>
<th>Total fuel consumption, l.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>35</td>
<td>15</td>
<td>762</td>
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<tr>
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<td>766</td>
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<td>0,2600</td>
</tr>
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<td>3</td>
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<td>0,0</td>
<td>0,2940</td>
</tr>
</tbody>
</table>

3. Conclusions

The simulation results and experimental studies show that the most energy-saving program of vehicle driving on a straight horizontal highway is waving driving, which includes the phases of acceleration and free rolling. The duration of each of these phases depends on the total road resistance, and on the power and weight parameters of the vehicle and the cyclic mileage. If the horizon of reliable forecasting is reduced, it does not prevent to obtain the minimum total energy consumption on the total given section of the route. However, this reduces the comfort and safety of driving as the total acceleration and deceleration during movement on this section increases. At any forecasting horizon, waving driving on a horizontal straight road gives more energy savings than any program of driving on a hilly highway.

If road and traffic conditions change, while the forecasting horizon is reduced, this in turn causes energy costs for the same section of the highway to increase. However, the potential of the hilly road is used more efficiently. The energy consumption of cycles on a road with uneven road resistance largely depends on the initial and final speed restrictions. The difference in resource consumption can vary up to 17%.

The developed energy-saving cycles can be used in the management of a heavy vehicle when driving on the highway, provided the use of telemetry vehicles. The prerequisites for achieving the minimum possible energy consumption for a given heavy vehicle are the minimum horizon for forecasting road conditions and traffic jams. Also, energy-optimal driving cycles should be closely related to the desired timetable, i.e. the times of departure and arrival from the start and end points of the route and the required speeds at these points.

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Research of the Impact of Road Surface, Tire Pressure and Automobile Speed on the Braking Distance

J. Liebuvienė¹, V. Jokubynienė²

Abstract

Tests of braking distance on roads have become increasingly more popular. The comparison of different sets of tires under various conditions, such as wet asphalt, different car speeds, tire pressure, etc. led to significantly intensified vehicular transport, and consequently an increasing number of traffic accidents, when people are injured and even killed. This is why it is paramount to ensure safety inside a vehicle in order to minimize the risk of death and injury. This article presents research conducted using four sets of tires. The experiment was carried out on a dry, wet and slippery road surface at speeds of 40 km / h, 50 km / h, 60 km / h and tire pressures of 1 bar, 2 bars and 3 bars. Each individual test drive was repeated 3 times to obtain an accurate result. The Physics Toolbox Accelerometer programme was chosen for the research, which allowed us to accurately determine the stopping time and braking acceleration.

KEY WORDS: braking system, braking distance, braking efficiency, tires, road surface.

1. Introduction

Modern technologies used in cars in the last decade (anti-lock braking system (ABS), traction control (TCS), electronic stability system (ESP)) have provided a significant protection from accidents [1-3]. Car braking system allows to safely stop a moving car, slow it down or keep a parked car in a stable position under various road conditions [2, 4]. Car driving stability, its dynamic and performance characteristics are highly dependent on the quality and efficiency of braking [1, 4, 5]. Braking system is one of the most important systems ensuring road safety, so it is essential that it works properly [6]. Braking system is subject to very stringent requirements, as it is the most important active safety instrument of cars. International standards govern the braking system requirements [5, 6].

Car braking efficiency depends not only on the braking system, its construction or technical condition, but also on road conditions [4, 7]. Braking efficiency is expressed as the maximum permitted braking distance at the start of braking at a certain speed (40 to 80 km / h, depending on the vehicle category) and the deceleration in the steady-state braking mode [6]. The braking distance must be as short as possible, with a car maintaining balance and remaining steerable [8]. The maximum braking force occurs when all the wheels brake, i. e. when the load on all the wheels and their friction forces are used to the fullest [8]. Traction coefficient is the key parameter in predicting vehicle behaviour while braking and in other critical situations, as well as when designing active safety systems [9]. When drive wheel tires transmit longitudinal force to the contact surface while driving, a displacement occurs between the tires and the road contact, i. e. kinematic distances. The linear speed of the outer part of the drive wheel at the point of contact with the road is higher during traction than the speed of the centre of gravity of the car itself [10, 11].

The process of braking a car is an integral part of driving. Cars decelerate as a result of braking forces acting between tires and the road surface and from braking forces of all the braking wheels [12]. Car friction between tires and the road surface directly depends on the road surface and its quality [11, 13]. To avoid a dangerous or emergency situation, braking is one of the main ways to control a car. Braking efficiency depends directly on the driving speed, but even at the same speed, characteristics of the braking process will differ with different tires and road conditions [14].

The research object was four sets of premium class tires made in 2019.

The aim of the research was to test the braking distance on the road and to compare different tires under various conditions, such as wet asphalt, car speed, tire pressure, etc.

2. Research Methodology

The test research was safely conducted in “Autodromas”. Each set of tires was tested on dry, wet and slippery asphalt, also testing them at various speeds - 40 km/h, 50 km/h and 60 km/h. Tire pressure was also changed in the range from 1 Bar to 3 Bars. Each test was repeated three times to obtain accurate data. Physics Toolbox Accelerometer programme was selected for the visualization of the test. This programme also helped to calculate and predict the car braking distance and braking speed.

Four different 205/55 R16 sets of new winter tires were used in the braking efficiency research; according to the European Union tire labelling, the first set (1K) was class C in rolling resistance, class A in wet grip, 69 dB noise, load
index 91 and speed index T. The second set (2K) was class C in rolling resistance, class B in wet grip, 67 dB noise, XL reinforcement, H speed index and load index of 94. The third set (3K) was class E in rolling resistance, class C in wet grip, 72 dB noise, speed index H, load index 91, RUN ON FLAT tire type and had a puncture driving technology, and the fourth set (4K) was class C in rolling resistance, class B in wet grip, 69 dB noise, speed index T and load index 91.

The Physics Toolbox Accelerometer was used in the research presenting X, Y, Z coordinate values used to measure the position and acceleration of the device. The device shows when acceleration took place, the direction and the position. Rotation direction and position were measured using gyroscope sensors. The device measures the accelerator acceleration in m/s² and has a function to measure the time in seconds. The accuracy of the device is 0.2 m/s. We presented one experiment each out of the three.

3. Results

Fig. 1 presents results of the braking distance obtained during the experiment on dry road surface and tire pressure of 3 Bars, 2 Bars and 1 Bar. The braking distance was observed to shorten at the speed of 60 km / h when reducing the tire pressure. The first set remained most effective in this test.

The analysis of the results at the speed of 60 km/h revealed that the first time the pressure of 1 Bar had a 1.09 % advantage against the pressure of 2 Bars, however, compared to 3 Bars, efficiency increased to 16.59 %. The second time, the pressure had equal efficiency for the braking distance. At the pressure of 1 Bar, the car stopped 6.34% faster than at 2 Bars. The worst result was demonstrated at 3 Bars, when efficiency decreased by 14.63%. The third time, the grip with the road surface was the worst compared to sets of other tires. The best result of 11.8 meters was achieved at the pressure of 1 Bar. As the pressure increased, the grip became increasingly worse, with efficiency dropping by 8.9% at 2 Bars and 15.68% - at 3 Bars. For the fourth time, the best result was at the pressure of 1 Bar, which was 10.4 meters. Having increased the pressure to 2 Bars, the efficiency decreased by a mere 0.96%, but the braking distance increased by 17.6 % at 3 Bars.

The theoretical braking on the road was calculated when driving on dry quality asphalt. Table 1 shows that the theoretical braking on the road was longer in all cases when driving at the speed of 60 km / h, but in practice, the braking distance of the first set was shorter by 6.82 meters, it was shorter by 5.74 meters for the second set, 3.94 meters shorter for the third set and 3.94 meters shorter for the fourth set.

The analysis of the results at the speed of 50 km/h revealed that the first set demonstrated the best result of 6.4 meters at the pressure of 1 Bar. Having increased the pressure to 2 Bars, road surface friction decreased, also significantly reducing efficiency by as much as 15.78%, which in turn decreased by 18.75% at 3 Bars. The second set showed the best braking result at the pressure of 1 Bar, which was 6.9 meters. Increasing the pressure, the efficiency decreased proportionally. For the third set, the pressure of 1 and 2 Bars did not have any impact on efficiency; the braking distance was 7.9 meters, but having increased the pressure to 3 Bars, tire friction coefficient decreased, resulting in an 8.23% longer braking distance. The best braking distance of the fourth set was achieved at the pressure of 1 Bar and the braking distance of 7.1 meters. At the pressure of 2 Bars, car’s braking rate fell slightly, by 1.41%. An increase of the pressure to 3 Bars further reduced friction, which fell by as much as 9.86%.

Table 1 illustrates that going at the speed of 50 km/h, the theoretical braking on the road was also longer in all cases, but in practice, the braking distance of the first set was 4.58 meters shorter, for the second set it was shorter by 4.31 meters, for the third set – by 3.6 meters and for the fourth set – by 4.34 meters.

The analysis of the results at the speed of 40 km/h revealed that comparing all the sets, the best result was achieved at 1 Bar for the first set, and it was 4.1 meters. Having slightly increased the pressure to 2 Bars, the efficiency dropped significantly by as much as 24.39 %, and, compared to the best result, it fell by 28.05% at 3 Bars. The second set demonstrated the average friction and result for all the sets. The braking distance at 1 Bar was 4.7 meters. At 2 Bars, the braking distance increased by 7.45 % and by 39.74 % - at 3 Bars. For the third set, the pressure difference between 1 Bar and 2 Bars did not have a significant impact, the braking distance increased by a mere 2 %, however, having increased the pressure by 3 Bars, the braking efficiency decreased to 39.74 %. The fourth set was the only set where pressure had the lowest impact on the braking distance.

Data presented in Table 1 show that when driving at the speed of 40 km / h, the theoretical braking on the road was longer in all cases. However, the braking distance of the first set was shorter by 2.58 meters, 2.34 meters shorter for the second set, 2.16 meters shorter for the third set and 2.14 meters shorter for the fourth set.
The conducted research of the dry road surface showed that the first set of tires remained the most effective both when changing speed and tire pressure. The data in the diagram show that reducing the tire pressure increases the braking efficiency because a flat tire has a larger contact area with the road surface, which leads to better friction and shorter braking distance.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Braking distance, in meters at 40 km/h</th>
<th>Braking distance, in meters at 50 km/h</th>
<th>Braking distance, in meters at 60 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical braking on the road</td>
<td>7.39</td>
<td>11.71</td>
<td>16.71</td>
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<td>4.81</td>
<td>7.13</td>
<td>9.89</td>
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<tr>
<td>Second set</td>
<td>5.05</td>
<td>7.40</td>
<td>10.97</td>
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<td>Third set</td>
<td>5.23</td>
<td>8.11</td>
<td>12.77</td>
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<td>Fourth set</td>
<td>5.25</td>
<td>7.37</td>
<td>11.04</td>
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</tbody>
</table>

Research was conducted on wet road surface. The first set demonstrated the best braking distance of all the sets used in the research. The braking distance was 11.9 meters at 60 km/h, however, having increased the operating pressure to 3 Bars, braking efficiency dropped by 15.97%. The second set achieved the most effective braking torque of 12.8 meters at the tire pressure of 1 Bar. Increasing the pressure to 2 Bars reduced friction by 3.91%, but compared to 3 Bars, the braking distance increased by 16.41%. The third set demonstrated the worst result. The best result was 12.9 meters. Increasing the pressure to 2 Bars reduced efficiency by 6.2%, and the braking distance increased by 20.93% at 3 Bars. Efficiency of the fourth set was moderate compared to that of the other sets (see Fig. 2).

The theoretical braking on the road was calculated while driving on wet high-quality surface. At the speed of 60 km/h, the theoretical distance on the road was twice longer and even more than twice longer in some cases. However, for the first set, the braking distance was shorter by 18.86 meters, for the second set it was shorter by 17.89 meters, for the third set – by 16.26 meters and for the fourth set – by 17.46 meters. Practical braking data in Figure 30 were used to calculate average air pressures of different tire sets (see Table 2).

The analysis of the results obtained at the speed of 50km/h revealed that the first set achieved the best braking result, which was 7.9 meters. Such a result was achieved at tire pressure of 1 Bar. An increase of the pressure to 2 Bars led to a lower friction of 11.39%. Having increased the pressure to 3 Bars, efficiency decreased by as many as 25.32% compared to the best result. The braking efficiency of the second set was lower compared to the first set. The length of the braking distance was 8.7 meters at the lowest pressure. Increasing the pressure led to worsening results, when friction decreased to 9.5% and 29.89%, respectively, at 2 and 3 Bars. The third set was the only set demonstrating minimum pressure effect at 1 Bar and 2 Bars, reaching a mere 0.85%, however having increased the pressure to 3 Bars, efficiency decreased to 10.17%. The best result of the fourth set was 9 meters at 1 Bar tire pressure. Having increased the pressure to 2 Bars, the efficiency coefficient decreased to 10%, and having increased it to 3 Bars, it decreased by as many as 27.78%.

Data of Table 2 revealed that at the speed of 50 km/h, the theoretical braking was longer in all cases. However, the braking distance was 12.94 meters shorter for the first set, 9.8 meters shorter for the second set, 9.63 meters shorter for the third set and 7.73 meters shorter for the fourth set. At the speed of 40 km/h, the theoretical braking on the road was longer in all cases. However, the braking distance of the first set was 6.73 meters shorter, for the second set – 6.36 meters shorter, for the third set – 4.76 meters shorter and for the fourth set – 6.06 meters shorter.

The analysis of the results at 40 km/h revealed that the braking efficiency remained the highest of the first set at the lowest tire pressure of 1 Bar. The car stopped in 6.8 meters. Having increased pressures, the braking efficiency decreased from 4.41% to 14.71%. The best result of the second set was 7.1 meters. In all the sets, increasing tire pressure led to increasing braking distance. Increasing the pressure to 2 Bars and 3 Bars increased the length of braking distance from 7.04% to 16.9%. The best result of the third set was 8.7 meters, however increased pressure had no significant impact. The braking distance increased by 2.3%, but it grew to 13.79% having increased the pressure to 3 Bars. The best braking distance of the fourth set was obtained at the pressure of 1 Bar. The car stopped in 7.4 meters. Having increased the pressure to 2 and 3 bars, car braking distance increased by 6.76% to 14.86%.

![Fig. 2 Braking distance at the speeds of 60, 50 and 40 km/h on wet road surface with tire pressure of 3, 2 and 1 Bars](image)
Table 2

<table>
<thead>
<tr>
<th>Braking</th>
<th>Braking distance in meters at 40 km/h</th>
<th>Braking distance in meters at 50 km/h</th>
<th>Braking distance in meters at 60 km/h</th>
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<td>Theoretical braking on the road</td>
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<td>21.83</td>
<td>31.56</td>
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<td>First set</td>
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<td>Fourth set</td>
<td>7.9</td>
<td>14.1</td>
<td>14.1</td>
</tr>
</tbody>
</table>

The research carried out on wet road surface allows stating that the first set of tires demonstrated the best results. The braking distance was 6.8 meters, which is the shortest of all tire sets at the speed of 40 km/h. The results remained proportionally the same when changing speeds to 50 km/h and 60 km/h. Low and medium pressure was observed to have no significant impact on the third set, and the braking results of this set were the worst.

Fig. 3 illustrates research results on slippery road surface. The analysis of results at the speed of 60 km/h revealed that the best result of the first set was 18.2 meters at the tire pressure of 1 Bar. The braking distance increased with increasing pressure. Having increased the pressure to 2 and 3 Bars, the braking efficiency fell from 2.2 % to 23.08 %. The second set demonstrated a mere 0.55 % lower result compared to that of the first set. The best result was 18.3 meters. Having increased the pressure to 2 Bars, braking efficiency decreased by 9.34 %, while a pressure increase to 3 Bars increased the efficiency to 28.02 %.

The third set with tire pressure of 1 Bar demonstrated the best result at 60 km/h, which was 18.3 meters. Having increased the pressure to 2 Bars, the car stopped 1.38 % slower compared to 1 Bar, however, having increased the pressure to 3 Bars, car braking efficiency decreased further more – to 16.06 %. The fourth set remained the most efficient with tire pressure of 1 Bar. The length of the braking distance was 19.8 meters. Having increased the pressure twice, the length of the braking distance increased by 3.03 %, and having increased it to 3 Bars, the braking distance increased to 18.18 %.

Table 3 illustrates that at the speed of 60 km/h, the theoretical braking on slippery road surface was longer in all cases. The braking distance of the first set was shorter by 20.87 meters, the braking distance of the second set was 20.07 meters, it was 17.47 meters shorter for the third set and 19.37 meters shorter for the fourth set.

![Braking distance at 60, 50 and 40 km/h on slippery road surface with tire pressures of 3, 2 and 1 Bars](image)

The analysis of the results at the speed of 50 km/h (Fig. 3) revealed that the first set demonstrated the best result of 12.7 meters. Having increased the pressure to 2 Bars, braking efficiency decreased by 2.36 %, and the pressure increase to 3 Bars decreased efficiency by 23.19 %. The second set demonstrated the shortest distance of 14.1 meters. Having increased the pressure to 2 Bars, braking efficiency decreased by a mere 0.71 %, while a pressure increase to 3 Bars increased the braking distance by 15.6%. Results of the third set demonstrated a braking distance difference of 2.63 % with tire pressure of 1 Bar and 2 Bars, however, a pressure increase to the maximum limit of 3 Bars decreased braking efficiency by 13.82%. The shortest braking distance of the fourth set was 13.62 meters. With increasing pressure, the braking distance also increased. It was 5.73 % longer with the tire pressure of 2 Bars and 20.4 % longer with the tire pressure of 3 Bars.

At the speed of 50 km/h (Table 3), the theoretic braking on slippery road surface was also longer in all cases. However, the braking distance of the first set was 14.29 meters shorter, it was 13.2 meters shorter for the second set, 12.07 meters shorter for the third set and 13.27 meters shorter for the fourth set.

The analysis of the results at the speed of 40 km/h (Fig. 3) revealed the best result of the first set of 8.1 meters. Having increased the pressure to 2 and 3 Bars, tires lost their maximum efficiency, thus the braking distance increased from 3.7 % to 16.05 %. In case of the second set, the braking efficiency dropped by 2.22 % between 1 Bar and 2 Bars.

The comparison with the pressure of 3 Bars revealed that the braking distance increased significantly to 7.78 %. Result of the third set was the worst. The braking distance was as many as 9.8 meters at the pressure of 1 Bar. Increasing pressure resulted in increasingly worse situation, with the braking distance increasing from 3.57 % to 21.43 %. The fourth set demonstrated the shortest braking distance of 8.5 meters at the pressure of 1 Bar. Having increased the pressure to 2 and 3 Bars, the braking distance increased from 4.71 % to 14.71 %.
Table 3

<table>
<thead>
<tr>
<th>Braking</th>
<th>Braking distance in meters at 40 km/h</th>
<th>Braking distance in meters at 50 km/h</th>
<th>Braking distance in meters at 60 km/h</th>
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<td>Theoretical braking on the road</td>
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<td>40.57</td>
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<td>8.6</td>
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<td>Third set</td>
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<tr>
<td>Fourth set</td>
<td>9.05</td>
<td>14.8</td>
<td>21.2</td>
</tr>
</tbody>
</table>

At the speed of 40 km/h, the theoretical braking on slippery road surface was assumed to be longer in all cases. However, the braking distance of the first set was 9.36 meters shorter, 8.66 meters shorter for the second set, 7.36 meters shorter for the third set and 8.91 meters shorter for the fourth set (Table 3).

The research on slippery road surface allows stating that the first set demonstrated the best results at different speeds and pressures, while results of the third set were the worst, where braking distance was the longest (25.3 meters) at 60 km/h.

The research conducted with all the selected sets, different speeds, road surfaces, and different pressures allows stating that the road surface type has a significant impact on the braking distance efficiency. Comparison of the braking distance on dry and slippery road surfaces revealed that the length of the braking distance increases by as much as 97.5%.

Results of decelerating acceleration. The use of the Physics Toolbox Accelerometer allowed presenting values of X, Y and Z coordinates used to measure the position of the device and acceleration. The device shows when acceleration occurred, the direction and the place. This way allows presenting each test accurately and visually. Three different diagrams at different speeds were drafted to illustrate how braking differed on different road surfaces: dry, wet and slippery.

The graphs illustrate high initial friction on dry road surface, when the stopping time was 2.2 s. A sudden initial friction was observed on wet road surface, but friction lost control at the maximum friction point, with tires slipping on the road surface, causing the graph to fall sharply and rise again. The stopping process lasted 2.6 s. Compared to the dry surface, stopping time on slippery surface doubled, and lasted 4.9 s. (see Fig. 4).

The first graph illustrating dry road revealed that braking efficiency was sudden and remained efficient throughout the entire braking distance. This was due to the road surface being dry. The stopping lasted 1.7 seconds. On wet road surface (b), coefficient was high initially, however, wet surface does not allow to maintain such stability, with the car slipping proportionately, thus the stopping time increased to 2.4 seconds. Slippery road surface demonstrates very low and variable efficiency. The stopping time on slippery road surface increased to 4.1 seconds (see Fig. 5).
Braking remained sudden and stable on dry road surface. The stopping time on dry road surface was 1.4 seconds.

Braking efficiency on wet road surface also remained sudden, however, wet surface makes tires lose the grip, leading to a sudden drop in braking efficiency. Therefore, the stopping time was 2 seconds longer. On slippery road surface the situation was even worse. Braking was not efficient, immediately losing road surface friction. ABS brake system was activated, but the result remained the worst. The braking time increased to 3.01 seconds (see Fig. 6).

4. Conclusions

The research allows stating that road surface and tire pressure had the greatest impact on the length of the braking distance. Braking efficiency turned out to decrease by 21.74% on dry and wet road surfaces and to increase by as many as 94.78% on slippery road surfaces compared to dry surface.

Experiments with tire pressure revealed that at the pressure of 1 Bar, all four sets braked much better than at the pressure of 2 and 3 Bars. The third set is equipped with Run on Flat technology, which strengthens the edges of the tires and prevents the tire cords from deforming even at the pressure of 1 Bar. This factor allowed tires maintaining the same structure at 1 Bar and 2 Bars, thus some of the test results remained the same at different pressures or changed slightly.

The first set, which had class A friction with wet road surface, demonstrated the best results. Results of the second and the fourth sets were identical.

The comparison of the theoretical and the practical braking revealed that practical braking distance remained shorter.

The chosen Physics Toolbox Accelerometer programme allowed determining that the maximum friction between tires and the road surface was obtained on dry road surface. The graphs illustrate a sudden and even braking from pressing the brake pedal to the complete stopping of the car. The effect was worse on wet road surface, when a high friction coefficient was no longer obtained – tires lost grip and slipped. This factor reduces braking efficiency, but the ABS braking system helps tires to maintain friction. Braking efficiency is unstable on slippery road surfaces. The ABS brake system helps tires to achieve the maximum friction on slippery road surfaces.

References

Impact the Train Wi-Fi Systems on the GSM-R Network Service Availability

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Abstract

The article presents a thesis on the negative impact of the passengers Wi-Fi systems in train’s wagons on the operation of onboard GSM-R radios. As the source of interference of GSM-R radios, the author identifies transmitters and antenna used in Wi-Fi systems for communication via a public operators' cellular network in the 900 MHz band. The following sections present evidence to justify the thesis and an example of calculation. In the final section, the author proposes a solution can mitigate the negative phenomenon of interference of GSM-R onboards radios.

KEY WORDS: Internet on trains, Wi-Fi devices, GSM-R interference

1. Introduction

Since two decades, Wi-Fi (Wireless-Fidelity) systems have appeared in public places, in many countries around the world. The choice of Wi-Fi technology was not accidental. The technology has been available for many years as a group of standards in the IEEE 802.11x series [10]. Nowadays, practically all mobile devices, including laptops, tablets, smartphones, are equipped with such modems allowing to use this standard as a medium for connecting to local WLAN (Wide Local Area Network) networks and along them to the Internet. Due to the popularity of this technology, it has become an unwritten standard of free access to the Internet in many public places, such as meeting places (e.g. pubs, conference rooms), hypermarkets, public spaces (e.g. old town promenades, railway station lounges, hotels), but also means of public transport. In passenger transport, it becomes an indicator of carriers’ care for their clients. The idea behind the use of this type of equipment is quite simple. "A passenger travelling by train should have an access to the Internet for free via the popular Wi-Fi technology".

However, there is a fundamental technical problem with mobile access to Wi-Fi systems. In assumption, a Wi-Fi access point should have a guaranteed, broadband access to the Internet, allow to manage comfortable access for many Wi-Fi network’s users. In the case of a system installed in trains, it is not possible to meet the above conditions, because the vehicle cannot be wired to the global network. In this case, the Internet access gateway is implemented in the form of an alternative broadband access technology i.e. via Public Mobile Network (PMN). Among them the most common is the LTE (Long Term Evolution) standard and now the use of 5G technology.

At this point, attention should be drawn to another important aspect related to the Internet access medium in question. It is PMN availability in a given location. For example city bus moves constantly within range of public mobile networks in a city and the speed of public vehicles is relatively slow. In the case of rail transport, trains move between cities, through areas without dense transmitter networks, where occurs problems with the radio coverage (e.g. in basins, forests). Experience shows that the access public mobile network providers is not the same in a given location. This leads to practical solutions where multiple modems configured to work in parallel with multiple PMN operators appears to achieve higher connection stability or bandwidth aggregation to the Internet access.

Independent from the Wi-Fi train systems in the second decade of the 21st century occurred of significant incrementation of incidents of radio interference on GSM-R (Global System for Mobile Communications - Railways) railway devices. The main radio specification of GSM-R system introduce [7-9]documents and also system specification described in [6]. Observed incidents have had a negative impact on the train voice communication service as well as on the operation of the on-board radio equipment supporting functions of the ETCS (European Train Control System) Level 2 and it caused great concern among railway undertakings in Europe and also railway agency. Investigations undertaken at that time by the International Union of Railways (UIC) and involving the European Railway Agency (ERA), railway managers, manufacturers of GSM-R equipment and scientific research institutions have led to a number of studies and approaches to mitigate the effects of interference on GSM-R receivers. For example, CEPT ECC Technical Reports 96 [2], 146 [3] and CEPT Report 41 [1] identify and consider several scenarios between public mobile networks and GSM-R. Later Technical Report ECC 162 [4] focuses directly on the coexistence between public mobile networks operating in the 900 MHz band and GSM-R networks operating both in the GSM-R band (876-880 MHz / 921-925 MHz) and the E-GSM-R band (873-876 MHz / 918-921 MHz). Finally, Technical Report ECC 229 [5] provides a number of practical guidelines for railway managers, the application of which may lead to mitigation of the effects of existing radio interference.

Despite the knowledge acquired to date and the requirement to use improved GSM-R modems, the problem of interference with GSM-R train receivers has not disappeared and is still emerging in new ways. It leads to appearing the voice and data radio communication problems for railway staff, mainly drivers, and corruption of onboard ETCS systems using GSM-R as a medium for data communication with the RBC (Radio Block Center) and for controlling train...
movements.

In the following part of the article, an analysis of the impact of train Wi-Fi systems as a source of interference for on-board receivers of GSM-R networks will be presented.

2. The Case for GSM-R Interference

The experience of the European railways in the area of interference in the proper reception of GSM-R network signals, presented in the introduction, undeniably shows the negative impact of the transmitters of the public mobile networks operators working in the 900 MHz band. At that point, the impact of PMN modems (transmitters) installed on the roofs of passenger carriages as the sources of interference to devices operating in GSM-R network should be considered.

In the further part of the article, the above thesis will be proved on the basis of the collected premises.

2.1. Transmitters and Antenna Systems

From the radio technology point of view, the open Wi-Fi bands (2.4 GHz and 5 GHz) are far enough away from the UIC - GSM-R band (900 MHz) to cannot have direct impact as a source of radio interference. This thesis is also supported by the fact that the permissible power of the Wi-Fi Access point transmitters does not exceed 100 mW (20 dBm). Therefore, this power is too low to effectively interfere with a GSM-R network receiver. Furthermore, these transmitters are installed inside vehicles and are shielded by the metal cladding of the car roof. On this basis, it can be concluded that transmitters operating in the Wi-Fi bands do not create a threat to GSM-R equipment.

The main reason to a careful analysis of the impact of Wi-Fi access devices on GSM-R receivers are the antennas of the PMN Internet access devices mounted on the roofs of wagons and are capable of transmitting broadband signals in a band close to the UIC (GSM-R) band. In addition, they can be located in close proximity to train installations of GSM-R.

Observation of today's trains indicates that we have the number of the PMN antenna installations depends on the intended public operators as well as carriages or train sections. This means that the number of potential sources of strong out-of-band radio signals is greater than one and they occur on every single wagon. The antennas are in fixed and easily identifiable places and distances. Most often with direct visibility of neighbouring antennas. It can be assumed that the estimated minimum distance between the cabin antenna installation and the antenna installation on the nearest wagon will be about 20 - 30 m. This is based on the average length of locomotives (about 15 - 20 m). Further antenna installations will be spaced approximately the length of the carriage. The length of a passenger car is approximately 25 - 30 m. Depending on the number of wagons put together in a train, the number of sources and their distances from the GSM-R installations in the train can be determined. Fig. 1 shows an example train with points of antennas installation.

![Fig. 1 Example of a train with marked places of antenna installations (green point - GSM-R installation, red points - installations transmitting in the public band).](image)

A final important aspect of antenna installation is the directional nature of GSM-R antennas on trains. For GSM-R on trains, directional antennas are used in relation to the track axis and thus the vehicle. This can lead to greater 'sensitivity' to sources of interfering signals occurring along this axis.

2.2. Radio Bands Neighbourhood

At the outset, it should be stated that the PMN radio modem of a Wi-Fi system on a train behaves essentially like any other terminal in a mobile network. This means that there is no case widely discussed in various publications, in which the separation from the public E-GSM (Extended GSM) broadcast band is practically non-existent (925 ÷ 960 MHz band), as the 900 MHz transmitters for the Wi-Fi access network transmit in a band shifted down by 45 MHz (880 ÷ 915 MHz band). Fig. 2 is an illustration of this bands' allocation.

The figure shows the 900 MHz band with the division into Up Link and Down Link and a more detailed division of the band for public and railway network operators (UIC band - GSM-R band, R-GSM - UIC and GSM-R bands, ER-GSM - Extended R-GSM band, P-GSM - public GSM band, E-GSM - extended public GSM band). Orange indicates the band used by the access transmitters to the public GSM network. The red gradient indicates the band which is more susceptible to interference on GSM-R devices. The railway band is coloured green (UIC Band) and blue (Extended UIC Band).
In this context, the fundamental causes of interference in the GSM-R network should be recalled. Research has shown [4, 12-14] that interference is caused by excessive extraneous signals at the input of the radio receiver or by intermodulation signals. Figs. 3 and 4 illustrate the described phenomena.

**Fig. 3** The effect of receiver blocking as a result of the strong out of band signals (source: T. Weber, Activities in CEPT ECC/WGFM/Project Team FM54)

**Fig. 4** Intermodulation products as a result of receiving two signals by the receiver (source: T. Weber, Activities in CEPT ECC/WGFM/Project Team FM54)

ETSI TS 102 933-1 [7] introduces a conventional permitted level for adjacent foreign signals of -40 dBm for interfering continuous wave and -26 dBm for wideband interfering signals (for a 5 MHz block). This means that if a signal of this value or higher appears at the input of a GSM-R train device, it can lead to blocking of the receiver.

In the most sensitive band area, this will be the highest part of the public band due to the narrowest distance to the GSM-R band.

### 2.3. Intermodulation

The second cause of interference in GSM-R network receivers is intermodulation. This phenomenon is well known and described in many sources and also in the context of interference in GSM-R devices [12-14]. In the case discussed here, we can expect the formation of intermodulation interference below the P-GSM transmit band, as it is the PMN access transmitters that will be the source of the strongest signals, whose synthesis may lead to the formation of intermodulation signals. In this respect, it is also important to point out the possibility of parallel operation of access transmitters, in multiple frequency blocks, depending on the availability of public operator networks in a given location. Combinations of active frequency bands may therefore be different and may be a source of intermodulation interference. Third-order intermodulation will occur when two essential conditions are met:

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1. $f_0 = 2f_1 - f_2$ or $f_0 = 2f_2 - f_1$;
2. the strength of the signals $f_1$ and $f_2$ is above a given threshold.

In case of wideband signals (i.e. E) signals, it has been shown that a GSM receiver perceives the wideband signal as multiple 200 kHz signals. Therefore each single IM3 product has a 600 kHz bandwidth. In that case, multiple IM3 products may fall within the GSM-R band but it is not so easy to show as a formula.

As an example of calculation two strong narrowband signals was taken with frequencies $f_1 = 900$ MHz and $f_2 = 910$ MHz. The products of intermodulation will be seen for frequencies:

$$f_0 = 2f_1 - f_2 = 890 \text{ MHz};$$
$$f_0 = 2f_2 - f_1 = 920 \text{ MHz}.$$ (1)

The second interfering frequency will occur in the GSM-R down-link band. It can be assumed that if the signals $f_1$ and $f_2$ have values above -40 dBm then the second frequency will be the source of intermodulation signals in the GSM-R receiver.

2.4. Additional Sources of Interference

It is worth mentioning at the end of this part of the article that train PMN access transmitters of Wi-Fi systems are not the only sources of interference to GSM-R receivers on vehicles. The transmitters of public mobile network operators are further the primary source of interference and the aspects of the impact of local Wi-Fi transmitters discussed here should be considered as an additional component of the sum of all interference sources.

3. Computational Case Study

The author of this article is not aware of the exact technical specifications of the devices installed in trains to distribute the Internet signal using Wi-Fi technology. However, some assumptions can be made to determine the minimum output power of the access transmitter to induce a strong interference field defined in terms of values in the technical specification TS 102 933-1 [7]. Other parameters taken at the stage of assumptions necessary to carry out the calculations were adopted on the basis of data sheets of various manufacturers of devices.

3.1. Assumptions

A general model of the radio link budget was assumed for the calculations. The formula describing the radio link budget is presented below.

$$P_{RX} = P_{TX} + G_{TX} + L_{TX} - L_{FS} - L_{M} + G_{RX} - L_{RX},$$ (2)

where

- $P_{RX}$ – received power (dBm);
- $P_{TX}$ – transmitter output power (dBm);
- $G_{TX}$ – transmitter antenna gain (dBi);
- $L_{TX}$ – transmitter losses (coax, connectors, ect.) (dB);
- $L_{FS}$ – path loss, here free space attenuation (dB);
- $L_{M}$ – miscellaneous losses (dB);
- $G_{RX}$ – receiver antenna gain (dBi);
- $L_{RX}$ – receiver losses (coax, connectors, ect.) (dB).

3.2. Calculation

The ITU-R recommendation P.525-2 [11] can be used to calculate the signal attenuation in free space between antennas on the roof of the train. The practical equation can be used for free space attenuation is:

$$L_{FS} = 32.4 + 20 \log f = \log d \ [\text{dB}],$$ (3)

where

- $f$ – frequency (MHz);
- $d$ – distance from the BTS to the point of a railway track (km).

On this basis, it was found that the signal attenuation in the transmission band of mobile public network terminals will be determined for two nearby values (875 MHz and 910 MHz were assumed) will be, depending on the distance, respectively:

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>875</td>
<td>51.3</td>
</tr>
<tr>
<td>910</td>
<td>51.6</td>
</tr>
</tbody>
</table>
Analysis of the attenuation values in Table 1 allows to state that the attenuations in two extreme parts of the band are lower than 1 dB. Additionally, an increase in the distance from the transmitting antenna to the receiving antenna by each additional 5 m causes an increase in attenuation by about 1 - 3 dB.

The parameters of antenna installations assumed for the following calculations are described in the next Table 2.

<table>
<thead>
<tr>
<th>Wi-Fi public transmitter side</th>
<th>Parameter</th>
<th>Value</th>
<th>GSM-R receiver side</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTX</td>
<td>Can be calculated</td>
<td>GTX</td>
<td>3 dBi</td>
<td>GRX</td>
<td>2.15 dBi</td>
</tr>
<tr>
<td>G_TX</td>
<td>3 dBi</td>
<td>L_TX</td>
<td>3 dB</td>
<td>LRX</td>
<td>3 dB</td>
</tr>
</tbody>
</table>

For wideband signal of PMN devices can calculate minimum transmitter signal power indicated in ETSI TS 102 933-1 [7] i.e. $P_{RX} \geq -26$ dBm by using the radio link budget formula as below:

$$P_{TX} \geq P_{RX} - (G_{TX} + L_{TX} - L_{FS} - L_{M} + G_{RX} - L_{RX}).$$

Using the Eq. (4) allows to calculate the value of the interfering PMN transmitter power in relation to the value of the transmitted frequency and the distance between antenna’s installations of the coexisting systems. The obtained results are presented in Table 3.

| Frequency (MHz) | Distance (m) |  |  |  |  |  |  |  |
|----------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 875            | 10           | 0,10         | 0,23         | 0,41         | 0,64         | 0,92         | 1,27         | 1,64         |
| 910            | 0,11         | 0,25         | 0,44         | 0,70         | 1,01         | 1,36         | 1,80         |

3.3. Results Interpretation

Evaluation of the above calculation results leads to the conclusion that even a low power broadband signal, transmitted from a nearby transmitter in the 900 MHz band, is capable of interfering with GSM-R (Cab Radio or EDOR) equipment. For example, for a GSM-R antenna 20 m away from a PMN antenna of Wi-Fi system, the minimum power transmitted by an interfering transmitter must be at least ~442 mW or 26.5 dBm. Typical mobile radio transmitters can emit signals with a power of 1 W but the cabin radios (e.g. GSM-R) emit signals with a power of 8 W. These values are much higher than calculated in Table 3.

4. Conclusions

The availability of basic voice and data services in the GSM-R network is an important element of train-to-infrastructure dispatcher communications. A lack of access to GSM-R services may affect the continuity of the transportation process and indirectly the performance of the railway system. Active wideband PMN transmitters of Wi-Fi systems operating in the 900 MHz public band are an element that can actively influence on occurring the out-of-band signals near the GSM-R band. Of course, the Wi-Fi systems also use other bands (B1(2100), B2(1900), B3(1800), B5(850), B7(2600), B20(800)), however not all bands are available in every country, as well as the signal propagation for higher frequencies is worse than for the band B8(900) or B20(800).

The results of calculations of values of transmitting-interfering signals presented in the paper should be verified by empirical tests. They will probably be undertaken during subsequent research works.

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The Impact of the COVID-19 Pandemic on Traffic Accident Statistics in Slovak Republic

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Abstract

This article analyzes the impact of pandemic COVID-19 on statistics of traffic accidents in the Slovak republic in the time period from the 1st of Jan 2014 until the 31st of Dec of 2020. The article is the definition of differences between case fortuity and traffic accident according to valid legislation in Slovak republic, disrupted pandemic situation in Slovak republic and intensity of traffic too. The next added value of the article is complete analyzes of all traffic accidents, traffic accidents with consequences for life or health and traffic accidents caused by drinking alcoholic beverages.

KEY WORDS: accident, traffic, covid-19, analyzes

1. Introduction

COVID-19 is part of a large family of viruses (Coron-aviruses) that may cause illnesses ranging from the common cold to more severe diseases [1]. The new coronavirus (SARS-CoV-2) is a highly infectious disease that caused an epidemic of the acute respiratory syndrome (COVID-19). Between January and April 2020, the epidemic turned into a global pandemic from its centre of origin in Wuhan, China to having reached most countries around the world [2]. The virus soon spread across countries with the number of cases and deaths related to COVID-19 quickly exceeding the numbers of the two other coronaviruses (SARS-CoV-1 and MERS-CoV). This rapid spread of COVID-19 around the world led the World Health Organization (WHO) to declare it a pandemic on 11 March 2020 [3]. As of May 5, 2021, there were over 153 million confirmed cases and 3.22 million deaths worldwide and 1.17 billion vaccine doses have been administered [4]. The rapid spread of the virus has forced countries to implement full or partial lockdowns. Various policies such as working from home and social distancing have been implemented [5]. By early March 2020, there were signs that the containment measures adopted in China were having the desired effect with consistent falls in the numbers of new cases [6]. It was the reason why in the other countries around the world were accepted restrictions related to the movement of people. Restrictions have also been established in the Slovak Republic to restrict the movement and mobility of the population. The first restrictions were adopted on 6 March 2020 and, as of 12 March 2020, a state of emergency has been declared which continues (05. May 2021) [7, 8]

Traffic accidents are a summary of information on traffic accidents that are continuously statistically evaluated. Information about traffic accidents is recorded and registered by the Police Force of the Slovak Republic during documentation of traffic accident sites. The basic indicator of a traffic accident is the total number of traffic accidents. The drunk culprit of a traffic accident, the number of people killed in traffic accidents, seriously injured, slightly injured and approximately 50 categories of information are recorded [9].

The legislation of the Slovak Republic regulates road traffic incidents to traffic accidents and damage events. The damage event can be resolved even without the presence of the Police, if the participants in the damage event agree among themselves on fault and they have a filled form to ensure compensation for the damage. It is a damage event if the event in road traffic:

- does not kill or injure the person;
- does not damage the road or the utility;
- dangerous goods do not escape; or
- any of the participating vehicles, including the transported goods or other property, will not suffer material damage in excess of € 3990 [10].

If at least one of the conditions is not met, it is a traffic accident. However, if, in the event of damage event, it is found that the driver of the vehicle involved is under the influence of alcohol or another addictive substance or refuses to undergo an examination to detect the ingestion of these substances in the blood or the participants in the accident do not agree on its fault, it is also a traffic accident [10].

Information on traffic accidents is from the sources of the Police Force of the Slovak Republic. These are traffic accidents and the statistics do not include information on damage events.

2. Material and Methods

The first interest number which I analysed was a total number of traffic accidents. This number represents all
traffic accidents on the territory of the Slovak Republic except for damage events (Fig. 1). It is one of the basic indicators of traffic accidents statistics. The second accident number is a traffic accident with injuries (Fig. 2). This indicator says that how many accidents we have with some injuries for example slight injury, severe injury or death of participants traffic accidents. Traffic accidents with injuries included only injuries that normally require transport to the hospital. When the doctor from the ambulance cares about participants only on the traffic accident site, it is for statistics accident without injuries.

The third indicator is a number of slightly injured people (Fig. 3). When participants had injuries with a limited way of life less than 7 days, it is only slightly injured. It is classifying as an offence. The fourth indicator is a number of severely injured persons in traffic accidents (Fig. 4). Sever injured person is a person who had injuries with a limited way of life of more than 7 days. It is classifying as a crime.

The fifth indicator shows how many people dead regarding with traffic accidents (Fig. 5). For this moment our statistics are counting people who died 24 hours after a traffic accident. People who died later it is counting only like severely injured persons.
Indicators of the drunk culprit of traffic accidents or a culprit of a traffic accident under the influence of drugs in Slovakia shown, that how many drunk drivers or drivers under influence of drugs – culprits caused a traffic accident (Fig. 6). Drunk drivers are people who have concentrated alcohol in the blood more than 0.15 milligram ethanol on liter blown air from the mouth. If drivers have a value between 0.15 to 0.44 milligram ethanol on liter blown air from the mouth, it is classifying as an offence. If drivers have value more than 0.45 milligram ethanol on liter blown air from the mouth, it is classifying as a crime [12]. Classifying drivers under influence of drugs between offence or crime dispense on expert opinion, because each case is unique.

Slovak road administration in the territory of the Slovak republic manually calculates the intensity of traffic. Counting was realized every 5 years. The last counting was done in 2015 and the next had should in 2020. As the COVID-19 pandemic came, Slovak road administration postponed counting on 2021 with some restrictions. For this reason, we do not have data from the national traffic census. The National Motorway Company owns automatic traffic counters on the highway, on road for motor vehicles, and on expressways. The National Motorway Company counting traffic nonstop and they gave a report about the intensity of traffic for the year 2020 compared with the year 2019.

Restrictions on mobility to prevent the spread of Covid-19 have significantly contributed to the reduction in traffic on all of the network of motorways and expressways in the (The National Motorway Company) report. Data from our automatic traffic counters showed that last year's traffic intensities averaged only 80% of the values measured in 2019. The largest decrease in average daily intensities was recorded on the D2 motorway, by 8,500 vehicles in 24 hours, which represents a decrease of about 21% [11].

3. Result

Table shows values (in percentages) that compare the history of accidents in a given year with the value from the previous year.

First indicator is Total number of traffic accidents in 2015 increased by 1.87% compared to 2014. Subsequently, a year later in 2016, it decreased by 0.18%. In 2017, it increased again by 3.72%. Subsequently, in 2018, 2019 and 2020 it had a declining trend of 0.79%, 1.16%. The largest decrease was in 2020, namely 13.58%.

Second indicator Traffic accidents with injuries in the years 2015, 2016, 2017, 2018, compared to the previous year, it increased gradually by 2.32%, 1.73%, 1.35 and 0.23%. Subsequently, a year later in 2019, the indicator decreased by 4.28% and in 2020 the largest decrease was recorded for the observed period, namely 15.68%.

The third indicator Number of death of participant traffic accidents shows an increase in 2015 of 6.20%. In the following year 2016 We can saw a significant decline, by almost 11.68%. In the following year 2017, an increase of 3.31% was recorded. In 2018, there was a decrease of 8.40% of deaths compared to 2017. In 2019, there was an increase in the number of deaths by 6.99% and in 2020 a decrease of 8.57%.

In 2015, the indicator number of severe injured increased by 2.25%. Subsequently, it decreased by 4.58%. In 2017 and 2018, an increase of 8.26% and 12.87% was recorded. Between 2019 and 2020, there was a decrease in the number of seriously injured by 17.45% and 12.95%.

Number of slightly injured the first two years 2015 and 2016 increased by 2.01% and 4.59% and then decreased in other years in 2017 by 2.6%, 2018 by 1.98%, 2019 by 2.27% and the most in by 19.09% in 2020.

The last indicator of interest Number of drunk culprit of traffic accidents or culprit of a traffic accident under the influence of drugs decreased in 2015 and 2016, namely 6.53% and 1.20%. In 2017 and 2018, it increased by 6.73% and 4.48%. In 2019 and 2020, there was a decrease of 4.77% in 2019 and 1.65% in 2020.

Based on information from The National Motorway Company, the decrease in traffic intensity on expressways and motorways in 2020 was on average 20% lower compared to 2019.

<table>
<thead>
<tr>
<th>Table</th>
<th>Comparison of the history of indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of traffic accidents</td>
<td>1.87%</td>
</tr>
<tr>
<td>Traffic accidents with injuries</td>
<td>2.32%</td>
</tr>
<tr>
<td>Number of death of participant traffic accidents</td>
<td>6.20%</td>
</tr>
<tr>
<td>Number of severe injured</td>
<td>2.25%</td>
</tr>
<tr>
<td>Number of slightly injured</td>
<td>2.01%</td>
</tr>
<tr>
<td>Number of drunk culprit of traffic accidents or culprit of a traffic accident under the influence of drugs</td>
<td>-6.53%</td>
</tr>
</tbody>
</table>

4. Conclusions

When we compare statistical indicators of traffic accidents with the intensity of traffic, it is clear that the traffic accident rate was favourably affected by the introduced restrictive measures and the associated restriction of population
movement in the territory of the Slovak Republic. In 2020, the state did not conduct a traffic survey after 5 years, so we will not be able to observe a real decrease in traffic intensity. It is understandable that carrying out a traffic survey during a limited movement of the population would not bring the desired result of the census of traffic intensities. In the territory of the Slovak Republic, according to the results of the traffic intensity census, forecasts are being made for the construction, renewal or reconstruction of the entire road network. However, The National Motorway Company has electronic automatic traffic counters, we had the opportunity to monitor the development of traffic intensity on motorways and expressways. According to their evaluation, in 2020 a decrease in traffic intensity was recorded by an average of 20%. The intensity was reduced mainly due to the restriction of the movement of persons and the associated demand for deportation.

The most significant decrease in the accident rate in 2020 was the indicator of the number of slightly injured persons 19.09%. The second most significant decrease was recorded in the indicator of traffic accidents with injuries, namely 15.68%. The third most significant decrease was recorded in the total number of traffic accidents, namely 13.58%. A 12.95% decrease was recorded in the indicator of serious injuries in traffic accidents, an 8.57% decrease in the number of participants in traffic accidents and the smallest decrease was recorded for drivers under the influence of alcohol, namely 1.65%. It follows from the above that the decrease in traffic intensity does not have a significant effect on the number of fatalities in traffic accidents and also on the number of detected drivers under the influence of alcohol or other addictive substances who caused the traffic accident. The measures taken to restrict traffic have reduced the number of vehicles on the road and made it easier to exceed the maximum speeds, as drivers have not been restricted by other road users. For this reason, higher impact velocities and the consequent more serious consequences of such accidents are more likely.

Other ways to reduce accidents can continue to reduce traffic intensity, such as making public transport more attractive, introducing more frequent use of home offices, increasing active and passive safety of vehicles and roads, improving the quality of driver education in driving schools, tightening legislation on penalties for non-compliance with road traffic rules.

References
10. Law Slovak republic n. 8/2009 Codex as amended
Analysis of Transport Services of Regional Railway Transport in the Area of Šumava Railways

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Abstract

The article deals with the analysis of transport services, especially the railway transport services of the administrative territory of the South Bohemian Region in the area of the Šumava Railways in the Czech Republic. The aim of the paper is the analysis of the selected area in terms of transport services, evaluation of the transport services level in selected municipalities of the South Bohemian region. Transport serviceability quotient will be used to analyse time, frequency, and distance availability. In the article, this quotient will be applied to municipalities whose locations fall into the studied area served by the Šumava Railways. The analysis and determination of the quotient will be followed by an assessment of the interconnection of individual connections. The analysis of the given area is a strategic basis for the introduction of an integrated transport system in the South Bohemian Region.

KEY WORDS: transport serviceability, railway transport, transport serviceability quotient

1. Introduction

Transport serviceability expresses a degree of possibilities and quality of transport connection between the individual locations, settlements, important centres, or economic and geographic areas of the country [1]. Transport serviceability is a sensitive issue, as it involves the functioning of the state, transport companies, as well as satisfaction of transported persons [2, 3]. In general, a strategy to improve transport serviceability is the most important link in transport policy. By law, transport services must be provided in all permanently inhabited municipalities and access to public transport must be ensured in the most appropriate way possible for all economic and age groups of the population. In recent months, significant support has been provided by the state for public rail and bus transport in the Czech Republic [4]. According to the interim estimates from the last year, a considerable increase in the number of passengers was recorded especially in railway passenger transport. This fact is one of the reasons why it is necessary to point out the importance of transport serviceability in regional railway transport in the South Bohemian Region, as rail public transport has recently been used by travelling public increasingly more often [5-7].

2. Methodology

Transport serviceability can be calculated using the transport serviceability quotient. First, it is necessary to collect and process data needed for the calculation of the quotient, including the number of lines, the distance between municipalities, and time spent in the means of transport. The calculation of transport serviceability quotient concerns the municipalities situated close to the area served by Šumava regional lines. The quotient is calculated as follows [8]:

$$K_{do} = \frac{d \cdot 60 \cdot f}{t \cdot 24},$$

where $K_{do}$ – transport serviceability quotient; $d$ – distance between a municipality and relevant MEA given in km; $f$ – number of connections in a given timeline; $t$ – time spent in a (railway) vehicle; numerical data - time given in minutes (60 minutes) and hours (24 hours) [9, 10].

3. Time, Frequency, and Distance Transport Accessibility of Transport Services

The analysis of time and distance accessibility of transport services considers only the communities which have direct access to a railway station within the territory of Šumava Railways served by GW Train Regio and whose demographic data are available on the statistical office websites and which are presented in submitted bachelor thesis. First, a general overview of municipalities situated in this territory will be made [11, 12]. In Table 1 of the surveyed segment, the municipalities are not be specified in detail; they will be assigned to the appropriate scale. Subsequently, to each municipality with extended administration (MEA) situated in this area (České Budějovice – ČB, Český Krumlov – ČK, Prachatice – PT, Strakonice – ST, Víperka – VI, Vodňany – VO), a municipality with the worst time accessibility within the relevant MEA will be assigned. Time accessibility of transport services is also clearly related to the distance of the municipality to the relevant MEA, which is a subject of further comparison presented in the tables below. For the
calculation of transport serviceability quotient, it is necessary to obtain the third essential piece of data, the frequency accessibility of transport services in the municipalities served by given connections. As already mentioned, the data will be included in the analysis of regional rail transport in the aforementioned area [13-15].

<table>
<thead>
<tr>
<th>Time accessibility in area served by Šumava Railways</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of municipalities</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Up to 15 minutes</td>
</tr>
<tr>
<td>16–29 minutes</td>
</tr>
<tr>
<td>30–44 minutes</td>
</tr>
<tr>
<td>45 minutes and more</td>
</tr>
</tbody>
</table>

The collected data indicate that out of 30,600 inhabitants and 37 analysed municipalities, for nearly 70% of inhabitants, adequate accessibility to a relevant MEA is ensured by regional railway transport (less than 30 minutes, which is considered to be acceptable for the residents of the given towns or municipalities. However, these data were could be partially predicted, since most municipalities are situated in the immediate vicinity of railway stations of the relevant local railway lines. In contrast, for more than 30% of inhabitants, the time accessibility is 30 minutes and more. Especially in the MEA Prachatice, there are municipalities with no direct connection to the relevant municipality with extended administration; therefore, in some cases, the time accessibility when travelling by rail is even more than 45 minutes [17, 18].

<table>
<thead>
<tr>
<th>Worst time accessibility to relevant municipality with extended administration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of municipality</strong></td>
</tr>
<tr>
<td>Vrábče (MEA – ČB)</td>
</tr>
<tr>
<td>Horní Planá (MEA – ČK)</td>
</tr>
<tr>
<td>Lenora (MEA – PT)</td>
</tr>
<tr>
<td>Bavorov (MEA – VO)</td>
</tr>
<tr>
<td>Malenice (MEA – ST)</td>
</tr>
<tr>
<td>Horní Vltavice (MEA – VI)</td>
</tr>
</tbody>
</table>

A specific example is the municipality of Lenora with its 740 inhabitants, where the time accessibility to the MEA Prachatice by rail is 110 minutes on average, since, as already mentioned, the time accessibility is significantly longer if there is no direct connection; in this respect, Lenora is one of the few examples. In this specific situation, it is much easier for the inhabitants to decide on scheduled bus transport; nevertheless, the time accessibility is adequately ensured in general. This is evidenced by the analysis of the worst time accessibility of specific municipalities to a relevant MEA, as presented in Table 2 above [19-22].

The following subchapter of the text submitted deals with the evaluation of transport serviceability in terms of the distance accessibility for inhabitants living in smaller towns outside MEA or in municipalities located in the area of the so-called Šumava railway complex. The information on the distances is based on the official data available on the GW Train Regio official website. Table 3 shows the information by the selected territory [23].

<table>
<thead>
<tr>
<th>Distance accessibility in municipalities in area served by selected local railway lines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of municipalities</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Up to 10 km</td>
</tr>
<tr>
<td>11–20 km</td>
</tr>
<tr>
<td>21–30 km</td>
</tr>
<tr>
<td>31 km and more</td>
</tr>
</tbody>
</table>

Table 3 above shows that for more than 70% of inhabitants who live in the immediate vicinity of the area of regional railway lines, whose serviceability is ensured by GW Train Regio, the distance accessibility to a relevant MEA is within an acceptable distance of 20 km or less from a relevant municipality with extended administration. The distance accessibility of other three municipalities is within a range of 21-30 km. In all these municipalities, there is a direct connection to a relevant MEA; this distance can thus be considered relatively acceptable. In terms of distance accessibility, five municipalities are located within a distance of 31 km or more away from a relevant MEA, which is considered relatively worse accessibility for the inhabitants who need to travel from their municipality to a relevant MEA [24].

As seen in Table 4 above, the town of Horní Planá with approx. 2,100 inhabitants shows the worst distance accessibility to the relevant municipality with extended administration; however, it is situated on the direct route to MEA Český Krumlov, the time accessibility by regional railway transport can thus be considered relatively satisfactory in this specific case.
A more complicated situation is in the case of several municipalities belonging to the MEA Prachatice, namely Lenora, and Nová Pec, where there is no direct train to the relevant MEA. The most complicated situation is in the case of Nová Pec, as seen in Table 4; the distance accessibility to the MEA is approx. 48 km. For this municipality, scheduled bus service transport appears to be a better option in terms of both time and distance accessibility, as it enables direct connection with MEA Prachatice on working days. Although this subchapter does not provide a direct comparison of local railway transport and bus transport, my opinion is that the advantages of using railway transport in the studied territory are comparable to those of bus transport; in some cases, bus transport appears to be a more suitable option when the time or distance accessibility of individual municipalities is worse [25, 26].

The final part of this sub-chapter deals with transport serviceability in terms of the frequency accessibility of municipalities. The transport services in individual municipalities are divided into five categories by the frequency of connections. The number of connections is determined for a normal working day within the interval of 24 hours. The frequency of the individual connections is considered only for direct connections operated on a given route from the municipality of departure to a relevant MEA. After carrying out the analysis of the frequency in the municipalities within a given territory, the municipalities with the highest and the lowest number of direct connections are detected. The data presented in Table 5 show the frequency accessibility of municipalities.

<table>
<thead>
<tr>
<th>Municipalities</th>
<th>Inhabitants</th>
<th>Share of inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–3 connections</td>
<td>2</td>
<td>1 191 (3.9%)</td>
</tr>
<tr>
<td>4–6 connections</td>
<td>3</td>
<td>984 (3.2%)</td>
</tr>
<tr>
<td>7–9 connections</td>
<td>10</td>
<td>7 085 (23.2%)</td>
</tr>
<tr>
<td>10–11 connections</td>
<td>18</td>
<td>16 589 (54.2%)</td>
</tr>
<tr>
<td>12 and more connections</td>
<td>4</td>
<td>4 751 (15.5%)</td>
</tr>
</tbody>
</table>

Tables 5 and 6 above clearly show that in terms of frequency accessibility of local railway transport, some municipalities have a more than satisfactory number of direct connections to a relevant MEA on a normal working day. Unlike this, in some other municipalities, e.g., Lenora or Nová Pec, there is no direct connection to MEA Prachatice; when travelling to MEA Prachatice by public railway transport, it is necessary to use connecting points. The connecting point for Nová Pec is Černý Kříž; for Lenora, it is Volary railway station. In this context, it shall be mentioned that for both the above municipalities, it is more convenient for the inhabitants to use bus transport, which provides better frequency and time accessibility on working days; frequency accessibility, however, is satisfactory in municipalities with more than 12 connections.

4. Transport Serviceability Quotient

Time, frequency, and distance accessibility are analysed using the transport serviceability quotient, which will be calculated for the municipalities belonging to the area served by Šumava Railways. The data collected in the previous chapters of this work are further analysed and used for calculating the transport serviceability quotient for individual
towns or villages. Within six selected municipalities with extended administration, the town or village with the worst and the best transport serviceability in accordance with a relevant MEA (except for the MEA themselves, which include ČB, ČK, PT, ST, VO, and VI) will be presented in a table. Time, distance, and frequency serviceability will be considered for regional railway transport in the area of the so-called Šumava railway complex. The initial data based on the collected information in the following calculation of transport serviceability quotient are given for a normal working day. The transport serviceability quotient will be calculated using the formula 1.

<table>
<thead>
<tr>
<th>Name of municipality</th>
<th>Transport serviceability quotient</th>
<th>Number of inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boršov nad Vltavou (MEA – ČB)</td>
<td>22</td>
<td>1 879</td>
</tr>
<tr>
<td>Zlatá Koruna (MEA – ČK)</td>
<td>16</td>
<td>795</td>
</tr>
<tr>
<td>Strunkovice nad Blanicí (městys) - (MEA – PT)</td>
<td>21</td>
<td>1 250</td>
</tr>
<tr>
<td>Pražák (MEA – VO)</td>
<td>22</td>
<td>317</td>
</tr>
<tr>
<td>Strunkovice nad Volyňkou (MEA – ST)</td>
<td>17</td>
<td>90</td>
</tr>
<tr>
<td>Čkyně (MEA – VI)</td>
<td>16</td>
<td>1 582</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name of municipality</th>
<th>Transport serviceability quotient</th>
<th>Number of inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hradce (MEA – ČB)</td>
<td>18</td>
<td>102</td>
</tr>
<tr>
<td>Horní Planá (MEA – ČK)</td>
<td>12</td>
<td>2 098</td>
</tr>
<tr>
<td>Stožec (MEA – PT)</td>
<td>7</td>
<td>195</td>
</tr>
<tr>
<td>Bavorov (MEA – VO)</td>
<td>20</td>
<td>1 597</td>
</tr>
<tr>
<td>Nišovice (MEA – ST)</td>
<td>14</td>
<td>231</td>
</tr>
<tr>
<td>Horní Vltavice (MEA – VI)</td>
<td>13</td>
<td>363</td>
</tr>
</tbody>
</table>

The Table 7 did not include the municipalities of Lenora (MEA – PT) and Nová Pec, whose territory belongs to (MEA – PT). These two municipalities are not considered for the calculation of Kdo in railway transport, since there is no direct railway connection to their relevant MEA; for this reason, their transport serviceability quotient would be zero. For reasons of completeness, the Kdo of these two municipalities to their relevant MEA within bus transport are presented in Table 9 below.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Transport serviceability quotient</th>
<th>Number of inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lenora (MEA – PT)</td>
<td>2</td>
<td>740</td>
</tr>
<tr>
<td>Nová Pec (MEA – PT)</td>
<td>10</td>
<td>451</td>
</tr>
</tbody>
</table>

The value of the average transport serviceability quotient in selected municipalities is about 15, given that the aforementioned municipalities of Lenora and Nová Pec are not included in the calculation. The value for the municipality of Stožec is significantly below the average value of the transport serviceability quotient; however, this can be due to the low frequency of trains (5 trains a day on average) to the relevant MEA Prachatice. This municipality and its surroundings is particularly suitable for hiking or cycling; nevertheless, it does not change the low value of Kdo and the frequency of the connections is considered to be increased, which would be particularly desirable for making this tourist-friendly location more attractive. Other municipalities in Table 8 do not differ significantly from the average value of Kdo; on the contrary, some municipalities considerably exceed this average value. Above-average values are recorded in the case of municipalities with a sufficient number of trains (10 and more), with good time accessibility (within 30 min), and distance accessibility (within 20 km). All these aspects were recorded for the municipalities with the highest Kdo, such as Boršov nad Vltavou, Strunkovice nad Blanicí, or Pražák.

5. Conclusions

The calculation of the transport serviceability quotient showed that Lenora and Nová Pec do not have direct connection with their relevant MEA Prachatice. Since the railway line in this area not enable direct connection between the individual municipalities and the relevant MEA, in order to meet the needs of the inhabitants for having adequate transport serviceability, it is necessary to operate more direct connections, at least by means of public transport. According to the current timetable, there is only one afternoon direct connection to the relevant MEA Prachatice on a normal working day. Although only 740 inhabitants are registered with permanent residence in this municipality, it is desirable to ensure
one morning connection within this relation, or to add connections with a possibility to change at changing points both for railway and bus transport.

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Development of a Monitoring System to Reduce the Spread of COVID-19 Through the Public Transport System

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Abstract

Due to COVID-19 and its rapid spread all over the world, the daily life of people all around the world has an effect on many levels, and people are trying to get along with the pandemic situation and support sustainability of development in every field. Public transport is a backbone of sustainable urban infrastructure development and has to be safe and reliable in this situation. In this research work, an IoT-based system that combines machine learning with electrical sensors for enrichments is proposed in order to prevent risks that can occur in the future. The proposed monitoring system targeted bus drivers during their work time due to their high risk of spread if they were infected. The system detects if a driver does restricted actions such as not wearing a mask, using it improperly, touching their faces, or shows some of the symptoms of COVID-19, the device equipped in front of them shows an alert and sends an action log to the centralized server. It prevents actions that can cause infection from the virus and collects data that can be used for many purposes, analysis, and other possible services as well. Machine learning based image recognition techniques were used to detect and monitor specified actions. In order to increase its functionality and efficiency, thermal sensors, cameras, and microphones were deployed as well. Therefore, IoT was used for collecting the data resulting from monitoring for future applications.

KEY WORDS: monitoring, public transport, sustainability, covid-19, safety, health, public transport system, algorithm

1. Introduction and State-of-the-Art

Motivation and actuality: Coronavirus disease, which people call the newly discovered COVID-19, is infectious. It is a contagious disease and can be transmitted through droplets from human to human directly or any objects to human non-directly like other respiratory infections. At an early stage of the pandemic, all countries were following different policies for preventing transmission of the infections. They were not in the same vision about the actions that have to be taken during the coronavirus situations. Some countries were forcing the citizens to wear masks, but some of them denied it due to its efficiency not proven. However, as time went by and much research has been done, most countries started to get along with prevention policies which have been suggested by WHO (World Health Organization). However, due to many reasons depending on human behaviors, people lose their attention to keep the rules, especially since the last season of 2020-started vaccination all over the world, people are calming down and lowering their attention. The vaccination is good news, but it brings some risks.

One of the significant fields people should focus more on is public transportation during this continuously changing pandemic situation. Even during the pandemic, not everyone can work from home. Because of that reason, public transport has to be the backbone of sustainable mobility and essential to economic recovery. Therefore, the bus driver is one of the occupations that mostly interacts with many people daily. In addition, who has to work even in its lockdown, and good examples of workers who are not affordable to work from home? Bus drivers have to be safe to interact, especially in the current situation where people are starting to lose their attention due to vaccination and get along with the pandemic, live with it.

By considering the importance of supporting the development of public transportation and its safety and sustainability, authors contribution in this research work is to develop an expanded monitoring system that helps to prevent and reduce the risk of the pandemic continuing currently and can occur in the future by combining computer vision with electrical sensors to increase its efficiency.

Goal: Aim of this work is to develop an IoT based monitoring system that targets drivers of public transport vehicles. The system monitors drivers during their work time and gives them alerts to fix prohibited actions in public places at the same time as it records action logs in a centralized server for future analysis. After a certain time of using the system during a pandemic, it is able to affect driver’s habits, which reduces the risk of spread, and increases the trust of citizens for using public transportation as well.
Tasks: To accomplish this goal, the first task is to determine functional requirements based on COVID-19 disease itself. Then architecture and workflow must be specified in detail depending on previously listed functionality. Therefore, theoretical and technical research that is significant for implementation has to be done in order to satisfy the requirements. In the last, discussion and future development possibilities will be explained.

State-of-the-art: There are some suggested possible methods, devices, and technologies that can be used to avoid risks of infection of covid-19 is mentioned in work [1]. The main system consists of 4 parts, detecting a face touch event, alerting the user, and collecting feedback metrics and statistics. At first, they suggested using GPS information that can be obtained from many devices which people bring in their daily lives to detect places that people have to worry about certain actions such as wearing masks, being careful to face touching, or washing hands. After that, it mentioned several devices could be used to implement system detects face touching events, for instance, video cameras to utilize image processing, some sensors which are contained in smartwatches and bands such as accelerometer gyroscope, magnetometer, etc., to detect position, orientation, velocity, and microphones to analyze and detect sneezing or coughing events. Depending on the information obtained from those devices and sensors, they considered alerting in different ways could affect in a positive way to anticipate or fix harmful habits. Lastly, by analyzing and processing all data gathered from the previous three steps, it is possible to contribute to preventing many risks of the pandemic in our daily lives and even more business fields.

However, disclosure [1] was only for the suggestion, implementation of preventing actions related systems are developed separately such as habit alerting, mask usage checking. To detect face touching actions, work [2] suggested using wrist-worn accelerometers commonly contained in smartwatches or bands to detect face touching action based on the specific motion pattern of raising one’s hand towards the face. In addition, there is a website, “Donottouchyourface.com” which utilizes a simple machine-learning algorithm to detect action through one’s web camera, and then it shows alerts to users when they touch their facial area.

In paper [3], authors suggested a mask detection method from surveillance cameras on special areas such as supermarket entrance, elevator, and purchase area. The aim was to build a method that is lightweight and able to work accurately on small objects in real-time. To reach that purpose, they improved SSD (Single Shot Detection), which is not suitable for small object detection based on separable spatial convolution and FEM (Feature Enhancement Model). After training a model using a proposed method on a dataset that is collected from internet and supermarket surveillance cameras, they compared a new approach with other frameworks. As a result, it had excellent detection accuracy and real-time performance, but detection speed was lower than some other popular framework.

Related to mask face detection tasks, the aim of research [4] is to restrict the spread of pandemic disease. The novelty was to use a smart city network that consists of many IoT sensors to collect data. The main flow of the automated system is to detect people who are not wearing masks in public places from CCTV’s located around the city and inform related information such as location coordinates and personal data to the corresponding authorities. Then, they will be able to take proper actions against those people. Due to their use of smart city merits, all training data are gathered from the whole city’s CCTVs. As a detection process, CNN is mainly utilized, and a tested result was 98,7%. In future study, some challenges, for instance, highly populated areas, have to be considered. Also, action taking can be executed by drones or robot technologies. Also, in [5], they trained a model based on a low-resolution facemask dataset. In this method, Mask R-CNN architecture has been used in person detection and classification. It generates bounding boxes by extracting features and classifies human action if it’s pedestrian, cyclist, or sitter, etc. By utilizing this classification every frame with the Deep Sort tracking algorithm, the system was able to identify each person. In the next stage, a CNN based binary classifier works on the bounding area to detect if the person is wearing masks or not.

In work [6], proposed a smart surveillance system that can perform functions finding criminals, identifying suspects, and finding missing persons. The main flow of the system starts with training a face recognition method using various images of criminals and missing persons. Then by using this method on detected faces from real-time CCTV input and notify this information to related authorities. In this system, only preparation of the target object’s image dataset involves human interventions. Because of the possibility to use this system even during a covid-19 era that requires most people to wear facemasks, authors considered this condition in the training process and reached a high accuracy result even while wearing a mask.

Additionally, about work [7], authors proposed deep learning with soft attention to solving detecting a proper or improper usage of mask problem. They used a MAFA dataset that divides a face into four major regions: chin, mouth, nose, and eyes to detect which part of the face is not occluded. Moreover, Mask R CNN was utilized as well to detect masks on the faces in order to detect proper usage of it.

Methods: Depending on the research works so far, which are aimed to detect masked faces, shows there are three options that can be used in monitoring systems depending on methods. Option 1: depending on the self-trained facial landmark detection model, but it takes time to develop, also occlusion problems occur. Option 2: is to use a predefined 3D landmark detection library with mask detection, but it is a heavy model to execute with other models. Option 3: consists of two steps are to first detect the human face and classify if it is wearing masks or not since it is executing two models, so it takes time.

2. The Effect of COVID-19 on the Public Transport System

As mentioned before, infection-spreading possibility gets higher as human interaction in the daily working
condition of the workers. Relating to this issue, the passenger count by each bus, which is mostly driven by one driver in a day, was analyzed. This data was gathered from a bus payment machine. One payment represents a passenger, and it means information about how many people are interacting with a bus driver a day will be clear from here. In order to make this result realistic depending on the pandemic situation, we had chosen the dates that are from before the pandemic starts, during the strict lockdown, and after lowering the quarantine level that partially restricted the businesses.

The graph in the Fig. 1 shows the changes in the number of passengers through three time captures (1 - no covid-19 case inside the country, 2 - strict lockdown, 3 - after loosening the restriction level).

The data was acquired from the information system of the bus payment card of Ulaanbaatar city public transportation. The X-axis shows the number of passengers who interacted nearly with one driver on that day. Y-axis shows the timeline. (1 for no covid-19 case inside the country, 2 for during strict lockdown, 3 for after loosening the restriction level). The graph shows the changes of the number of passengers through three time captures.

Here is a huge decrease after COVID-19 was shown. People started to refuse to use public transportation. From here, we can get to two conclusions:

Ɣ First, people do not trust public transport because it is unsafe. To solve this problem, our monitoring system inside public transportation is being proposed. Which will be explained in detail after.
Ɣ Second, even though people started to trust public transportation due to vaccination, it also brings another risk. Until all of us get back to a normal lifestyle, people should not lose their attention to be careful. Because even vaccinated people can carry the virus and infect other people, and it is still not clear how long the protection of vaccines lasts. If something happens in the future after passengers in public transport increase and people loosen their attention to prevention, this can cause huge damage. The proposed system in this work also can contribute to this situation.

3. Sustainability of Public Transport During and after the Pandemic

To keep public transportation reliable during the pandemic public transportation focusing on the adaptation of infrastructure and resources. Basic challenges in public transportation are closed space, close interaction, and a crowded area. In order to solve these problems, they need to reduce capacity on each individual service. For example, The New York Metropolitan Transit Authority decided to request 97 km of new bus lanes. Changing the schedule and increasing lanes sounds easy and effective, but it brings the drawback sides that are overlaps, the workload of public transport operators, financial risks. Therefore, to avoid close contact inside the bus, Rio de Janeiro has prohibited standing passengers, the train companies in Spain are starting to operate at 30% of capacity. Also in, Lima, the government is installing emergency bike lanes and showing support for developing affordably priced bicycle models.

Other actions being taken to prevent the risks:
Ɣ Increase frequency and quality of cleaning of vehicles and stations;
Ɣ Installing hand sanitizers and handwashing facilities;
Ɣ Promoting and requiring wearing masks;
Ɣ QR code tracking system.

All cities are trying to remain sustainable in the public transport system by adapting their policies and strategies and taking all possible action to prevent the risks depending on the most recently proved research results in the rapidly changing situation of COVID-19.

4. Monitoring System and its Functionality

WHO (World Health Organization) advises everyone to follow these basic precautions to limit the risk of infections. Depending on COVID-19 and its features, the functionality of the proposed system is defined as below:
Ɣ Continuously monitoring during work time;
Ɣ Able to set in front of the bus driver;
Ɣ Connected to the internet;
Monitor actions on input data from the camera (○ Proper usage of the mask; □ Improper usage of the mask; ○ Without any mask; □ Touching to the facial area); ● Monitoring body temperature; ● Recording voices; ● Detect restricted actions; ● Send request about actions to the server; ● REST API server to save all records to the database; ● Relational DB; ● Responsive website to show the result of analysis; ● Alerting module for bus driver’s action.

According to this functionality, our system’s main working flow would be demonstrated as below (Fig. 2):

Our system’s hardware part will be settled inside the bus and execute monitoring processes through its input modules such as camera module, microphone module, thermo-sensor. The monitoring device contains its operating system that is used for computation on input data from additional modules according to predefined threshold values. According to the result of its computation, it takes the main two actions: the first one is to send requests to the server through the internet, and the second one is to show alerts to the driver through output modules. System implementation consists of three parts:

PART 1: In this part, the model was trained to detect certain actions that are restricted to be taken during their work. The trained model will work on video images obtained from surveillance cameras. It has to distinguish if the target is wearing the masks properly and detect actions such as touching their faces. The main two functionalities of this part are to distinguish objects into three categories which are “with mask”, “without mask”, “with mask but with improper usage” and detect hand as an object in order to know if the hand is touching on the face of its getting closer to the facial area by using its border box location.

PART 2: In this part, the thermo-sensor was used to monitor the human body temperature according to the determined threshold value. In addition, a sound sensor was used to acquire sound input to detect coughing or sneezing sounds.

PART 3: This part implies the back-end of the system that covers a centralized server to store data acquired from the devices, API for transmitting the data in real-time, and shows analytics to the public transportation agents through a web site.

5. Practical Implementation and Future Work

Raspberry Pi + Raspbian (Raspberry Pi 4 Model B 4GB RAM with 16 GB SSD card) is used for the prototype. Fig. 3 shows the schema of the raspberry pi with modules.

On the raspberry pi raspbian OS is installed and calculation code is on it as well. The calculation algorithm is
described in Fig. 4. It executes pre-trained object detection on images from a video camera, and if it detects any object except only with proper usage of masks, then it shows the alert and sends a request to the server. In addition, if there is a hand object detected, it checks the bounding box location of its collapsing other objects. It also shows an alert to stop touching the facial area.

Fig. 4 Action detection workflow

Tensor flow object detection API - 1208 images containing one or more people with masks, without a mask, masks with improper usage from different angles and distances were used. The images were acquired from Kaggle’s dataset collection, collected from the internet by myself as well. Therefore, an annotation tool which is named “labeling” written using python, well known and most used lightweight tool were used. In annotation, objects labeled as PascalVOC format in 4 main categories in XML files for each image. We trained our model by customizing model architecture “ssd_mobilenet_v2_fpnLite_320x320_coco17_tpu-8” on Google colab as a training machine with its free GPU in runtime type. The model working in real-time is shown in Fig. 5.

Fig. 5 Execution of trained model

Server (Ruby on Rails + MySql DB). For centralized server which serves as API to collect data from devices through internet, as well as shows collected data in a form for easy to understand and suitable for future usage. Ruby on Rails framework is used for front-end back-end implementation of the server connected MySQL database server. Here is a simple and early phase DB model for the rails server in Fig. 6.

Fig. 6 DB model
The current solution is a step to help in the adaptation of the public transport system to the challenge of COVID-19 [8], which can be, for example, a part of [9] to be able to keep public transport system in a sustainable and safe position. If we talk about the sustainability [10] of public transport system and about the sustainability at all, it is clear that now we need to take into account the new vector – the vector of epidemiology and epidemiological safety. It is a new reality! Our future depends on the answer - how good and how fast we will be able to adapt all the systems to a new reality.

6. Conclusions

Because it has not been a long time since the pandemic, there is not enough work that has been done yet especially targeted public transportation. Some works relating to mask detection or action detection, but all separately. The proposed system is complex, adaptive, and uses only one model for both functionalities. As well as, through the feedback to the driver with an alerting system that is implemented in a single device for each bus, it keeps the driver's action behaviors in safe value during their work times. Therefore, the collected data in the server has the potential to contribute to the efficiency of the alerting methods and public transportation planning for the future. Due to hardware and software solutions and its utilized technologies have lots of opportunities to expand, the proposed system can be adaptive depending on continuously changing pandemic situations.

If the monitoring system that targets bus drivers succeeds, the next step is to expand the system by targeting all passengers in public transport. Therefore, currently, buzzer modules and some lights are used to alert the driver, but disturbance to the driver of this method is not the best solution, text to speech technology can be used instead. Also, by enriching the model, our system has the possibility to serve as an evaluation for driver’s drowsiness and stress levels.

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/4/20/658 “Adapting the public transport system to the COVID-19 challenge, ensuring its sustainability”).

References

Use of RFID Technology in the Logistic Process of Distribution with the Support of a Dynamic Simulation Software Tool

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Abstract

In recent years, the volume of parcels sold electronically has increased significantly. The current pandemic period has amplified this, as the volume of e-shop transactions has grown even more. Due to the COVID-19 pandemic and related restrictive measures, most shops are closed in the Czech Republic. Customers most often use e-shops to buy goods. As a result, the volume of parcel transport, which is provided by parcel carriers, is increasing to finish customers. Improving distribution logistics and the entire logistic system are constantly under pressure in the context of existing competition, maintaining the declared level of customer service and increasing volume of parcels. One way to streamline the logistic distribution process is to use RFID technology as one of the automatic identification technologies. The aim of the article is to create the proposal for the use of RFID technology in the distribution process of parcels in order to make it more effective. Simulation software the Witness Horizon will be used to achieve the aim. The software uses the dynamic simulation to evaluate the benefits of using RFID technology before its implementation.

KEY WORDS: logistic process, distribution, distribution centre, dynamic simulation, parcel, RFID technology

1. Introduction

With the development of the economy, the logistic industry, as an ancillary industry, has developed very rapidly and its level of service has been constantly improving, but the high cost of logistics is still a matter of great concern. Logistic distribution costs make up a large part of the total logistic costs. If the journey can be reasonably planned and optimized to reduce time and distribution costs, logistic costs can be reduced. A number of basic capabilities of logistic companies between mutual influence and mutual support, overall increase of basic capabilities of logistic companies. The basic skills of logistic companies are constantly improving.

Logistic companies generally do not have key competitiveness, there is a lack of awareness of service innovation about the problems to be solved, and dynamic research methods should be used to study the key competencies of a company to study the key competencies of logistic companies. The development of the basic competence of logistic companies is a process of dynamic change. The aim of the article is to create the proposal for the use of RFID (Radio Frequency Identification) technology in the distribution process of parcels in order to make it more effective. Simulation software the Witness Horizon will be used to achieve the aim of the article.

2. Theoretical Background

Logistics is the part of supply chain management that plans, implements and effectively manages the forward and reverse flows of products, services and relevant information from the place of origin to the place of consumption and warehousing of goods to meet end customer requirements. Typical managed activities include transportation, fleet management, warehousing, material handling, order fulfilment, logistic network design, inventory management, supply and demand planning, and logistic service provider management especially in distribution part of logistics. To varying degrees, logistic functions also include sourcing and purchasing, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and implementation - strategic, operational and tactical. Logistic management is an integrative function that coordinates and optimizes all logistic activities, as well as participates in the connection of logistic activities with other functions, including marketing, production, sales, finance and information technology [1]. Distribution centres, as important nodes, perform processes such as cargo concentration, processing and distribution, with the support of equipment such as handling equipment [2]. The selection of logistic distribution centres is a problem that includes qualitative and quantitative criteria [3-4]. In order to better meet the distribution needs of companies, economic efficiency and customer satisfaction are increasing and the number of logistic distribution centres is increasing from year to year [5-6].

Most researchers in China and overseas have studied the location of competing distribution centres from the largest market share gained by new distribution centres [7]. It was analysed ways to make effective decisions about the location
of new distribution centres so that they could gain the largest market share given the existing multiple distribution centres [8]. Other scholars proposed a mathematical model for selecting a competitive logistic distribution centre, taking maximum market share as their objective task to achieve the best profit [9].

Pandemics and epidemics are far-reaching threat scenarios that are increasing in frequency [10]. The resulting crises can have serious consequences, especially from a medical, social and economic point of view, as demonstrated by the COVID-19 pandemic in 2020. In pandemics, measures such as reducing social interaction and self-isolation are aimed at managing the disease and mitigating negative impacts [11]. Because grocery stores are places of close personal contact, they can cause infections. Visits should be limited while following public isolation recommendations [12-13]. However, the supply of basic goods, especially food, to the population must be maintained at all times. Home delivery is a logistic solution that reduces social interactions and is therefore suitable for pandemic conditions [14-15]. Disruptions in the logistic chain can jeopardize supply [16]. Last-mile relief logistics is the last stage in aid supply chains and aims to distribute goods to people with disabilities [17]. Other authors emphasize the importance of limited transport resources for emergency delivery in last mile logistics [18]. Distribution costs form a large part of the final selling price of the product and consist of both fixed and variable costs. Therefore, companies must reduce one or both of these costs in order to achieve higher demand for products from customers. Fixed costs come mainly from the driver's salary or the cost of using the vehicle and burden the distribution company by the mere use of the vehicle, regardless of the route and the number of customers served [19].

As the importance of innovation in logistic businesses becomes increasingly important, companies continue to help improve user relationships, improve operational efficiency and reduce logistic costs [20-22]. The ability to innovate services has therefore become one of the most important parts of the core competencies of logistic companies. The phase of forming the basic competence of logistic companies, the basic competence of the modernization phase and the main competence of modernization [23].

The operation of the model simulation consists mainly in testing the accuracy and validity of the results of the model simulation and the validity is mainly testing whether the information obtained by the model can objectively reflect the operating rules of the real system and whether problems can be solved after studying the model. Test methods include model structure and validity detection, model structure behaviour, and real system consistency detection [24].

3. Methods

The following scientific methods were used to create the proposal for the use of RFID technology in the distribution process of parcels in order to make it more effective within this article: scenario analysis, experimental testing of barcodes and RFID technology and dynamic simulation.

The scenario analysis is based on formulated alternatives when probabilities of uncertainties are un-known and can be used to integrate uncertainties into the performance robustness assessment [25-27]. Scenarios are used to present a range of possible alternatives so that the performance robustness of designs can be assessed based on how different designs perform in each of these alternatives [28]. Authors analysed, simulated and tested two scenarios (scenario A and B) related to the logistic process of parcels distribution. Both scenarios simulate the final phase of distribution of parcels from the distribution centre. Parcels are prepared in the dispatch zone and must be registered in the internal information system and handed over to the driver for loading into a truck. In both scenarios, there are two workers (picker and driver).

![Fig. 1 The visualization of the RFID technology experimental testing [authors]](image)

The crucial difference between the scenarios is from a technological perspective because the picker in scenario A uses barcodes technology, specifically handheld mobile terminal and barcodes reader CipherLab CP30 WM 6.5 Pro and EAN-13 barcodes. After loading the parcel into the information system, the parcel is then handed over to the driver for loading. In scenario B, the picker uses a belt conveyor to deliver parcels to the driver and RFID technology (specifically fix reader Motorola FX9500, RFID dual antenna AN440, notebook including SessionOne software for device discovery, inventory operations, access operations, export tags, tags Alien ALN-9613 Sit Inlay and connecting cables) to ensure that
parcels are loaded into the internal information system. The experimental testing of barcodes and RFID technology was provided in a specialized Laboratory of Automatic Identification of the Faculty of Transport Engineering, University of Pardubice. As part of this testing, the average durations of individual processes within the parcels distribution process were experimentally measured using RFID technology and barcode technology. The visualization of the RFID technology experimental testing is presented in Fig. 1.

The logistic process of parcels distribution was analysed, simulated and tested using the specialized software for dynamic simulation (Witness Horizon, version 22.5b). In recent years, many companies have begun to use dynamic simulation to optimize business processes, as it can make it easier to understand the relationships between processes, help simplify and innovate processes, and indirectly save costs [29]. The use of dynamic simulation in the field of logistics has been very popular in recent years, for example in the area of: demand planning in the supply chain [30], optimization of production lines [31], modelling of city logistics [32], optimization of production logistics [33], and supply chain management [34]. The dynamic predictive simulation can be used in any logistic process, from warehousing and handling through optimization of production lines to distribution [29]. For the correctly generalized simulation results there have to be multiple tests, and multiple possible scenarios have to be examined [35]. Firstly, models were created for both scenarios using Witness Horizon. The models were subsequently verified and validated. Then the individual scenarios were tested and evaluated. The models were calibrated for the distribution of 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 parcels. The durations of the individual sub-processes included in the models were defined on the basis of experimental testing and measuring in a specialized Laboratory of Automatic Identification. The duration of the sub-processes is assumed to the triangular probability distribution with parameters \( a \) (minimum duration [s]), \( b \) (average duration [s]), \( c \) (maximum duration [s]). The overview of the duration of the individual sub-processes is in Table 1.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Picker</th>
<th>Driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

The main monitored parameter was the total duration of the distribution process for both scenarios and 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 parcels. Both scenarios assume flawless functionality of the simulated and tested technologies.

4. Results and Discussion

Firstly, models of both scenarios were created in the Witness Horizon software for dynamic simulation. An example of both created models is presented in Figure 2. Scenario A model is based on the use of barcodes technology in the parcels distribution process. Scenario B model is based on the use of RFID technology and a belt conveyor in the parcels distribution process. The durations of the sub-processes correspond to the values in Table 1.

Fig. 2 Created models for both scenarios [authors, Witness Horizon]

The models were subsequently verified and validated. Then the individual scenarios were tested and evaluated for the distribution of 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 parcels from the perspective of the main monitored parameter (the total duration of the distribution process). The results of the main monitored parameter of both scenarios for different parcels volumes are presented in Fig. 3.
The total duration of the distribution process for 50 parcels was based on a dynamic simulation results for scenario A 2 386 s (40 minutes after rounding) and for scenario B 1 823 s (31 minutes after rounding). The total duration of the parcels distribution process in scenario B is shorter by 9 minutes, so the time saving is 23.6%. The situation is very similar for other tested numbers of parcels, for example for 300 parcels was based on a dynamic simulation results for scenario A 13 652 s (3 hours and 48 minutes after rounding) and for scenario B 10 604 s (2 hours and 57 minutes after rounding). The total duration of the parcels distribution process in scenario B is shorter by 51 minutes, so the time saving is 22.3%, and for 500 parcels was based on a dynamic simulation results for scenario A 22 797 s (6 hours and 20 minutes after rounding) and for scenario B 17 696 s (4 hours and 55 minutes after rounding). The total duration of the parcels distribution process in scenario B is shorter by 1 hour and 25 minutes, so the time saving is 22.4%.

The results clearly show that the total duration of the parcels distribution process in scenario A is significantly longer for all simulated parcels amounts than in scenario B. This finding implies the conclusion that the use of RFID technology in the distribution process shortens the duration of this process compared to the use of barcodes technology. The use of RFID technology resulted in a time saving of 22.2 to 24.5% in individual tests. This study also contains many limitations. The first limit is the technical and technological equipment used because there are other barcode readers, other types of barcodes, RFID tags, RFID readers and RFID antennas on the market. Another limitation may be the fact that RFID technology may not work flawlessly in every environment. This requires further testing and debugging. The last limit is the fact that the study assumes flawless functionality of the simulated and tested technologies.

5. Conclusion

The simulation of the distribution process is the excellent tool for the data analysis, which takes place in almost every parcel carrier. The aim of the article was to create the proposal for the use of RFID technology in the distribution process of parcels in order to make it more effective within this article: scenario analysis, experimental testing of barcodes and RFID technology and dynamic simulation. The conclusion that the use of RFID technology in the distribution process streamlines the duration of this process compared to the use of barcodes technology. Witness Horizon software is the important tool to support logistic planning and optimization of logistic processes because dynamic simulation enables to virtually streamline processes before their implementation in practice.

Acknowledgements

This article is published within the realization of the project “Cooperation in Applied Research between the University of Pardubice and Companies, in the Field of Positioning, Detection and Simulation Technology for Transport Systems (PosiTrans)”, registration No.: CZ.02.1.01/0.0/0.0/17_049/0008394.

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Refined Model of Asynchronous Traction Electric Motor of Electric Locomotive

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Abstract

The active power utilization factor and the efficiency of asynchronous traction electric motors of electric locomotives significantly depend on losses in steel and saturation of the motor magnetic circuit. These components influence the accuracy of the traction motor characteristics such as stator currents, speed, active and apparent power consumption, and motor shaft power. During the operation of traction motors, an turn-to-turn short circuit of the stator windings may occur. As a result, the stator windings become asymmetrical. With the asymmetry of the stator windings, their mutual inductance changes. The authors proposed a refined model of an asynchronous traction electric motor of an electric locomotive, based on taking into account losses due to eddy currents, saturation of the magnetic circuit with asymmetry of the stator windings. A new principle of constructing a mathematical and simulation model of a traction asynchronous electric motor has been developed. A model of an asynchronous electric motor in three-phase fixed coordinates was taken as a basis. To take into account the losses due to eddy currents, an algorithm is proposed and the active resistance of the magnetic circuit is calculated. The saturation of the magnetic circuit of the electric motor is taken into account using the relative inductance of the magnetic circuit, which is a function of the total flux linkage of the magnetic circuit. An algorithm is proposed for calculating the total mutual inductance, which are functions of the geometric dimensions of the windings. To study the dynamic processes in the traction drive, the transition from fixed coordinates to real coordinates was used. The proposed model makes it possible to determine with high accuracy the instantaneous values of the active power utilization factor and the useful power factor for various operating modes of the electric locomotive.

KEY WORDS: asynchronous motor, saturation of the magnetic circuit, losses in the magnetic circuit, unbalance of the stator windings

1. Introduction

The study of electrodynamic processes in the traction drive of an electric rolling stock requires the development of its simulation model, which makes it possible to determine with high accuracy certain parameters of the engine [1]. For the operation of electric rolling stock, the issues of losses in the traction engine are relevant [2, 3]. The consideration of engine losses should also be taken into account when creating its simulation model.

Due to the fact that asynchronous motors have a number of advantages in comparison with collector motors, such as: high power with the same weight and size parameters, simplicity of design, greater efficiency [4], asynchronous motors are used as traction motors on modern rolling stock.

There are several approaches to modeling induction motors. The simplest is to build a mathematical model of an induction motor in single-phase coordinates [5, 6]. This approach to modeling the operation of an induction motor is effective if all the motor windings are symmetrical. Otherwise, the use of this method is incorrect.

During operation in an asynchronous motor in the stator windings, asymmetric modes may occur, caused by an turn-to-turn short circuit on one of the windings [7]. For such modes of operation of an induction motor, there is an approach to modeling using a three-phase coordinate system [8, 9]. In work [10], the optimal operating modes of an asynchronous traction drive of a rolling stock are considered, the provision of which is necessary for the implementation of optimal control of a traction electric drive.

But, in these works, the influence of saturation of the magnetic circuit on the dynamic properties of the model is not taken into account and an algorithm for calculating the active resistance of the magnetic circuit is not proposed, which makes it possible to take into account the losses in an induction motor. An algorithm for accounting for saturation in the magnetic circuit of an induction motor can be found in [11, 12]. Taking into account the active resistance of the magnetic circuit for losses in an induction motor is proposed in [13].
In addition, in works on modeling an asynchronous motor in three-phase coordinates [8, 9], an algorithm for changing the mutual inductance of phases when changing the geometric dimensions of the phase windings caused by an inter-turn closure is not given. Such an algorithm is proposed in [14], but it is presented conceptually. Thus, the development of a model of a traction induction motor, taking into account the saturation of the magnetic circuit and losses in the magnetic circuit and the possible asymmetry of the stator windings, is an urgent task.

2. Refinement of the Mathematical Model of an Induction Motor

2.1. The Object of Research

The object of research is an asynchronous traction motor for electric locomotives. The CTA-1200 traction motor used in AC electric locomotives of the DS-3 series, which is operated in Ukraine, was chosen as an example for modeling.

2.2. Mathematical Model of Asynchronous Motor

The mathematical model of a three-phase asynchronous motor (AM) is based on a mathematical model of a three-phase electric machine in a braked coordinate system, the axis α, β, γ which is combined with the phase axes of the stator A, B, C [15]. This system, in order to take into account losses in steel, is supplemented with active resistances of the magnetizing circuit \( r_\mu \), connected in each phase in parallel with the main inductance \( L_\mu \) (analogy with the T-shaped equivalent circuit of an induction machine).

The equations of the electromagnetic processes of AM are given in the system (1) [15]

\[
\begin{align*}
\dot{u}_{\alpha} &= r_{\alpha} \cdot i_{\alpha} + \frac{d\psi_{\alpha}}{dt}, \quad 0 = r_{\alpha} \cdot i_{\alpha} + \frac{d\psi_{\alpha}}{dt} + \frac{(\psi_{\beta} - \psi_{\gamma}) \cdot p \cdot \omega_r}{\sqrt{3}}, \\
\dot{u}_{\beta} &= r_{\beta} \cdot i_{\beta} + \frac{d\psi_{\beta}}{dt}, \quad 0 = r_{\beta} \cdot i_{\beta} + \frac{d\psi_{\beta}}{dt} + \frac{(\psi_{\gamma} - \psi_{\alpha}) \cdot p \cdot \omega_r}{\sqrt{3}}, \\
\dot{u}_{\gamma} &= r_{\gamma} \cdot i_{\gamma} + \frac{d\psi_{\gamma}}{dt}, \quad 0 = r_{\gamma} \cdot i_{\gamma} + \frac{d\psi_{\gamma}}{dt} + \frac{(\psi_{\alpha} - \psi_{\beta}) \cdot p \cdot \omega_r}{\sqrt{3}},
\end{align*}
\]

where \( u \) - voltage; \( i \) - current; \( t \) - time; \( r \) - active resistance; \( \psi \) - flux linkage; \( \omega_r \) - mechanical rotor speed; \( p \) - number of pole pairs.

Subscripts \( \alpha, \beta, \gamma \) denote belonging to the corresponding phase. The subscript \( s \) denotes the stator affiliation, \( r \) - the rotor affiliation index. In these expressions and further, the index \( \mu \) belongs to the magnetization branch. The details of the components of system (1) are given in expressions (2) (5).

Voltages at the terminals of the magnetizing branches (derivatives of the flux linkage of mutual induction) of the phases [15]:

\[
\begin{align*}
\dot{u}_{0\alpha} &= \frac{d\psi_{\mu\alpha}}{dt} = r_{\mu\alpha} \cdot \left[ (i_{\alpha} + i_{\beta} + i_{\gamma}) - \frac{1}{2} \cdot (i_{\beta} + i_{\gamma} + i_{\gamma}) - \frac{\psi_{\alpha}}{M_\alpha} \right], \\
\dot{u}_{0\beta} &= \frac{d\psi_{\mu\beta}}{dt} = r_{\mu\beta} \cdot \left[ (i_{\beta} + i_{\gamma} + i_{\gamma}) - \frac{1}{2} \cdot (i_{\alpha} + i_{\alpha} + i_{\beta}) - \frac{\psi_{\beta}}{M_\beta} \right], \\
\dot{u}_{0\gamma} &= \frac{d\psi_{\mu\gamma}}{dt} = r_{\mu\gamma} \cdot \left[ (i_{\gamma} + i_{\gamma} + i_{\gamma}) - \frac{1}{2} \cdot (i_{\alpha} + i_{\beta} + i_{\gamma}) - \frac{\psi_{\gamma}}{M_\gamma} \right],
\end{align*}
\]

where \( M_\alpha, M_\beta, M_\gamma \) - the mutual inductances of the phase of the rotor and stator windings of the IM; \( r_{\alpha}, r_{\beta}, r_{\gamma} \) - active resistances of magnetizing circuits of each phase.

EMF of the magnetizing branch [15]:

\[
e_{0\alpha} = -\dot{u}_{0\alpha}; \quad e_{0\beta} = -\dot{u}_{0\beta}; \quad e_{0\gamma} = -\dot{u}_{0\gamma}.
\]

Rotation EMF of the rotor phases [14]

\[
\begin{align*}
e_{r\alpha} &= \frac{(\psi_{\beta} - \psi_{\gamma}) \cdot p \cdot \omega_r}{\sqrt{3}}; \quad e_{r\beta} = \frac{(\psi_{\gamma} - \psi_{\alpha}) \cdot p \cdot \omega_r}{\sqrt{3}}; \quad e_{r\gamma} = \frac{(\psi_{\alpha} - \psi_{\beta}) \cdot p \cdot \omega_r}{\sqrt{3}}.
\end{align*}
\]
Expressions (3) and (4) for the flux linkage of the stator and rotor phases [15]:

\[
\begin{align*}
\psi_{\alpha} &= L_{\alpha} \cdot i_{\alpha} + \psi_{\mu\alpha}; \\
\psi_{\beta} &= L_{\beta} \cdot i_{\beta} + \psi_{\mu\beta}; \\
\psi_{\gamma} &= L_{\gamma} \cdot i_{\gamma} + \psi_{\mu\gamma}.
\end{align*}
\]

(5)

The equations of the electromagnetic moment of the AM has the form [15]:

\[
T = p \cdot \frac{\sqrt{3}}{2} \left[ \left( i_{\alpha} \cdot i_{\gamma} \cdot i_{\alpha} + i_{\beta} \cdot i_{\alpha} \right) - \left( i_{\alpha} \cdot i_{\gamma} \cdot i_{\beta} + i_{\beta} \cdot i_{\gamma} \right) \right].
\]

(6)

Equations of motion for the IM shaft with a single-mass mechanical part [15]

\[
\frac{d\omega}{dt} = \frac{1}{J} \cdot (T - T_c),
\]

(7)

where \( J \) – the moment of inertia; \( T_c \) – the moment of resistance.

2.3. Calculation of the Value of the Active Resistance of the Magnetizing Circuit

In modeling, the problem lies in the correct setting of the value \( r_\mu \), the criterion of which is the correct value of losses in the steel AM (\( p_\mu \)). Since the correct is not known exactly, its value is calculated based on the reference for the nominal mode of AM operation [13] value \( p_{st} \):

\[
p_\mu \leq \frac{P_2}{3} \left( \frac{1}{\eta} - 1 \right) = \frac{1200}{3} \left( \frac{1}{0.955} - 1 \right) = 56,545 \text{ kW},
\]

(8)

where \( P_2 = 1200 \text{ kW} \) - the power on the AM shaft; \( \eta = 0.955 \) - AM efficiency (Table 1). Assuming that, all other things being equal, the voltage at the terminals of the magnetizing circuit \( U_0 \) is practically independent of the value \( r_\mu \), since it is stabilized by a large inductance, it is possible to correct the value \( r_\mu \) in accordance with the required value \( p_{st} \) using the formula [12]:

\[
r_\mu = \frac{3 \cdot U_0^2}{p_{st}} = 171.685 \text{ \Omega}
\]

(9)

The voltage \( U_0 = 1800 \text{ V} \), was determined on the model in the absence of resistance \( r_\mu \). Additionally, during the correction \( r_\mu \), the value of the current of the IM stator phase was monitored.

2.4. Consideration of the Saturation of the Magnetic Circuit Along the Path of the Main Magnetic Flux

The saturation of the magnetic circuit is an important factor affecting the AM dynamic characteristics [11, 12]. In these studies, in order to take into account the saturation for each phase and the AM electromagnetic moment equation, the dependence of the main inductance is used as a function of the instantaneous value of the amplitude of the representing vector of the mutual induction flux linkage: \( L_{\mu} = f \left( \psi_{\mu2n} \right) \). The total flux linkage \( \psi_{\mu2n} \) is obtained from the expressions [10, 11]:

\[
\psi_{\mu2n} = \sqrt{\psi_{\mu\alpha}^2 + \psi_{\mu\beta}^2 + \psi_{\mu\gamma}^2},
\]

(10)

where \( \psi_{\mu\alpha} \) and \( \psi_{\mu\beta} \) – the projections of the imaging vector of the magnetizing current on the orthogonal coordinate axes X and Y. For three-phase "hindered coordinates", these projections obtained from the phase magnetization flux linkages [11, 12]:

\[
\psi_{\mu\alpha} = \frac{2}{3} \left( \psi_{\mu\alpha} + \psi_{\mu\beta} \cdot \cos \left( \frac{2 \cdot \pi}{3} \right) + \psi_{\mu\gamma} \cdot \cos \left( \frac{2 \cdot \pi}{3} \right) \right); \quad \psi_{\mu\beta} = \frac{2}{3} \left( \psi_{\mu\alpha} + \psi_{\mu\beta} \cdot \sin \left( \frac{2 \cdot \pi}{3} \right) + \psi_{\mu\gamma} \cdot \sin \left( \frac{2 \cdot \pi}{3} \right) \right).
\]

(11)

Saturation of the magnetic circuit leads to the appearance of harmonic components with orders of multiples of
three in the spectrum of the main magnetic flux. As a consequence, changes in the harmonic composition of voltages and currents may occur [11]. To reflect this in the mathematical model, it is necessary to enter separate accounts $L_{ψμ} = f(ψ_μ)$, $L_{ψβ} = f(ψ_β)$, and $L_{ψγ} = f(ψ_γ)$, in the expressions for each AM phase, and. For the convenience of modeling, taking into account the indicated inductances as functions of the flux, the inductance and magnetic flux are expressed in relative units. Instantaneous value of the total inductance of the stator winding phase in relative units [10, 11]:

$$L_μ^* = \frac{L_μ}{\sqrt{2} \cdot L_{ψμ, nom}},$$

where $L_μ$ - the instantaneous value of the total inductance of the stator winding phase; $L_{ψμ, nom}$ - nominal value of the total inductance of the stator winding phase. Instantaneous value of the main magnetic flux [10, 11]:

$$ψ_{μ, 0}^* = \frac{|ψ_{μ, 0}|}{\sqrt{2} \cdot ψ_{μ, nom}},$$

where $|ψ_{μ, 0}|$ - the modulus of the instantaneous value of the main magnetic flux; $ψ_{μ, nom}$ - the nominal value of the main magnetic flux.

2.5. Consideration of Possible Winding Unbalance

Unbalance in the windings can be caused, for example, by a turn-to-turn short circuit in the stator windings. With turn-to-turn closure, one or more turns of the winding are short-circuited. That is, the number of undamaged turns is reduced. The study [14] shows the relationship between the geometric dimensions of the windings and leakage inductances and mutual inductances. This study shows that the mutual inductances of stator windings, rotor windings, stator and rotor windings are a function of the number of windings

$$L_{ij}^w = L_{ji}^w = f_w^w (w^w, w^w), \quad L_{ij}^r = L_{ji}^r = f_w^r (w^r, w^r),$$

where the superscripts denoting belonging to the stator (s), or rotor (r); superscripts (i) or (j) indicate phase (α, β or γ).

Then the mutual inductances for each phase will be the sum of local inductances that are formed with the participation of this phase

3. Results of Modeling a Traction Induction Motor

3.1. Simulation Results of an Undamaged Traction Motor

Based on expressions (1) - (8) and (16) - (21), a simulation model of a traction induction motor is implemented in the MATLab software environment. For an undamaged motor, the shaft speed and electromagnetic torque diagrams are shown in Fig. 1 and Fig. 2 respectively.

![Fig. 1 Diagram of the shaft speed of an undamaged motor](image1.png)

![Fig. 2 Diagram of the torque of an undamaged motor](image2.png)

Comparison of the shaft rotation speed obtained as a result of the simulation ($n = 1109$ rpm) with the data of the manufacturer's plant ($n = 1110$ rpm) and the electromagnetic moment of the model ($T = 10695$ N·m) and the
manufacturer's plant \((T = 10700 \text{ N}\cdot\text{m})\) for the nominal mode show a high convergence of the simulation results with the data of the manufacturer. In addition, as a result of the simulation, it was found that in the nominal mode, the amplitude values of the stator current are \((I_s = 212 \text{ A})\). Manufacturer's data is \((I_s = 214 \text{ A})\). All these results indicate that the proposed model is adequate and can be applied to study electrodynamic processes in induction traction motor.

3.2. Simulation Results of a Traction Motor with Unbalanced Stator Windings

When simulating the operation of a traction motor with asymmetric stator windings, it is assumed that turn-to-turn short circuit occurred on the stator phase winding A. 6 turns of 48 stator windings are damaged. As a result of the simulation, the diagrams of the shaft rotation frequency and the electromagnetic moment are obtained are shown in Fig. 3 and Fig. 4 respectively.

![Fig. 3 Diagram of the shaft speed of an damaged motor](image1)

![Fig. 4 Diagram of the torque of an undamaged motor](image2)

From the diagrams given (Fig. 3 and Fig. 4) it follows that with a damaged stator, the starting torque of the motor increases, in the steady state mode, stable torque pulsations appear on the motor shaft with an oscillation frequency that is equal to twice the supply frequency.

4. Conclusions

A model of a traction asynchronous electric motor, made in decelerated coordinates, is proposed. An algorithm is proposed for taking into account losses in the motor steel, which made it possible to obtain, as a result of modeling, the values of stator currents with higher accuracy. An algorithm for accounting for saturation in the magnetic circuit of the motor is proposed. This makes it possible to improve the dynamic characteristics of the model. The proposed method for taking into account the change in the value of the mutual inductances of the motor phases in the event of such a defect in the traction induction motor made it possible to study the electrodynamic processes in the traction motor with asymmetry of the stator windings. The obtained results of modeling and their comparison with the data of the manufacturer's plant indicate high accuracy of determining the controlled parameters of the engine on the model. This model can be used to simulate a traction drive of an electric rolling stock with an asynchronous motor to study electrodynamic processes.

Acknowledgment

This work was supported by the Ministry of Education and Science of Ukraine in the project DR No. 0120U101912: Increasing the energy efficiency of rolling stock based on resource-saving technologies and smart energy systems.

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Development of Electromobility in the Context of the Economic Situation of Selected Countries

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Abstract

Electromobility is currently a very topical issue. The reasons for the growth of markets for electric vehicles are efforts to reduce emissions and cleaner transport. The popularization of this sector has contributed in recent years mainly company Tesla. Recent research and innovations in the field of electromobility indicate positive trends in market development. The competitiveness of electric cars is gaining real contours to internal combustion engines. According to Bloomberg New Energy Finance, a significant determinant of the development of electromobility is the price of batteries. This problem affects the base price of the vehicle. The second element is the state subsidies that increase the demand for electric cars. Psychological factors are important. They are related to the planned restrictions on the use of internal combustion engines, especially in the countries of Western Europe, and the strong environmental feelings of the country and its population (e.g., Norway, Netherlands...). From an economic point of view, it is to reduce dependence on fossil fuels. Insufficient infrastructure and the real range of the vehicle appear to be a negative aspect of the development of electromobility in some countries. The development of electromobility will affect commodity markets. The production of batteries will increase, the demand for materials will increase. This increase will affect the price of lithium and other metals such as nickel, cobalt, cadmium.

The paper aims to identify the impact of electromobility on the economy and financial markets based on quantitative analysis. The research question seeks to find answers about the development of electric car markets. The basic model works with quarterly data on gross domestic product per capita in the surveyed countries. The regression models used to data from relevant statistical databases from the OECD, the European Alternative Fuels Observatory, The Global Electric Vehicle Policy Database, and the Nation statistics dataset.

KEY WORDS: electric vehicle; gross domestic product per capita; electric vehicles registration; subsidies

1. Introduction

The European Union's (EU's) objective of achieving a competitive low carbon economy is based on enabling environmentally sustainable investments, particularly in terms of transition to electric vehicles, and developing smart electricity networks, while promoting renewable energy [4]. As the authors state, since, transport is one of the main sectors responsible for EU’s emissions; diffusion of Electric Vehicles (EVs) could allow immense reduction [2, 4, 8, 12].

Electromobility is a concept of road transport. It is a system consisting of vehicles equipped with electric traction, infrastructure for electric vehicles, relevant information technology, and legislation. The transition to electromobility increases society's dependence on electricity. The key challenge is to ensure the availability of raw materials for low-carbon electricity generation, safety, stability and efficient management of the electricity transmission system, which will be important in the case of simultaneous charging of more electric vehicles in households in densely populated areas. The issue of electromobility (technical, technological, design, energy, and environmental aspects) is currently addressed by many authors [3, 4, 6, 7, 10, 13, 19]. European classification for vehicle category is based in UNECE standards [16]. Its impact on the environment or the country's economy and sustainability can be found in the works of other authors [8-11, 19, 20, 22, 23]. We understand electromobility from a global and national perspective [2, 3, 5, 19, 20, 21].

Aspects of the development of electromobility in the world.

The pace of development and the share of hybrid and electric vehicles in different parts of the world depends mainly on:
- activity and orientation of national governments to initiate the electric vehicles market and regulation at EU level;
- the development of world oil and fuel prices;
- affordability and operating costs throughout the life cycle of an electric vehicle (EV);
- gradual expansion of infrastructure and large-scale production of electric vehicles;
- the pace of technological progress and innovation of batteries in relation to price and energy density.

Aspects of electromobility development in Slovak republic.

- supporting the economy and industry in the context of the strong position of the automotive industry and supply companies;
2. Current Situation

2.1. Electromobility Development Trends

The worldwide market shares of electric cars reached a record high of 2.6% of global car sales in 2019. It expanding in all major markets except Japan, Korea and United States. The global number of electric passenger cars continued to expand at a rapid pace in 2020 and reaching 10.2 million units (40% higher than in 2018). Nearly half of the world’s electric car fleet (43%) was in China in 2020. The number of 4.4 million electric cars in China in 2020 was a 46% increase from the previous year. Europe, with 1.7 million electric cars, accounted for 25% of the global stock in 2020, and 1.2 million units in the United States represented 20%. Norway was the global leader based on shares of electric cars, at 13% of the total stock in 2020. Battery electric vehicles (BEV) accounted for 67% of the world’s electric car fleet in 2020 [8, 10, 15-18].

The offer of electric car models has mushroomed. In 2019, worldwide were available some 250 models (in 2014 around 70 models). More than new 200 models have been expected to come to market by 2025. Technology improvements have increased the attractiveness of electric cars for consumers. Charging time is significantly reducing (with chargers of 250-500 kilowatts [kW] for new deployed cars an advance from the 50-120 kW capacity of most current electric car models). Also, battery costs have decreased by more than 85% since 2010 [9, 11, 15-18].

Infrastructure for charging electric vehicles is an important element of accessibility for electromobility in the countries. By the end of 2019, there were 7.3 million electric vehicle chargers installed worldwide, of which 6.5 million chargers were private light-duty vehicles slow or normal chargers. The offer and accessibility of chargers increased by 40% from 5.2 million in 2018 [9, 11, 15-18].

In its Global Outlook for Electric Vehicles scenarios, the IEA predicts 130 million to 250 million EVs in 2030, with EVs' share of the fleet expected to increase from 0.2% in 2016 to more than 5% in 2030 [4]. This forecast includes not only passenger and light-duty vehicles, but also buses and heavy-duty vehicles. In addition to the IEA, other companies share a similar view on the global development of EV:

- International Renewable Energy Agency estimates that 150 million personal EVs in 2030 and more than 1 billion EVs in 2050;
- Bloomberg New Energy Finance (BNEF) predicts 28-30 million new passenger EVs worldwide in 2030;
- Boston Consulting Group estimates that by 2030, 46% of new passenger cars in the world will be electric;
- Deloitte estimates that by 2030, 21 million electric passenger cars will be sold annually worldwide.

In addition to the above-mentioned IEA, the BNEF also published a forecast for various vehicle categories in 2019. It assumes that by 2040, electric buses will account for 68% of all buses worldwide and light commercial vehicles 38% of vehicles in their category. In freight transport, in addition to electric propulsion, vehicles powered by alternative fuels such as natural gas or hydrogen, which are more suitable for heavy duty vehicles, should be used to a greater extent.

2.2. Financial Factors of Electromobility and its Support

The most important financial factors include the price of the vehicle, the price of the battery, the cost of operation, maintenance and repair of the vehicle, or the price of fuel (electricity, oil). The consumer is interested in the return on investment in EV and is mostly compared to buying a car powered by fossil fuels. The financial costs of purchasing and operating electric cars and conventional cars were also compared by the Institute for Environmental Policy [19].

Research shows that a higher purchase price of EV may discourage some consumers. In EU countries with gross domestic product (GDP) per capita below 29000 euros/capita in 2018 EVs had less than a 1% share in new vehicle registrations. [1, 11] It is almost half of the EU countries, mainly the Member States of Central and Eastern Europe, but also Spain, Italy and Greece.

An important financial aspect is state support in the form of subsidies, fee reductions and taxes. This trend is subsequently reflected in the number of registered vehicles, where Norway, Germany, France and the Netherlands maintain the leading positions in Europe. An example is Norway, which provides significant subsidies and relief for EV users. E.g. EVs are exempt from VAT, do not pay road tax, tolls, 50% discount on ferries, and use of lanes for public transport, exemption from parking fees, entry to the center exempt from registration tax, etc. [11] These instruments are mainly related to the country's environmental policy and with the aim of achieving zero emissions for all vehicles sold by 2025 [11, 19, 18].

In contrast, the countries of Central and Eastern Europe do not have a system in place to support the sale of EVs. Exceptionally, these are isolated and one-off subsidies. In the future, according to government documents and
memoranda, motorists in the Slovak Republic and the Czech Republic can also count on various subsidies, but these will probably not be fully implemented until after 2025 [11, 19, 21].

3. Objective and Methodology

In connection with the search for global solutions to the climate crisis, the issue of electromobility is currently one of the most discussed topics. As we have already indicated, the position of a particular country within the chosen policy has a great influence on the development of electromobility. The aim of the paper is to examine the impact of the GDP level on the expansion of electric vehicles in the conditions of selected countries. These are countries with a large share of registered electric vehicles (Norway, Sweden, and Netherlands) and countries where these trends are still beginning to be enforced (Slovak republic, Czech Republic, Iceland). GDP is a basic parameter that reflects the purchasing power of the population. The development of BEV markets is observed between the periods Q1 2011 - Q4 2020. The research is detailed data obtained from OECD databases [14] based on quarterly periodicity. The size of the market is expressed by the number of newly registered electric vehicles (battery vehicles) in the country. Statistics from the European Alternative Fuels Observatory and the global electric vehicle sales database (EV Volumes) were also used. [15, 17]. The SPSS statistical tool was used to examine the impact of GDP per capita and the number of newly registered BEVs. The analysed data were checked for normal distribution. To interpret the conclusions and determine the regression equation, it was necessary to examine various statistical characteristics, e.g. the strength of the relationship between the investigated variables by means of the Pearson correlation coefficient (R), as well as the coefficient of determination (R Square) explains how many percent of the variability of the dependent variable Y is affected by the independent variable X.

4. Results and Discussion

Using regression linear analysis, we examine the existence of a dependence between the number of registered BEVs and GDP (as one of the aspects determining the purchasing power of the population).

Research hypotheses:

H0: The value of GDP per capita has no statistically significant effect measured by linear regression of the number of newly registered BEV.

H1: The value of GDP per capita has statistically significant effect measured by linear regression of the number of newly registered BEV.

The following figures represent a graphical representation of the markets of the countries studied (according to GDP per capita) in relation to the registered number of BEVs. For graphical representation, the absolute values of GDP per Capita in US dollars in the examined quarters are plotted on the X-axis and the numbers of quarterly BEV registrations are plotted on the Y-axis.

The first group consists of SK, CZ and Iceland, which are considered to be countries starting with electromobility. At the same time, according to the evaluation reports, Iceland is considered to be a country where the use of alternative fuel has recently started to be significantly used, which is reflected mainly in the number of purchased and registered BEVs and PHEVs (plug-in hybrid electric vehicles).

![Graphical representation of the markets of the countries studied (according to GDP per capita) in relation to the registered number of BEVs.](image)

Fig. 1 Slovak trade

Fig. 1 shows that with increasing GDP, the number of registered electric cars also increases. Simple expression of the result: if GDP per capita is increased by $ 1000, the number of registered BEVs will increase by 19. There is a strong dependence between the studied variables and the model expresses that 31% of the variability of the dependent variable is influenced by an independent variable.
Fig. 2 Czech trade

Fig. 2 shows that with increasing GDP, the number of registered electric cars also increases. A simple expression of the result: if GDP per capita increases by $1000, the number of registered BEVs will increase by 28. There is a strong dependence between the studied variables and the model expresses 28% of the variability of the dependent variable influenced by the independent variable.

Fig. 3 Iceland trade

Fig. 3 shows that with increasing GDP, the number of registered electric cars also increases. A simple expression of the result: if GDP per capita increases by $1000, the number of registered BEVs will increase by 18. There is a strong dependence between the investigated quantities and the model expresses that 41.6% of the variability of the dependent variable is influenced by the independent variable.

In the first group of analyzed countries, it is possible to say on the basis of the examined statistical characteristics and values of the linear regression model that we accept H1 about the existence of a dependence between the value of GDP and the number of newly registered BEVs. This applies to each country examined separately.

The second group of countries consists of Norway, the Netherlands and Sweden. These are countries that have long been considered leaders in the number of EVs operated, even in the category of BEV per capita.

Fig. 4 Norway trade
Fig. 4 shows that with increasing GDP, the number of registered electric cars also increases. Simple expression of the result: if GDP increases by $1,000, the number of registered BEVs will increase by 818. There is a large dependence between the investigated quantities and the model expresses 25.3% of the variability of the dependent variable influenced by the independent variable.

Dependent Variable: BEV new registrations
Predictor (Constant): GDP per Capita
Linear Regression Model: \[ Y = -58171.678 + 1.194X \]
Mean (BEV): 4498.925
R: 0.633
R Square: 0.401
Sig. (p): 0.001
F(1,38): 25.457

Fig. 5 Netherlands trade

Fig. 5 shows that with increasing GDP, the number of registered electric cars also increases. Simple expression of the result: if GDP per capita is increased by $1000, the number of registered BEVs will increase by 1,194. There is a large dependence between the investigated quantities and the model expresses 40.1% of the variability of the dependent variable influenced by the independent variable.

Dependent Variable: BEV new registrations
Predictor (Constant): GDP per Capita
Linear Regression Model: \[ Y = -20491.198 + 0.443X \]
Mean (BEV): 1549.775
R: 0.724
R Square: 0.525
Sig. (p): 0.001
F(1,38): 41.946

Fig. 6 Sweden trade

Fig. 6 shows that with increasing GDP, the number of registered electric cars also increases. Simple expression of the result: if GDP increases by $1,000, the number of registered BEVs will increase by 443. There is a very large dependence between the investigated quantities and the model expresses 52.5% of the variability of the dependent variable influenced by the independent variable.

In the second group of surveyed countries, it is possible to say on the basis of the examined statistical characteristics and values of the linear regression model that we accept H1 about the existence of a dependence between the GDP value and the number of newly registered BEVs. This applies to each country examined separately.

5. Conclusions

The obtained data on the dependence between the country's wealth, expressed in terms of GDP per capita and the number of newly registered BEVs in individual quarters can be extended by assessing the dependence between the values of stock exchange indices (in closing values) and many registered BEVs. Due to the lack of space, we only state that even here, a positive dependence was demonstrated in all the countries studied.

The role of the authors is to further search for answers to questions related to the development of electromobility in the next decade, especially in connection with the announced decline and cessation of production of vehicles with combustion propulsion. It is also interesting to find out which factors will support or slow down the development of electromobility. In connection with the environmental aspect, we are interested in whether electromobility will really contribute to the reduction of emissions from transport in the Slovak Republic and what impact it will have on electricity consumption.
Acknowledgement

This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund.

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Health Protection Measures and Physical Distancing Model for Airports

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Abstract

The current pandemic situation caused that airports need to adapt their operational processes to new health protection measures that include for example physical distancing, use of face masks or more detailed cleaning and disinfection of airport terminals. Airport infrastructure is usually not designed for the full application of physical distancing principles. A model and an application were created in order to simulate the expected space per person in the arriving corridors of the terminal according to the imported flight schedule. The output of the model allows calculating of the decrease of airport operational performance in case of implementation of physical distancing principles. The results of the model also help to improve the efficiency of the use of space in airport terminals.

KEY WORDS: airport; health protection measures; physical distancing; physical distancing model

1. Introduction

The outbreak of COVID-19 pandemic led to the tremendous decrease in the air traffic all over the world. It has been calculated that international air passenger traffic fell by 60 % and airport revenues were 65 % lower in 2020 compared to 2019 results [1]. Airports had to implement protective measures to prevent the spread of COVID-19 in the airport environment. Aviation organizations such as ICAO (International Civil Aviation Organization), IATA (International Air Transport Organization) or ACI (Airports Council International) introduced guidelines for health safe air travel.

According to ICAO [2], the basic risk mitigation measures are public education, general hygiene, physical distancing, face masks, routine sanitation, health declarations, health screenings, and health monitoring with contact tracing. ICAO and WHO (World Health Organization) recommend at least 1 m between individuals, while ACI Europe and EASA (European Union Aviation Safety Agency) consider a minimum distance of 1,5 m to minimize the risk of disease transmission [2-4]. Physical distancing needs to be observed in queues, passenger flows, waiting for areas, shops, elevators, buses and also during any interaction between passengers and airport staff. Passenger flows should be one-way to avoid cross-flows [4].

Physical distancing principles have a significant impact on airport operations. Airports still need to maintain sufficient handling capacity while reducing the financial impact of protective measures and decrease of air traffic. EUROCONTROL (European Organization for the Safety of Air Navigation) considers a distance of 1,5 m as the most widely used in Europe. Space demand for such a distance is 2 m². According to the EUROCONTROL’s calculations, the capacity of queuing lanes at the security checkpoint drops by 50% due to physical distancing. The capacity of buses for passenger transfer from remote aircraft stands to airport terminals reduces to 18,7% while applying physical distancing. This would lead to the need for five times bigger bus fleet which is neither efficient, nor economic. The situation at the arrival passport control and arrival health checkpoint is similar. The capacity of the waiting area is estimated to drop by 50% [5].

Airport performance is also affected by health screenings for both departing and arriving passengers. Departure health screenings are considered to prevent infectious disease contamination, whereas arrival health screenings are used to mitigate the risk of disease spread in case that the airport of departure does not follow health protection measures and screenings [6, 7]. Another way how to mitigate the risk of infection is by implementing new technologies that enable minimization of physical contact between passengers and airport staff, for example, self-service kiosks, automated documents controls or biometrics for contactless identification [8].

This paper brings an approach to the preliminary evaluation of expected available space per person in the arriving corridors of an airport based on the imported flight plan. An application was created for a comprehensible user interface. Entering of several input parameters in the application enables adjusting the generic model for a wide variety of airports with a different layout of arrival corridors. The result is presented as a graph showing an expected space per person in the chosen time interval according to the imported flight schedule. The minimum reached space per person is highlighted and displayed for an easier evaluation of results. This generic model can be used by airports as a tool for preliminary
verification of the capacity of arrival corridors while using any flight plan, either historic or expected, that is in the required format.

2. Physical Distancing Model and Application for Airports

The aim of the model is too preliminary assess physical distancing possibilities in the arrival corridors of airports. The basic precondition of the generic model is that after disembarking from the aircraft, passengers walk from their arrival gate to the arrival health checkpoint or transfer desk without stopping and abide by physical distancing rules during their journey. Immigration is usually the point where passenger’s travel documentation and arrival forms including for example negative test results or quarantine requirements are controlled. The health checkpoint can be designed as a stand-alone checkpoint or can be integrated into existing arrival control according to the effective local legislation. This checkpoint is commonly located ahead of the baggage reclaim area. It is not considered that passengers form queues in the arrival corridors as there are usually no controls that would cause bottlenecks. One of the tools that airport can use for optimization of passenger flow according to operational requirements is gate allocation. In case the airport needs more time to empty the health checkpoint area, arriving flights are assigned to remote gates, so the walking times from those gates to the checkpoint are prolonged. A standard walking speed of 1,25 m/s is considered in this model.

The approach to this model requires inputs from both imported data source files and from the application’s user interface. This solution enables preliminary assessment of physical distancing possibilities for airports with different layouts of arrival corridors. The core of the program are matrices that are filled with passengers coming in and out of arrival corridors in a cycle. The number of matrices corresponds with the number of arrival corridors. The program’s time unit is in seconds and the reference time is the same for all the matrices. This solution provides knowledge of an exact number of passengers in the health checkpoint area. The output of the model is a graph showing available space per person in the chosen time interval in the arrival corridors. The minimum space per person is highlighted and displayed in the numeric form.

There are several inputs that need to be entered including two structured data source files before the graph can be displayed. The model is based on flight schedule that is open to the public via webpage flightera.net [9]. For purpose of this paper, a flight schedule of arrivals during one week at an unspecified airport was imported. Following data loaded from the flight schedule are necessary for the program: date of arrival, real landing time, passengers on board and arrival gate. These data are further processed in the program.

The second data source is the list of arrival gates together with walking times from each gate to the end of the arrival corridor. For purpose of this paper, an airport layout with three arrival corridors was used. The following location of gates was considered: 6 gates in the Corridor 1, 6 gates in the Corridor 2, and 16 gates in the Corridor 3. Changes of the layout are enabled by importing different file with appropriate data for a concrete airport. The file must follow the same formatting rules as the original to enable correct run of the program.

The application was designed to enable further personalization of the model. There are 8 input parameters that need to be entered before pushing the Start button (Fig. 1). In case any of the fields is not filled, an error notice shows up to notify the user to fill in the empty field. Time intervals with four-hour duration were programmed after experiments with shorter time intervals and discussions with experts. This solution provides a sufficient overview of the corridor’s capacity, for example in the morning, midday time or in the evening peak hour etc.

Input parameters:

- 1 – Floor space of arrival corridor 1 [m²]
• 2 – Floor space of arrival corridor 2 [m²];
• 3 – Floor space of arrival corridor 3 [m²];
• 4 – Time interval between two passengers grants them a given distance as displayed after pressing the Start button under this field [s];
• 5 – Average taxi time is the time difference between the real landing time imported from the flight schedule and the beginning of passenger disembarkation from the aircraft [s];
• 6 – Average load factor is the average occupancy of arriving flights [%].

Buttons and pop-up menus:
• A – Button to show calendar and enable selecting a date;
• B – Pop-up menu to select time interval;
• C – Button to start the calculation and show the graph and the lowest reached space per person in each corridor;
• D – Button to reset the entered values and graph;
• E – Button to confirm user’s choice of date.

One of the limitations of this model is that the health checkpoint area is not included as this area must be dealt with the queuing theory. Passengers have to individually undergo the control of arrival forms and documents. This check has been implemented since the outbreak of COVID-19 pandemic in spring 2020 and usually causes congestions in the health checkpoint area. The research team intends to focus on the queuing theory in the further research.

Immigration controls for arriving passengers while travelling within the member states of the European Union may be modified or cancelled with the launch of Digital Green Certificates [10]. These certificates would cover three options: vaccination certificates, test certificates, and certificates for persons who have recovered from COVID-19. Digital Green Certificates would be scanned through QR codes. This solution could significantly accelerate the passenger flow.

3. Results

The results of the generic model are considered to have a preliminary character that enables assessment of physical distancing capabilities at airports. The resulting graph is displayed below the Start and Reset buttons. For purpose of introducing the model in this study, input parameters, as shown in Fig. 2, were entered.

After running the program, the following components are displayed: the graph, information about minimum space per person in each corridor, and a number of arriving flights in the chosen interval.

Different colors were assigned to each corridor as shown in the legend that is located in the right upper corner of the graph. The space per person in the first corridor with a floor space of 750 m² is displayed using magenta color. The lowest space per person in this corridor was 10 m²/person. This minimum was reached around 5 PM as shown in the graph by red asterisks. The second corridor had similar results. The minimum of 10,1149 m²/person was reached before 6 PM. The third corridor has the lowest floor space but the majority of arriving flights were assigned to the corridor. This corridor can be used as an arrival hall for passengers from aircraft at remote stands. Thus, the minimum space per person in this corridor reached only 1,8481 m²/person before 8 PM. According to EUROCONTROL, the minimum safe space per person is considered to be 2 m²/person [5]. This airport layout in combination with chosen testing flight plan ensures physical distancing space requirements only in Corridor 1 and 2. The third corridor is close below the limit of 2 m²/person.

Better slot allocation could in some cases solve the problem of insufficient space capacity of arrival corridors.

Results of the model are satisfactory in view of the fact that testing data were used and off-season flight schedule
was imported. The issue of physical distancing at airports has two dimensions: seasonality and the area where passenger flows from all the arrival corridors merge. It is expected that summer season together with partially recovered airport performance will bring problems with higher density of persons in the arrival corridors. The research team is intended to focus on these two dimensions affecting the available space per person in airports terminals in the further research.

4. Conclusions

The current pandemic crisis had a large impact on airport operations. Airports had to implement health protection measures to prevent the spread of COVID-19 in airport terminals that have a negative impact on airport capacity. This article offers an approach to a model that can be used for the preliminary assessment of the capacity of airport arrival corridors. Airports with different layouts and floor space of arrival corridors can import their own flight schedule and information about walking times from individual gates to the end of the corridor to find out whether physical distancing can be fully applied.

Input parameters that were used to illustrate the functions of the model show that physical distancing can be reached only in two of three corridors in the low season. It is considered that physical distancing at airports is not fully applicable even in the low winter season as airports were not designed to comply with physical distancing space requirements. It is expected that health protection measures will be still developing given the fact that aviation is awaited to fully recover from the pandemic crisis since 2024 [11]. It may be withdrawn from physical distancing principles in the future as new reliable measures are expected to be introduced, for example dependable antigen tests with quick results, etc. These new measures would minimize the probability that infected persons could get on board an aircraft. Thus, the need for health checkpoints at the airport of arrival would decrease.

Acknowledgement

The publication was created partly thanks to a DAAD scholarship awarded by prof. Miroslav Svitek.

References


Hard and Soft Telematics Systems

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Abstract

The paper attempts to define hard and soft railway telematics systems. In the first part of the article the circumstances of the emergence and evolution of the notion of telematics and telematic systems in transport are introduced. The next section refers to the wide range of telematics applications in different transport modes, including the railway area according to Regulation (EU) No 1315/2013 [15]. In the railway transport is pointed out the gap between the ERTMS indicated in 1315/2013 and the telematics applications indicated in Technical Specifications for Interoperability, i.e. TSI TAP [3] and TSI TAF [4]. The analysis carried out allows a distinction to be made between hard and soft telematics systems.

KEY WORDS: telematics systems, railway transport, definition

1. Introduction

The development of information and communication technologies (ICT) in transport, which has been observed for over twenty years, is not a new idea. Nor does it result only from a desire to find new areas of application for computer technology, but is rather a natural process of human technical development. The phenomenon of the popularisation of information technology (IT) and operational technology (OT) come from a deeper human need, which is the need for knowledge and cognition. Almost sixty years ago (1963), the Japanese journalist-sociologist Umesao Tadeo published a work on the information society entitled "Information Industry Theory: Dawn of the Coming Era of the Ectodermal Industry" [17]. This work points to the future use of computer techniques and their interconnection with communication systems to disseminate the various types of information needed by society.

Fifteen years later (1978), French researchers Simon Nora and Alain Minca, in their report to the French government on the computerisation of French society [11] used the term of "telematics" (French word "telematique"), as a combination of two words: telecommunications and information technology.

In the 1980s, groups of scientists, telecommunications engineers and traffic control engineers began to form at the transport departments of the USA, Japan and Australia the first special teams to develop and implement information solutions to improve transport operations. At that time, systems were developed to enable adaptive control of intersections using magnetic loops, CCTV images (Close-Circuit Television), geolocation of vehicles and wireless voice communication with emergency vehicles. In the same period of time also brought a significant development in transport logistics, with the introduction of ICT enabling the optimisation of transport processes and the storage of goods.

The first mature applications of computer systems linked to communication systems for transport began to emerge in the 1990s. These activities were termed Intelligent Transport Systems (ITS) and were largely concerned with road transport. The United States report issued in 2001 provided a coherent vision of the state and development of ITS systems in the US and also influenced the development of ITS systems in Europe. During the rapid development of ITS systems, the term telematics, identified only with the integration of computer techniques and communication systems, became less popular. The problem was not only the correct interpretation of the concept now associated as ICT, but most of all its placement among various computer-aided systems.

In the perspective of visible development trends in the automotive industry as well as in transport logistics, a series of European conferences dedicated to the development of telematics systems was initiated at the beginning of the 21st century. The TST conference (Transport Systems Telematics) has been held in Poland since 2001 and has been an opportunity for researchers, industry and institutions to exchange experience in the field of telematics systems.

Despite the fact that the concept of telematics is an interdisciplinary field that encompasses telecommunications, vehicular technologies (road transport, road safety, etc.), electrical engineering (sensors, instrumentation, wireless communications, etc.), and computer science (multimedia, Internet, etc.) and has a wide range of applications indicated, among others, in work [18]. Nowadays, the term of telematics is most often identified with transport areas and refers to:
- the technology of sending, receiving and storing information using telecommunication devices to control remote objects;
- the integrated use of telecommunications and informatics for application in vehicles and to control vehicles on the move;
- global navigation satellite system technology integrated with computers and mobile communications technology in automotive navigation systems;
- (most narrowly) the use of such systems within road vehicles, also called vehicle telematics.
In summary, the essence of telematics is a set of issues related to the transmission of information as a data using telecommunications technologies and whose purpose is to operate information [12]. It concerns its acquisition, processing, distribution together with its transmission and use in various decision-making processes related to transport.

2. Telematics Applications and Services in Transport

‘Telematics applications’ means systems using information, communication, navigation or positioning/localisation technologies in order to manage infrastructure, mobility and traffic on the trans-European transport network effectively and to provide value-added services to citizens and operators, including systems for safe, secure, environmentally sound and capacity-efficient use of the network. They may also include onboard devices, provided they form an indivisible system with corresponding infrastructure components.

Article 31 of regulation (EU) No 1315/2013 [15] of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU indicates Telematics applications shall be such as to enable traffic management and the exchange of information within and between transport modes for multimodal transport operations and value-added transport-related services, improvements in safety, security and environmental performance, and simplified administrative procedures. Telematics applications shall facilitate seamless connection between the infrastructure of the comprehensive network and the infrastructure for regional and local transport.

In the next part of this regulation the most important telematics applications for the different transport modes are:

- for railways: European Rail Traffic Management System (ERTMS);
- for inland waterways: River Information Services (RIS);
- or road transport: Intelligent Transport System (ITS);
- for maritime transport: Vessel Traffic Monitoring and Information Systems (VTMIS) and e-Maritime services, including single-window services such as the maritime single window, port community systems and relevant customs information systems;
- for air transport: air traffic management systems, in particular those resulting from the SESAR system.

The systems indicated above, refers to the technologies and the services in other legal acts:
- ‘River Information Services (RIS)’ means information and communication technologies on inland waterways as specified in Directive 2005/44/EC of the Parliament and of the Council [8];
- ‘Vessel Traffic Monitoring and Information Systems’ (VTMIS) means systems deployed to monitor and manage traffic and maritime transport, using information from Automatic Identification Systems of Ships (AIS), LongRange Identification and Tracking of Ships (LRIT) and coastal radar systems and radio communications as provided for in Directive 2002/59/EC of the European Parliament and of the Council [7], and includes the integration of the national maritime information systems through SafeSeaNet;

At this point, it is also necessary to refer to telematics services. A telematics service is the application of telematics through the use of an appropriate telematics system. The term telematics service or In ITS Transport Telematics Services (TTS) is most often used in the context of road telematics systems. As indicated in the introduction to this article, the area of road telematics is the best developed and has the widest catalogue of telematics services. ITS services have been standardised, which is proved by the standard ISO 14813-1 [13]. The standard divide services into ‘ITS service domains’ like:

1. Transport network operations and maintenance activities;
2. Freight mobility and inter-modal connectivity;
3. Multi-modal travel including both pre-trip and on-trip information and journey planning where the trip starts and/or finishes in the road transport domain;
4. Variable road pricing strategies for freight and personal travel;
5. Emergency and natural disaster-related response activities and coordination;
6. National security needs related to transportation infrastructure;
7. Cooperative-ITS – sometimes referred to as ‘connected vehicles’ or ‘connected vehicle/highway systems’.

Within these there can be a number of ‘ITS service groups’ for particular parts of the domain.

3. Railway Telematics Applications

The technologies and services listed in preview paragraph, identified explicitly as telematics applications, belong to control systems, i.e. those that directly influence transport processes through control devices. The ERTMS railroad
system is a particular case in which this is evident. European Rail Traffic Management System (ERTMS) is a complex hardware and software-based system involving ‘trackside control-command and signalling’ and ‘on-board control-command and signalling’ subsystems indicated in directive 2016/797 [10]. The ERTMS includes the European Train Control System (ETCS) enforcement subsystem supported by the GSM-R (GSM for Railways) digital wireless communication network. This is indicated in the technical specification for interoperability relating to the ‘control-command and signalling’ (TSI CCS) [5]. The ETCS is implemented with standard trackside equipment and unified controlling equipment within the train cab. In its advanced form, all lineside information is passed to the driver wireless inside the cab, removing the need for lineside signals watched by the driver. It allows to implementation different kind of safety systems as Automatic Train Control (ATC) system which is a class of train protection systems for railways that involves a speed control mechanism in response to external inputs and Automatic Train Protection (ATP) system which continually checks that the speed of a train is compatible with the permitted speed allowed by signalling, including automatic stop at certain signal aspects. These systems, in connection by the radio-communication system i.e. GSM-R give the foundation for Automatic Train Operation system. Automatic Train Operation (ATO) is an operational safety enhancement system used to help automate the operation of trains. The degree of automation is indicated by the Grade of Automation (GoA), up to GoA level 4 (where the train is automatically controlled without any staff on board).

At present it is not possible to use ATO in the ERTMS because the system does not belong to class of the safety operation systems and is the ‘non-safety’ part of train operation related to station stops and starts, and indicates the stopping position for the train once the ATP has confirmed that the line is clear. Nevertheless, the ATO systems are being used with great success on metro lines, for example The Victoria line of the London Underground in UK, the Montreal Metro in Canada, the Lille Metro in France, the Barcelona Metro in Spain, the Milan Metro in Italy, and many others.

In conclusion, by reference to the definition given at the beginning and confirmed by the regulation [15], railway automation systems which use information transmitted via telecommunication systems can be classified as railway telematics systems.

The ERTMS system indicated in the regulation [15] is different from the rail telematics applications described in the Technical Specification for Interoperability. The Directive (EU) No 2016/797 on the interoperability of the rail system within the European Union indicates in Annex II Section 2.6 two functional subsystems focused on telematics applications. These are the Telematics Applications for Passenger services (TAP TSI) [3] and the Telematics Applications for Freight services (TAF TSI) [4].

The maintenance subsystem relating to the telematics applications for passenger services [3] includes the provision of information on the following aspects:
- systems providing passengers with information before and during the journey;
- reservation and payment systems;
- luggage management;
- issuing of tickets via ticket offices or ticket selling machines or telephone or Internet, or any other widely available information technology, and on board trains;
- management of connections between trains and with other modes of transport.

Annex II to regulation (EC) No 1371/2007 [16] on rail passengers’ rights and obligations lists the minimum information to be provided to passengers by railway undertakings and/or by ticket vendors. In the reservation and payment systems information is exchanged between the reservation and ticketing systems, and the payment systems of the different ticket vendors and railway undertakings in order to enable the passenger to pay for the above tickets, reservations and supplements for the journey and service chosen by the passenger. The luggage management application provide information to the passenger relating to the complaints procedures in the event of registered luggage being lost during the journey. Moreover, passengers will be provided with information about sending or picking up registered luggage. Issuing of tickets application provide information between railway undertakings and ticket vendors in order to enable the latter to issue, where available, tickets, through tickets, and supplements, and to make reservations. And finally telematics application for management of connections between trains and with other modes of transport is proposed as a standard for the provision of information to and exchange of information with other modes of transport.

The subsystem Telematics Applications for Freight includes particular applications [4]:
- applications for freight services, including information systems (real-time monitoring of freight and trains);
- marshalling and allocation systems, whereby under allocation systems is understood train composition;
- reservation systems, whereby here is understood the train path reservation;
- management of connections with other modes of transport and production of electronic accompanying documents.

All the applications are connected to software and data communication protocols, functional methods of use, management of the information, updating and maintenance of databases. These applications handle information, the use of which has a beneficial effect on transport processes through better information and accessibility of services for passengers and better management of transported cargo. Under contractual agreement the Lead Railway Undertaking shall provide information to the Customer in particular:
- path information;
- train Running Information on agreed reporting points, including at least departure, interchange/handover and
control the trains running. In the second case, when we talk about telematics applications as described in the TAP TSI [4] with amended [2] clearly differs from the ERTMS indicated in Regulation 1315/2013 [15]. The difference lies in the different use of the information transmitted remotely by means of communications. In the case of the ETRMS system, or rather ETCS, the information transmitted is used to control the railway automation equipment and ultimately to control the trains running. In the second case, when we talk about telematics applications as described in the TAP TSI [3] and TAF TSI [4], we are dealing with systems where the use of information may or may not occur.

In this way we come to the division of telematic applications into two groups, one of which directly influences the course of the transport processes, and the other is a source of knowledge and an advisory element in processes, where the decision-making role is performed by humans. According to this division, hard and soft telematics systems can be defined.

4. Hard and Soft Telematics Systems

It may be stated that telematic systems have an essential role as an assistive technology. In this sense telematics systems are some kind of an umbrella for any device or system that allows individuals to perform tasks the would otherwise be unable to do or increases the ease and safety with which tasks can be performed. The telematic services assist in the selection, acquisition, or use transport for own purposes.

As it was shown above the telematics systems can be broadly divided into devices and IT services powered by telecommunications systems. In addition, a subdivision of telematics systems can be found. This division arises as a result of the impact of these systems. To explain this difference, two examples of different railway telematic systems will be presented.

The main function of the ETCS Level 2 system is the calculation of the braking curves which are used to determine the safe speed of the train. These curves are calculated by comparing the static and dynamic speed profile. The static speed profile is a graph representing the maximum speed versus the distance. The dynamic speed profile is the calculated maximum train speed for each position, taking into account the braking distance. Based on the calculated braking curves the ETCS system is responsible for control and reaction in case of overspeed. The emergency brake is called automatically by the system when the speed exceeds 15 km/h, the emergency brake curve is exceeded or the service brake fails. The emergency brake can only be released when the train is stationary. It can therefore be concluded that the system actively acts on the vehicle without the driver's intervention.

Second example is a reservation and payment systems. It is a system based on IT technologies. The information exchange are between the reservation and ticketing systems, but also the payment systems of the different ticket vendors and railway undertakings in order to enable the passenger to pay for the above tickets, reservations and supplements for the journey and service chosen by the passenger. The system is able to dynamically present to the customer the available train connections and for selected one all of available types of accommodation in the train such as seats, couchettes, sleepers, priority seats, wheelchair spaces, or universal sleeping compartments. The information provided by the telematics system is a source of knowledge and an aid to the decision-making process taken by the passenger. On this basis, the passenger may take any decision at his/her own discretion and will. This brings us to the distinction between hard and soft telematics systems.

Hard telematics systems is a system merging of two technology fields i.e. telecommunications and informatics allowing for collecting, storing, and exchanging information between fleet of vehicles and an operational centre. Hard telematics systems create a network of sensors, converged wireless telecommunication systems, computing architecture, decision support systems and finally executive devices to force on vehicles, through on-board equipment or infrastructure equipment, to take action in order to improve driver and vehicle safety, balanced traffic flows, optimization the speed and braking to reduce fuel and operating costs. In short, hard telematics systems have a direct impact on the transport processes taking place.

Soft telematics systems is a system merging of two technology fields i.e. telecommunications and informatics allowing for collecting, storing, and exchanging information between sources of information (trains, other IT systems, to deliver reliable data to make more reliable source of real time data improving decisions process performed by railway stuff, passengers or other involved services. Soft telematics systems can be equipped in the sensor devices but the output of information flow on Man – Machine Interfaces (MMI) such as variable message platform board, DMI in the train or even passenger’s smartphone screen. The following table sets out the essential characteristics of the telematics systems described.

The features of telematics systems indicated in Table were chosen arbitrarily. It is not excluded that there is a possibility to extend this list with further features or difficulties in qualifying a specific telematics application to one of the groups. Nevertheless, for the railway telematics systems identified in the European regulations, it can be considered that the ERTMS system belongs to the hard telematics systems group and the applications indicated in the TSI TAP [3] and TSI TAF [4] belong to the soft telematics systems group.
### List of features hard and soft telematics systems

<table>
<thead>
<tr>
<th>№</th>
<th>Feature</th>
<th>Hard telematics systems</th>
<th>Soft telematics systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Type of system</td>
<td>Automation system</td>
<td>Advice decision system</td>
</tr>
<tr>
<td>2</td>
<td>Decision Maker</td>
<td>Executive devices</td>
<td>Human</td>
</tr>
<tr>
<td>3</td>
<td>Process Responsibility</td>
<td>System</td>
<td>Human</td>
</tr>
<tr>
<td>4</td>
<td>Real-Time Data Access</td>
<td>Obligated</td>
<td>Not necessary</td>
</tr>
<tr>
<td>5</td>
<td>Real-Time Monitoring</td>
<td>Obligated</td>
<td>Not necessary</td>
</tr>
<tr>
<td>6</td>
<td>Real-Time Processing</td>
<td>Obligated</td>
<td>Not necessary</td>
</tr>
<tr>
<td>7</td>
<td>Two Way Communication</td>
<td>Often obligated</td>
<td>Not necessary</td>
</tr>
<tr>
<td>8</td>
<td>Emergency Communication</td>
<td>Often obligated</td>
<td>Not obligated</td>
</tr>
<tr>
<td>9</td>
<td>Executive Devices Control</td>
<td>Obligated</td>
<td>Not applied</td>
</tr>
<tr>
<td>10</td>
<td>High Level of Reliability</td>
<td>Obligated</td>
<td>Depend on the application</td>
</tr>
<tr>
<td>11</td>
<td>Enhanced Safety</td>
<td>Often obligated</td>
<td>Not obligated</td>
</tr>
<tr>
<td>12</td>
<td>Enhanced Security</td>
<td>Obligated</td>
<td>Often obligated</td>
</tr>
<tr>
<td>13</td>
<td>Vehicle Diagnostics</td>
<td>Often obligated</td>
<td>Depend on the application</td>
</tr>
</tbody>
</table>

### 5. Conclusions

The article attempts to redefine the concept of telematics. This has become necessary due to the departure of the technical world from the meaning originally given by its authors. Over the years, the term has been progressively replaced by ICT. Attempts to link the concept with ICT applications to different areas of technology have not come into use. The area of transport has become an exception, where the term of telematics has found its place and is fully accepted as a set of different types of applications improving the efficient use of available means of transport through the use of an ICT component. At this point, it is also worth referring to ITS systems, which are de facto transport telematics systems, but which relate only to road transport.

The author of the article, by using the example of railway mean of transport, made an additional distinction of the concept of transport telematics into soft and hard telematics systems. The introduced distinction is not artificial, because, as it has been shown, on the basis of current legal regulations and existing technical solutions, transport telematics systems can interact with vehicles as automation systems do, or provide additional knowledge on the basis of which a human being or other systems can make more informed decisions. These systems may be similar in many aspects, including the sources of data acquisition, the means of data dissemination used, and even the way in which local or centralised data is processed, but in the final decision-making phase the result of the work will be sent to the appropriate HMI (Human Machine Interface) or to an actuator that is part of the infrastructure or vehicle. As a consequence of the application of telematics systems in transport, benefits are achieved for the passengers, the carriers, the infrastructure managers, but also for the environment through the reduction of journey times, stoppages, reloading places, exhaust emissions, synchronisation with other means of transport and, finally, the safety of persons and goods involved in the transport process.

In summary, the use of telematics applications in transport positively influences the development of this branch of the economy and provides scope for many more activities and innovations.

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deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport


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Application of Orthogonal Decomposition of Mixed Laws’ Density Distribution of Navigational Measurement Errors

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Abstract

The analysis of application possibility of orthogonal decomposition of mixed laws' density distribution of errors in navigation measurements instead of densities was carried out. It is shown that the best coincidence of the density distribution and its orthogonal decomposition is achieved by using only its first term.

The results of the density distribution coincidence with its orthogonal decomposition for different values of the essential parameter of mixed laws of distribution are given.

KEY WORDS: navigational safety, navigational measurement errors, mixed distribution laws, generalised Poisson distribution law, orthogonal density decomposition

1. Introduction

Improving the accuracy of vessel position control when navigating in congested waters is one of the essential aspects of the problem of ensuring an adequate level of navigational safety. If available, the choice is made in such a way that redundant position lines are used to improve the accuracy of the ship's obtained coordinates. In this case the coordinates should be calculated by the maximum likelihood method, the algorithm of which is unambiguously determined by the probability distribution law of position line errors.

Therefore it is necessary to know the distribution law of navigational measurement errors to ensure maximum accuracy of vessel position observations in the presence of redundant position lines. Often when statistical materials of errors are not enough it is impossible with standard procedure to define their distribution law, though it is possible to estimate central moments of distribution and if histogram of sample has "weighted tails" it is possible to use expansion of error distribution density into Gram-Charlier series of type A by means of orthogonal Hermite polynomials without having its analytical expression. What is essential is the accuracy of correspondence of the distribution density to its orthogonal expansion, which is the subject of this article.

Alternatively to normal law of distribution for description of random errors of navigation measurements the mixed laws of the first and second types are offered in work [1], and in work [2] statistical materials on accuracy of definition of a vessel position by means of the satellite radio navigation system receiver which have shown that the assumption about distribution of casual errors of latitude and longitude definition under the Gauss’s law is not correct are presented.

An analysis of statistical data of navigation measurement errors obtained in field observations is presented in articles [3, 4], which showed the invalidity of the hypothesis about the distribution of errors by the normal law. In article [5] generalized Poisson's law was offered for description of random errors, and in article [6] there are results of research of description possibility of dependent random variable systems by means of generalized Poisson's law of distribution with basic normal distribution.

In article [7] results of identification of laws of error distribution of navigational measurements are given, which show that errors of radar bearing and distance measurements mainly obey mixed laws of the first and second type.

If navigational measurement errors do not follow the normal law, then, as shown in [8], application of the least squares method to calculate the obtained vessel coordinates does not provide the possibility of obtaining their effective estimates. So in articles [9, 11], it is shown, that at the mixed laws of distributions efficiency of the obtained coordinates of a vessel at excess lines of position is less than unity, and with growth of essential parameter it aspires on value to unity.

The aim of the article is to analyse the degree of coincidence of the probability density distribution of random errors with its orthogonal expansion and possibilities of its use by the example of mixed laws of the first and second types, as well as the generalised Poisson distribution law.
2. Main Part

Very often the statistical data of navigation measurement errors have bad agreement with known laws of distribution, however it's possible to calculate the central moments of distribution which allows using orthogonal decomposition for description of the probability density of random variables.

In article [10] it is shown that orthogonal decomposition of density \( f(x) \) in a Gram-Charlier series of type A has the following form:

\[
f(x) = (2\pi)^{-1/2} \sigma^{-1} \exp\left(-x^2/2\sigma^2\right) \left[1 + \sum_{k=2}^{s} \frac{c_k}{(2k)!} H_{2k}(x/\sigma^2)\right],
\]

in which the expressions for the paired Hermite polynomials \( H_{2k}(y) \) are given below:

\[
\begin{align*}
H_2(y) &= y^2 - 6y^2 + 3; \\
H_4(y) &= y^4 - 15y^4 + 45y^2 - 15; \\
H_6(y) &= y^6 - 28y^6 + 210y^4 - 420y^2 + 105; \\
H_8(y) &= y^8 - 42y^8 + 630y^6 - 3150y^4 + 4725y^2 - 945; \\
H_{10}(y) &= y^{10} - 45y^{10} + 630y^8 - 3150y^6 + 4725y^4 - 945; \\
H_{12}(y) &= y^{12} - 66y^{12} + 1485y^{10} - 13860y^8 + 51975y^6 - 62370y^4 + 10395,
\end{align*}
\]

in which the coefficients \( c_{2k} \) are in turn expressed as follows:

\[
\begin{align*}
c_2 &= \mu_4 / \sigma^4 - 3; \\
c_4 &= \mu_6 / \sigma^6 - 15\mu_4 / \sigma^4 + 30; \\
c_6 &= \mu_8 / \sigma^8 - 28\mu_6 / \sigma^6 + 210\mu_4 / \sigma^4 - 315; \\
c_{10} &= \mu_{10} / \sigma^{10} - 45\mu_8 / \sigma^8 + 630\mu_6 / \sigma^6 - 3150\mu_4 / \sigma^4 + 3780; \\
c_{12} &= \mu_{12} / \sigma^{12} - 66\mu_{10} / \sigma^{10} + 1485\mu_8 / \sigma^8 - 13860\mu_6 / \sigma^6 + 51975,
\end{align*}
\]

where \( \sigma^2 \) and \( \mu_{2k} \) are calculated from the initial density \( f(x) \).

As a result of the study, the convergence of navigation parameter error density to its orthogonal decomposition was analysed depending on the number of its terms. For this purpose, the orthogonal decomposition of several known non-normal distribution laws was performed and the values of the distribution density itself were compared with its orthogonal decomposition. The densities of mixed distribution laws of the first and second type, as well as the density of the generalized Poisson distribution law were chosen as the initial densities.

The comparison has shown that the best convergence of the orthogonal expansion is achieved when it contains only the first term \( \phi_1^{(n)}(y) \), i.e. the optimal orthogonal expansion is expressed in the form:

\[
f^{(n)}(y) = (2\pi)^{-1/2} \exp\left(-y^2/2\right)\left[1 + \phi_1^{(n)}(y)\right],
\]

in which \( \phi_1^{(n)}(y) = \left(\mu_4^{(n)} - 3\right)\left(y^4 - 6y^2 + 3\right)/24 \).

For the three considered distribution laws the orthogonal decomposition of the density in a Gram-Charlier series of type A, which contains only the first term, can be applied instead of the density itself. The accuracy of correspondence of the density to its orthogonal decomposition increases with increasing value of the significant parameter. In order to compare density curves and its orthogonal decomposition, their values have been calculated.

In Fig. 1 normalised density curves \( g_1(\eta) \) of the mixed law distribution of the first type are shown for values of the essential parameter \( n = 4, 6 \), which are coloured red. Since the density curves are symmetrical, only half of the curve is shown for positive error values, which take values in the range of six standard deviations. In the same figure the corresponding orthogonal decomposition curves are shown in blue.

The analysis of Fig. 1 shows that the normalised density \( g_1(\eta) \) and its orthogonal decomposition at a significant parameter \( n \geq 4 \) are almost identical.

Curves of normalized density \( g_2(\eta) \) of mixed law distribution of the second type for values of the essential parameter \( n = 4, 6 \) are shown in red in Fig. 2, in the same figure the corresponding curves of orthogonal expansion are shown in blue. As in the previous case, normalized density \( g_2(\eta) \) and its orthogonal expansion practically coincide.
The study also found that the orthogonal expansion of the density of the generalized Poisson distribution of errors in navigation measurements, which contains only the first term, has a good agreement with the distribution density itself.

As the example in Table there are given the results of calculation of normalized values of the generalized Poisson density of the distribution $g_3(\eta)$ and its orthogonal decomposition $f(\eta)$ containing only one first term. In the example, the value of the significant parameter $c = 3$ is chosen.
The resulting table shows that the orthogonal decomposition of the density of the generalized Poisson distribution of the navigation error, containing only the first term, has good convergence with the distribution density itself.

### 3. Conclusions

An expression for an optimal orthogonal decomposition containing only one term which provides maximum convergence with normalized density is presented.

The curves of normalized densities of mixed laws of first and second type and their corresponding orthogonal expansions into the Gram-Charlier series of type A have been calculated. Their analysis has shown a good agreement between the densities and the expansions.

Presented in tabular form the values of the density of the generalized Poisson distribution law and its orthogonal expansion and showed their coincidence.

### References

Impact of Low Level N-butanol and Gasoline Blends on Engine Performance and Emission Reduction

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Abstract

The paper presents results of experimental research of gasoline, and three different blends with 3%, 7% and 10% n-butanol addition to gasoline, named nB3, nB7 and nB10. All blends were tested on Volvo S80 vehicle on chassis dynamometer MD-1750. Emission tests were completed at idling, IM-240 cycle, 50 and 90 km/h. The analysis of obtained results has shown a slight reduction of engine power and torque for all blends based on n-butanol addition compared to gasoline, demonstrating better perspectives for nB3 and nB7. The results showed the positive tendency in n-butanol addition to gasoline in the case of CO, CO2 and HC emission reduction, but it also confirmed that n-butanol promotes a slight increase in NOx emissions. The largest decrease of HC was observed during 50 km/h reaching almost 51% reduction for nB7 in comparison to gasoline.

KEY WORDS: blends, gasoline, n-butanol, testing, dynamometer

1. Introduction

For a sufficient period of time, ethanol was considered to be the most suitable alternative fuel, or at least an additive, to spark ignition (SI) engines (see Table 1). This ranges from 1908 Ford Model T production times, where the engine was created for operation on gasoline or ethanol, to the wider introduction of fuel flexible vehicles (FFV) in the automotive industry in 1996. Ford was the first manufacturer, who introduced FFV. The main positive side of this type of vehicle was that it could run on gasoline or a blend of up to 85% ethanol and 15% gasoline, but unlike others, it was adapted to use such fuel. As it is known, ethanol could be used in gasoline without adaptation of vehicle at 15% addition to gasoline. This means that it will not make engine damage due to wear connected with higher ethanol content in fuel. This makes a much better chance for butanol produced in a similar way to ethanol, but creating a wider range of more positive properties, also similar to gasoline.

The physical and chemical properties of butanol offer a number of different advantages over ethanol and making it more suitable for operation in SI engines. First of all, butanol has no restrictions on blending at any concentration, which is based on a longer chain hydrocarbon similar to gasoline. Secondly, the hygroscopicity of butanol allows to transport it through pipelines as it is not miscible with water. Thirdly, butanol energy content contains about 86% of the gasoline while ethanol contains about 65% [1], which leaves an impact on the acceleration and mileage of the vehicle. Fourthly, butanol is less corrosive than ethanol [2] allowing it to distribute it by the same infrastructure as gasoline.

However, some of the properties of butanol could limit its usage instead of ethanol. For example, the octane rating for butanol is lower than for ethanol (96 instead of 108), but at the same time it is similar to gasoline (95). The same with oxygen content, which demonstrates lower values (21.6% instead of 34.8% for ethanol), but at the same time...
is much higher than for gasoline (0%). Additionally, the lower vapour pressure of butanol could leave an impact on engine cold start demonstrating it more acceptance for blending neither used as a neat fuel [4].

The fuel properties of butanol depend on its type. Four different isomers of butanol occur based on the position of the hydroxyl (OH) group — secondary butanol (s-butanol), tertiary butanol (t-butanol), iso-butanol (i-butanol) and n-butanol – each one with some essential advantages over others. The main difference between those four isomers is connected with the carbon-chain structure and the hydroxyl radical position [5], which could further leave an impact on engine combustion and operating parameters. For example, s-butanol usually is industrially produced by the hydration of butane isomers, but also can be produced indirectly by microbial fermentation from biomass based materials. The field of application of s-butanol is relatively wide including solvents and gasoline octane components. T-butanol also is used as an octane improver for gasoline, but it can be refined by petroleum [5]. Iso-butanol like all previous isomers has high octane value and also can be used as a raw material for different chemicals, but mainly it is used as a solvent. It can be produced industrially from propylene or hydrogenation of isobutyraldehyde, but it can be produced also in a natural way by bioengineered organisms, like cyanobacteria, E. S. cerevisiae, or Ralstonia eutropha [6, 7]. The last method at the moment does not give large enough quantities for commercial use [7]. The main advantages of iso-butanol are good miscibility with conventional fossil fuels, high energy density and octane value, as also good hygroscopicity preventing corrosion of spare parts of engines. This shows isomer suitability with existing fuel infrastructure, if it is used as a conventional fuel additive. N-butanol has very similar properties to iso-butanol with the exception that it is produced by fermentation through ABE (Acetone-Butanol-Ethanol) process. Both iso-butanol and n-butanol are the most popular choices from all mentioned isomers for most researchers especially, if they are produced from agriculture resources [8].

The main part of studies concerning usage of n-butanol was performed on conventional SI engines, while there are also studies with conventional diesel engines. There is a number of researches, which demonstrates different aspects of n-butanol usage: fuelling a port fuel-injected SI engine with neat n-butanol [9], n-butanol addition to diesel [10], diesel-biodiesel blends [11], hydrogen addition to an n-butanol engine [12], and even n-butanol usage in fuel containing isopropanol-ethanol-gasoline blends [13]. Most of those researches confirm that butanol addition improves engine performance and pollutant emissions in comparison to conventional fuels. Tang [14] examined n-butanol/gasoline blends on the effects of the n-butanol blend ratio, spark timing and lambda on engine performance. Results showed that such blends can improve the performance of the SI engines and expanded the research field of n-butanol application in engines. Elfasakhany [15] studied the impact of different rates of n-butanol-bioethanol in gasoline on the engine performance and emissions of four stroke SI engines in laboratory conditions. He concluded that such blends lower unburned hydrocarbons (UHC), carbon dioxide (CO2) and carbon monoxide (CO) emissions, as also most engine performance parameters have no significant changes for fuel blends till 10% by volume. Dhamodaran [16] confirmed a decrease of CO and HC emissions with increased percentages of n-butanol in the blend, as also an increase in NOx emissions testing blends comprising 10%, 20%, and 30% by volume of n-butanol in unleaded gasoline on multi-point fuel injection (MPFI) SI engine. Research presented by Varol [17] stated that butanol is a viable alternative to methanol and ethanol testing 10% blends of methanol, ethanol and butanol with gasoline on a four-cylinder Ford engine. It was based on results that n-butanol provides lower CO2 and HC emissions than other alcohols at all rotational speeds. Other research [2] focussed on combustion processes in a spark-ignited internal combustion engine using blends of n-butanol to gasoline with ratios of 0%, 20%, and 60% by volume in a single cylinder SI engine with variable compression ratio. Researchers concluded that the behavior of neat n-butanol is similar to the characteristics of pump octane number (PON) 87 gasoline including the sensitivity to spark timing and compression ratio.

Regarding the use of butanol-gasoline blends a number of researches have been done in the last few years more attention putting on engine testing on the test bench in laboratory conditions, while a number of researches on chassis dynamometer testing emissions and fuel consumption in road tests in real driving conditions or cycles are limited. Therefore this research put more attention on registration of main performance parameters and emissions of the vehicle in driving conditions based on the most common driving modes.

2. Materials and Methods

Experiments were carried out on Volvo S80 five-cylinder, four stroke naturally aspirated spark ignition (SI) engine. Characteristics of the dynamometer and vehicle are shown in Fig. 1 and listed in Table 2, respectively.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Volvo S80</td>
</tr>
<tr>
<td>Engine type</td>
<td>B5244S</td>
</tr>
<tr>
<td>Engine capacity</td>
<td>2435 cm³</td>
</tr>
<tr>
<td>Cylinder number and arrangement</td>
<td>5, in line</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>10.3</td>
</tr>
<tr>
<td>Maximum power</td>
<td>125 kW at 5900 rpm</td>
</tr>
<tr>
<td>Maximum torque</td>
<td>230 Nm at 4500 rpm</td>
</tr>
</tbody>
</table>
The SI engine was operated with different fuel blends to determine the engine performance and emissions under different testing conditions. Blends were prepared at different ratios ranging from 0%, 3%, 7% and 10% by volume. Tested blends were prepared just before the experiments by splashing mixing technique in the proportions mentioned before in the laboratory to ensure accuracy of further performance and emissions tests. In overall, tests were completed with gasoline (nB0), meeting EN 228 standard, and three blends containing 3% (v/v) of n-butanol with 97% (v/v) of gasoline (mixture code: nB3); 7% (v/v) of n-butanol with 93% (v/v) of gasoline (mixture code: nB7); 10% (v/v) of n-butanol with 90% (v/v) of gasoline (mixture code: nB10). 100% of n-butanol (nB100) is used only for blending and analysis of physico-chemical properties (see Table 3).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>nB0</th>
<th>nB3</th>
<th>nB7</th>
<th>nB10</th>
<th>nB100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at 15 °C, kg/m³</td>
<td>726.0</td>
<td>728.5</td>
<td>731.8</td>
<td>734.3</td>
<td>809.0</td>
</tr>
<tr>
<td>Heating value*, MJ/kg¹</td>
<td>43.58</td>
<td>43.24</td>
<td>42.80</td>
<td>42.48</td>
<td>33.56</td>
</tr>
<tr>
<td>Elements* (% wt)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>86.00</td>
<td>85.30</td>
<td>84.36</td>
<td>83.67</td>
<td>64.68</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>14.00</td>
<td>13.98</td>
<td>13.96</td>
<td>13.95</td>
<td>13.51</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.00</td>
<td>0.72</td>
<td>1.67</td>
<td>2.38</td>
<td>21.62</td>
</tr>
</tbody>
</table>

*Calculated and some taken from Reference [18]

Fuel consumption measurements were done on a laboratory chassis dynamometer MD-1750 by AVL KMA Mobile fueling consumption measuring device, with 0.1% accuracy of reading and fuel consumption measurement up to 150 l/h fuel flow. MD-1750 chassis dynamometer was used to apply a load to the test vehicle, as also to obtain power and torque curves, used for engine power and torque analysis for mentioned fuels. Starting tests a car was fastened with straps on a chassis dynamometer MD-1750 realizing simulation of road and air resistance providing experiments in different driving cycles [19]. Measuring range was set according to the characteristics of the testing vehicle. Test was started with driving at speed slightly less than the minimum speed set in the control software, however further the accelerator pedal was pressed down and kept until the indication on realization of the test was received. The test was conducted at a particular fixed transmission gear and the maximum fuel delivery.

Fuel consumption, as also emission tests were realized at the most popular vehicle operating conditions, which include idling, IM-240 cycle, 50 and 90 km/h. The choice of the last ones was based on the reason that it corresponds to the maximum allowed speed in most European urban and suburban areas. Constant speed measurements were performed for 2 minutes with the reading step of 1 second. Besides that, a combined cycle IM-240 was done as it simulates driving in urban conditions and non-urban areas. The longitude of the test is 4 minutes. Emissions measurement values were continuously sampled during the cycle and mean values for each cycle were calculated as...
arithmetic averages.

Emission measurements were performed by AVL SESAM FTIR multicomponent exhaust gas measurement system. It allows to measure up to 25 gases simultaneously and some components calculating from the process, as also another analyzer OPUS 40 was used for additional control of some components. During research all gases were fixed, and more detailed analyses was done only for some components: NOx, CO, CO2, HC. Relative uncertainty for exact components: 0.22% (CO2), 0.29% (CO), 0.5% (HC, NOx).

The drivability of the vehicle was unimpaired during tests; the vehicle was tested with all the fuels in random order and each reading was repeated three times. The results of these replications were averaged to decrease the uncertainty and reported. Additional error analyses of the results was completed taking into account accuracies and uncertainties of measuring instruments.

3. Results and Discussion

All realized experiments were carried out under the same conditions to ensure precise measurements and output results, which include engine performance factors like power, torque and fuel consumption, as well as emissions of pollutants of carbon monoxide (CO), carbon dioxide (CO2), hydrocarbons (HC) and nitrogen oxides (NOx). The results of power and torque were obtained as the relationship between the output variables and engine speed, but the results of emissions were summarized based on testing conditions mentioned in the methodological part of this article.

Research shows that engine power decreases slightly based on additive rates in the fuel blends. Despite a little bit higher octane number for n-butanol, maximal values of power were observed directly for nB0 – 103 kW at 5800 min⁻¹, while other fuels showed a decrease from 0.9% to 3.8% presenting the contribution of n-butanol. One of the main reasons for such reduction could be explained by the lower energy content of the blends in comparison to gasoline. In combination with the higher latent heat of evaporation of blends it makes this reduction moment more pronounced. Therefore it is possible to conclude that increasing the blend rates with n-butanol addition leads to decreasing of the energy content and increasing the heat of evaporation of blends. Despite to increasing oxygen content of blends, which should enhance fuel combustion, it seems that it does not leave a great impact on power, while some researchers have observed an increase in power, when the engine works at a fuel-lean mixture in such a way recommending to put more attention on the calibration of the lambda in the application of n-butanol [14].

A similar reduction was observed also in the case of torque demonstrating the largest values in the case of neat gasoline – 176.2 Nm at 4500 min⁻¹, and the slight reduction for other blends – 173.1 Nm for nB3, 172.5 Nm for nB7 and 171.8 Nm for nB10 (see Fig. 2). Such trends are based on the previously explained combination of lower energy content and higher heat of evaporation. Although there exist other factors that can affect the final value of the torque, in this combination of fuel rates it is not possible to observe them.

Based on the fuel consumption data obtained in experiments was observed increase in fuel consumption with the addition of n-butanol in all testing conditions. Results for nB3 (increase by 1.2%) and nB7 (increase by 2.1 %) at 50 km/h, as also at 90 km/h (2.1% and 4.5% respectively), were slightly similar to gasoline and did not show such rapid increase as in case of nB10 at 50 km/h (increase by 8.2%) and 90 km/h (increase by 6.7%). During a cycle IM240 fuel consumption increased by 5.2% (nB3), 18.9% (nB7) and 27.9% (nB10) in comparison to nB0. The main reason for increased fuel consumption can be explained by lower heating value and a further reduction in thermal efficiency of each additional n-butanol/gasoline blend instead of gasoline.

The addition of n-butanol has left a serious impact on CO emissions with the largest reduction with nB10 at 50 km/h reaching -67.8% (see Fig. 3, a). At the same time it was observed that n-butanol has left a great contribution on CO also in other testing conditions, where CO emission reduction varied from 6.2-28.4% (idling), 31.5-67.8% (50 km/h), 7.2-28.5% (90 km/h) and 31.1-46.8% (cycle IM-240). Overall, decrease in CO emissions is based on the increase in blending rates resp. the highest rate of blended fuel provides the lowest CO emissions. As the n-butanol rate increases, the oxygen content of the blend increases resulting that the combustion of the mixture is more complete and CO emissions are lower. The additional oxygen content can speed up the burning rate better than in the case of gasoline.

![Fig. 2 Torque for gasoline and n-butanol/gasoline blends](image-url)
This can provide the faster laminar flame speed of n-butanol resulting in more sufficient combustion [20].

As seen from Fig. 3, b, HC has a similar reduction trend as CO. Largest reduction of HC was observed at 50 km/h using nB10, while for nB7 reduction reached 51.2%. All other testing regimes showed not so great cut in emissions, and reduction was based proportionally on the added volume of n-butanol – by 8.1-18.9% at idling, by 31.5-58.1% at 50 km/h, by 21.7-37.5% at 90 km/h, by 4.5-7.1% at cycle IM-240. In overall, an increase of oxygen content contributed by n-butanol can produce large amounts of OH free radicals promoting the process of C-H chain reaction and resulting in more complete fuel burn, as also continuous oxidization even in the late combustion stages [21].

![Fig. 3 CO (a) and HC (b) emissions for gasoline and n-butanol/gasoline blends](image)

N-butanol has not left a serious impact on CO₂ emissions in low level blend rates and reduction of this component reached 6.5% (Fig. 4, a). A slight decrease of CO₂ emissions is based on higher oxygen content, lower C/H contents in blends in comparison to gasoline, as also an adequate time in the cycle to complete the combustion process. Reduction of CO₂ emissions using n-butanol, especially under the fuel-lean mixture was observed also in other research [14]. The more rapid decrease of CO₂ could be observed only with an increase in n-butanol blend rate.

![Fig. 4 CO₂ (a) and NOx (b) emissions for gasoline and n-butanol/gasoline blends](image)

Many factors can influence the combustion process, including lower heating value, octane number, oxygen content and flame speed. If some of the factors give a positive effect on the reduction of CO and HC emissions, then some, like oxygen content, can increase NOx emissions (Fig. 4, b). The addition of n-butanol could increase pressure inside the combustion chamber and increased engine speeds promote high temperature of the combustion gases. As NOx is mainly generated in high temperature conditions enriched with oxygen, then it results in higher NOx formation, which is observed also in current research. A slight increase of NOx emissions was observed at 50 km/h reaching 5.2-30.5% based on blend type, while the more rapid increase was observed at cycle IM-240.

4. Conclusions

The results showed that low level n-butanol/gasoline blends could be used in SI engines without any technical problems. Such blends could be used with the aim to improve SI engine emissions, but it should be expected that the reduction level will be closely connected with the increase of blending rate. During this research negative effect was observed according to NOx emissions, which showed slight increase based on testing conditions, although this increase was negligible. Besides that, there should be an expected a slight increase in fuel consumption and reduction in power and torque also based on the blending rate – the highest rate of the blended fuel provide the lowest values for power and torque. Although this increase in fuel consumption and reduction in power or torque is not so great to reduce n-butanol...
contribution, it leaves an impact on the economical viability of the blend. Therefore optimal results in the case of most exhaust emissions and engine performance were observed for nB3 and nB7. This means that partial replacement of gasoline with n-butanol by 3-7% (vol.) will not leave a significant impact on the physicochemical properties of gasoline, but will ensure less emissions. This additive could be a more effective alternative to ethanol on the market taking into account its properties. However, additional physicochemical tests of used fuels and blends, as also combustion tests should be performed in the future to give more detailed analyses on exhaust emission components and their variations.

References

Proposal of Suitable Control System and Measure in Internal Logistic Process

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Abstract

In order to choose the right procedure for optimizing production processes, it is necessary to get acquainted with the issues of logistics, logistic operations and modern logistic methods. Today, the term logistics is used in all companies and industries. The automotive industry is one of the fields in which special emphasis is placed on understanding proper logistics and all its sectors. Its understanding and penetration into the depth of its essence is key to succeeding in the market in leadership positions and leads to gaining new customers, retaining existing customers, saving time and thus increasing the company's financial stability in the existing market. The article addresses the issue of reducing errors at the beginning of the production of individual bus parts and proposes the introduction of new control systems for employees. The aim of the article is to propose a suitable system and measure in the internal logistic process in a manufacturing company. The article is based on research of world literature, in-depth interviews with top managers in a manufacturing company, detailed analysis of internal data of a manufacturing company and analysis of the working environment of employees.

KEY WORDS: internal logistic process, suitable system and measure, control systems, modern logistic methods

1. Introduction

In developed markets, where it is generally difficult to increase sales volumes and where corporate profitability shows a long-term declining trend due to pressure from competitors, it is necessary to constantly look for ways to improve productivity. Logistics is an important factor in promoting globalization and developing international trade flows. Logistics has become one of the main factors determining the competitiveness of the economy. A significant part of logistics tasks is performed by logistics service providers, these companies play a key role in more efficient and effective operation of selected industries. Therefore, their operation must be sufficiently efficient, which means that logistics service providers must be aware of the main operational factors of logistic processes. Warehousing provides space and time benefits and helps ensure a high level of customer service. Currently companies are trying to minimize logistics costs [1-4].

The aim of the article is to propose a suitable system and measure in the internal logistic process in a manufacturing company.

2. Theoretical Background and Methodology

It is pointed out that in connection with the delivery of goods to customers, logistics activities arise from the activities of information, handling, packaging, warehousing, identification, transport and other elements in the links of logistics chains. Associated with them are logistics costs, usually related to the unit of logistics performance, to order, to the product, which represent about 80% of the total logistics costs, and standby costs, fixed costs due to the existence (availability) of a warehouse in a particular place [5]. Logistics has been under pressure for a long time to reduce business costs. As a result, areas of logistics are explored where there are opportunities to streamline costs with a focus on individual logistics activities and procedures. Inbound logistics includes activities in the procurement process and supplier integration. Improved supplier integration can affect several aspects, such as logistics performance and cost, quality, technology, flexibility of response, and profit [6-8]. Internal logistics can include operations in the field of production, material handling and performed regular inventories [9]. Internal logistics begins when the raw materials enter the company until the final product is ready for distribution. Internal logistics activities affect numerous aspects of logistics performance and costs. As a result, individual outputs and costs must be constantly monitored and evaluated [10].

Some authors rank the case study among the methods of qualitative research [11-12]. A case study is briefly characterized as a detailed study of one or a small number of cases in order to apply the acquired knowledge in understanding similar cases. It contains an intensive analysis and description of a separate unit or system bounded by time and space [13].
3. The Case Study

There is no employee control system in place at the workplace that will be dealt with in the article. This is a very important and important part in the production process of electrical material, which, if not produced correctly, can cause considerable problems and its production error will only occur after the bus is put into operation. Which is the worst case error rate that can occur. As long as the error rate of the worker results in the production of bad parts, the so-called "scrap", which is visible immediately at the exit of the line, or its incorrect operation, or other shortcomings workers encounter during installation in the bus, it is a serious error, but can be small a number of such shortcomings tolerate. However, if a part is produced which is not defective at first sight, and even after connection it appears to be a functional element, while its hidden defect will only become apparent when the vehicle is put into regular operation and may result in fatal damage, such a fault must be prevented on the assembly line. It is inadmissible for the bus manufacturer to detect the error only by the customer himself while using the purchased product. There are a total of 157 drawers on the lashing template (see Fig. 1), of which 109 drawers are for connectors, without additional detents. Cables are connected to these connectors, the ends of which are provided with their own locking, so it is not necessary to lock the connector after connecting all cables. Another 48 sockets are used to connect the connectors, which must be locked after the complete untiring of the bundle. These drawers occupy an area of approx. 65 x 35 cm on the lashing template. There are several free spaces on the template that could subsequently be used to install control measure. When dividing the template into imaginary red sectors 1-6 (see Fig. 2), there are drawers in sector number 5. The space for installation of new control systems or measure is located in sector number 3, where a handling area of 65 x 40 cm is available. In sector number 4 there is a free strip 30 cm wide in the left part, then free space in sector number 5 just below the drawers in question, where there is an area of 35 x 15 cm and in sector number 2 where there is a free space of 20 x 15 cm.

Fig. 1 Mooring template; Source: Authors

Fig. 2 Scheme of mooring template; Source: Authors

Several factors must be taken into account when designing control systems. The first of them is to maintain the layout of the workplace and not to exceed the free space on the mooring template. Another requirement is financial demands, investment in the modernization of the workplace and the introduction of control systems should be as low
as possible. However, the error rate after the introduction of the control system should be zero. The introduction of the system should also not increase the time needed to produce one bundle. Thanks to advance modern technologies, a larger number of control systems are available that are on the market and thanks to which 100% of production errors would be achieved. However, these systems are costly and, even in terms of maintaining the dimensions of the workplace, it would not be possible to implement them due to a lack of free space.

3.1. Proposal of Control Measure

The first proposal focuses mainly on meeting the requirement of financial demands. Therefore, this proposal is not about introducing a control system, but only about control measure that would contribute to better clarity of arrests, and the worker would know exactly after completing the untying of the bundle, whether he forgot to place an arrest.

Fig. 3 Scheme of mooring template adjusted for control measure; Source: Authors

Fig. 3 is a schematic of a mooring template. In this case, the free space in the red marked sector was used, where four boxes would be placed in colour corresponding to the colours of the arrest at the given workplace. The worker must set the parameters of the volume to be completed on the computer in advance. This program will determine exactly how many locks it will need for a given volume. The worker would first divide the detents and put in each box the appropriate number of detents needed for a complete bundle. After completing the untying of the bundle and its testing, the locking of the forks is placed. Sometimes it happens that some forks are released and fall out of the drawers before the worker locks them, and the worker then jumps over and thinks that the fork is already locked because it is no longer inserted in the drawer with this fork. In the current state, where workers have an unlimited number of detents, it is not possible for them to realize in time that they forgot to place one and send a poorly secured bundle for installation on the bus. If the worker has the exact pieces of the locks ready and forgets to place one during securing the forks, she notices at the end of the process that she has locks left in the box and knows that she has to check the bundle again to find the fork she forgot to secure. The introduction of such a measure would not be costly in terms of finances or space. However, it would still depend on human attention. If the worker recalculated at the very beginning and placed the wrong number of detents in the pits, this measure would not serve its purpose. In the first case, the worker could put a smaller number of detents in the box than she has. If she had properly secured all the forks, she would have come to the end of the mooring that she had miscalculated and placed the locks at the beginning. In that case, she would complete them and the bundle would eventually be properly secured. However, if the worker forgot to place a locking device in the fork during the gradual securing, it would in the final state look as if the bundle was correctly locked. When checking the boxes to see if they are empty, there would be no locking, so the worker would not check the bundle and send it to another workplace, where it would be installed in the bus. In the second case, a situation could arise in which the worker, after completing the securing of the bundle, finds out that she is left with arrest in some box. At this point, however, she would not know what error she had left in the lock. This could have happened for two reasons. Either she could recalculate at the beginning and place one or more extra locks in the box, or she forgot to lock a fork while securing the bundle. In such a situation, it would then have to go fork by fork and check the individual detents to see if they are present on all forks. A big disadvantage of this measure is the time required both for preparation and for the detection of an error and the subsequent search for a fork that is not locked. By counting and dividing the detents, the time to untie one bundle would increase by approximately 3-5 minutes, depending on the size of the bundle. On average, the time required to untie one bundle is 30 minutes. About 16 bundles are created during one shift. With 3 shifts, an average of 48 bundles are exported per day. If we extended the production of the bundle by 5 minutes, it would produce 2.5 bundles less per shift and 7.5 bundles less per day. The introduction of this control measure would not achieve zero production error, and the time required to produce one bundle would be significantly increased.
3.2. Proposal of Control System Number 1

In this proposal of the control system, the focus is primarily on the requirement of zero error in the production of bundles. With the help of the installation of a control system and optical sensors, this requirement should be met 100%. To implement this system, it would be necessary to provide the mooring template 47 with optical sensors. Each sensor would have to be located next to the inspected socket. The sensor dimensions are 12 mm x 31.5 mm x 21 mm. The location of such sensors would not be a problem in the case of the first, second and fourth rows of marked sockets (see Fig. 4). There is a free space that could be used to install sensors. However, the problem would occur when installing the sensors to the third row of sockets, there is not enough free space for the installation of these optical sensors. It would therefore be necessary to adjust the lashing template so as to obtain more free space above the third row of drawers. Enlarging the template would not be drastic and the space needed for optical sensors could still be made here. Each sensor would then be programmed to monitor colour contrast. The forks and the locks they secure each have a fixed colour. For example, yellow forks are secured by locking brown, blue forks are secured by locking yellow, green forks are secured by locking blue, and brown forks are secured by locking green. If the worker forgets to secure the fork with a lock, the sensor will not detect a colour contrast and will immediately alert the worker to the missing lock. The same warning would occur even if the sensor did not detect a precisely determined colour contrast and, for example, the yellow fork was equipped with a green lock. The introduction of this control system would meet the requirement of zero error in securing cable harnesses. Another requirement that this system would meet is the minimum time required. The time required to produce one cable would not increase in any way. The requirement to maintain the layout of the workplace would also be met. However, the essential condition, which is the financial demands for implementation and subsequent operation, is no longer met. One optical sensor is based at FPC, which specializes in this issue at EUR 1,000, in the case of 47 optical sensors it is EUR 47,000, which at the exchange rate of CZK 26,235 (average exchange rate for the first quarter of 2021) is CZK 1,233,045. Other costs for the installation of sensors and the modification of the mooring template are also not negligible and the total amount for the introduction of such a control system would reach CZK 1,500,000. The return on such an investment would take several years to produce an average of 48 unbound bundles per day.

![Fig. 4 Scheme of mooring template modified by control system number 1; Source: Authors](image)

3.3. Proposal of Control System Number 2

This control system is called Pick to Light (or Pick by Light) and is one of the ways of the Poka Yoke method. With its use, zero error rate of the worker at the workplace is achieved. In general, the Pick to Light system guides the worker by means of light instructions on the monitors, thus showing him how many and what components the worker has to remove and where to place them. This system has many forms and is very adaptable to customer requirements. It is most often used in warehouses, where when picking orders, the number of pieces that he has to remove at a given moment and send on for processing is lit on the shelf worker. If the employee does not remove all of them, or possibly removes more, the system immediately notifies him of the error. Until the worker clears the error, the system will not allow him to continue working. If the Pick to Light control system is installed on the mooring template, the free space above the template will be used. This will not interfere with the desktop, nor will it be necessary to modify the template and invest in its modification, as was the case in previous cases. The locking boxes, of which 8 are now in use, would be replaced by 4 special boxes (see Fig. 5), which are equipped with LED rails and scales. Each box would be designed for one type of locking. For even better orientation in the workplace, it is recommended to purchase boxes in colour corresponding to the arresters, i.e. one box of green, blue, brown and yellow. Depending on the colour of the detent, the worker would pour the detent into a box of the same colour. When loading the system, the value of the weight of one detent would be assigned to each box, and after inserting the detents, the number of pieces in the box would
be automatically calculated. Before each untangling of the cabling, the worker on the computer would enter the program intended for the given bundle, and according to it, she would gradually show on the LED bars which box to remove the lock. If the worker removes the lock from a box other than the one under which the LED bar is lit, the system will report an error, and until the worker returns the bad lock to the box and removes it from the correct box, there will not be much to continue and the system would not allow it print a label about the correct binding of the volume. Implementing such a system is less costly than in the previous case. Pick by Light technology, a system comprising 4 weighing boxes, 4 LED rails with displays, system installation and compilation of special programs for approx. 175 types of cabling, transport and commissioning would cost EUR 19,500, which at the exchange rate of CZK 26,235 (average exchange rate for the 1st quarter of 2021) is CZK 511,583. This system thus meets all the requirements that have been set for the introduction of a new control system. When using it, there will be no increase in time for the production of one bundle, so the average production of 48 bundles per day will be maintained.

![Fig. 5 Scheme of mooring template modified by control system number 2; Source: Authors](image)

3.4. Evaluation of the Proposed Control System and Control Measure

All proposed control systems and measure meet at least one requirement set by the company's management. The most important of the requirements for the introduction of a new control system or control measure was the achievement of zero error rate when tying cable harnesses to buses, or when securing their plugs with detents of the appropriate length. Only control systems can meet this requirement, as they are completely independent and cannot be influenced by the human factor in any way. If one of the control measure were introduced, the error rate would certainly be reduced, but zero error would still not be achieved, as the allocation of arrests would be up to the person and he could easily confuse, recalculate, overlook or inadvertently change the type of arrest. The second most important requirement was the minimum financial demands on the implementation of the system or control measure and its subsequent maintenance and operation. Table shows that the financial complexity is acceptable for 2 of the 3 proposed solutions. In the case of control measure, this is a negligible amount of investment and the question therefore arises as to whether it would not be worthwhile to introduce such a measure, even though the measure does not guarantee that production will be 100% without unlocked forks. If the implementation of this measure did not increase the time for the production of one cable harness, its implementation would certainly be useful. However, there is a time increase, which is not negligible, and after being projected into all-day operation, it is assumed that production would be delayed in the event of the introduction of a control measure by 7.5 pieces of the bundle. In production, which is on average 11 pieces of bundles per day lower than usual, after being reflected in the monthly turnover, the production loses about 330 pieces of bundles, which is as if production lasted 7 days a month. This financial loss would be noticeable after only a few months of operation and would very soon exceed the acquisition value of control system number two. In the case of the number one control system, the investment of CZK 1,500,000 is significantly higher. And the cost of subsequent operation would also not be negligible, as small optical sensors that sense the colour contrast of the plug and detent would be installed as close as possible to the plug sockets due to limited space, threatening their frequent damage and the need for repair or replacement. Another requirement for the introduction of a new control measure was the time needed to produce one bundle. The time to untie the cabling should be maintained, in the best case it should be reduced. The introduction of any of the control systems and measure would not reduce the time required to untie a single cable harness. For control systems, the time would at least be maintained, while for both control measure, the time to untie one bundle increases significantly. The last requirement was to maintain the layout of the workplace. Due to the rapidly growing production, the free spaces are constantly shrinking and there is no longer enough free space for new machines, equipment or other equipment in the electrical materials workplace. For this reason, it was not allowed to interfere with the layout of the workplace. This requirement has been partially met for all proposed solutions. The limited space...
intended for the workplace of untying bundles would not be exceeded in any case, but a part of the workplace is also an untying template, which would have to be intervened in the first three cases of the proposed solutions. For this reason, only the last proposed control system meets the requirement to maintain the layout solution 100%.

<table>
<thead>
<tr>
<th>Requirements for control measure or system</th>
<th>Workplace layout</th>
<th>Time required to produce one bundle</th>
<th>Financial burden</th>
<th>Zero error rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control measure</td>
<td>It will change</td>
<td>Increases by 3-5 minutes</td>
<td>600 CZK</td>
<td>No</td>
</tr>
<tr>
<td>Control sys. no. 1</td>
<td>It will change</td>
<td>It will stay the same</td>
<td>1,500,000 CZK</td>
<td>Yes</td>
</tr>
<tr>
<td>Control sys. no. 2</td>
<td>It will be preserved</td>
<td>It will stay the same</td>
<td>511,583 CZK</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Source: Authors

Of the 3 proposed solutions, only control system number two - Pick to Light - meets all requirements. This system guarantees zero error when locking the forks. During its operation, the time required for the production of one cable bundle is not increased. The introduction of the Pick to Light control system will not interfere with the mooring template or change the layout of the workplace. Its financial demands for introduction into production are not the lowest, but its operation does not increase production costs and subsequent maintenance is also not high. As in other cases, the company will not intervene in the financial budget of the company more drastically, and on the contrary, its introduction will reduce scrap and thus increase the profit from production. For these reasons, the requirement for minimum financial demands is also met, although it is not the cheapest option.

4. Conclusion

Both control systems and measure met some of the requirements, but only the Pick to Light control system met all the requirements of the selected company. The introduction of the Pick to Light system will achieve zero error in securing the forks with detents, there will be no intervention in the mooring template, the layout of the workplace will be maintained, the time required to produce one bundle will still be on average about 30 minutes, thus maintaining the average number of bundles produced day. As for the requirement of financial demands, it was also met. The costs amounting to CZK 511,583 are one third compared to the optical sensor system and the subsequent operating costs are significantly lower.

Acknowledgements

The work was created in connection with the scientific research project of the University of Pardubice no. SGS_2021_018. The authors are grateful for their support.

References

Accident Analysis with the Participation of a Cyclist with Using a Dynamic Model of Traffic Simulation

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Abstract

The paper deals with the safety of cyclists, as road users. Identifies areas with the highest accident rates and their negative consequences. Accidents of cyclists are characterized within the accident event and their peculiarities, as well as the most common types of vehicle-cyclist relative positions. Part of the paper is the assessment of a selected traffic accident with the participation of a cyclist in reduced visibility in two possible variants. The first variant is when the driver reacted to the collision situation in time. The second variant is when the driver reacted to the collision situation late. The article also includes an analysis of a selected traffic accident involving a cyclist. The article further assesses the development of traffic accidents with the participation of cyclists in the Slovak Republic, through processed statistical data for the period 2013-2019.

KEY WORDS: analysis, cyclist, road accident, simulation, vehicle

1. Introduction

In the field of road traffic, accidents involving cyclists are generally which occur when the movement of the vehicle meets the cyclist. These accidents occur mainly during the summer months and are characterized by various material damage, minor or severe consequences for the health of road users, but often also by irreparable loss of human life. The failure of the human factor, non-compliance with the rules of the road, or incorrect estimation of the given situation have a large share in their origin.

The increasing intensity of bicycle traffic also contributes to the traffic accident with the participation of cyclists, and it is therefore important to identify the causes of road accidents, the degree of fault of road users, the locality with the highest number of traffic accidents, analyse the seasonal development of traffic accidents, and also focus on the number of accidents involving cyclists. Traffic accidents involving cyclists are usually analysed on the basis of the direction of movement of the vehicle and the cyclist during the accident, their final positions, the condition of the road surface, the deformations of the vehicle and the bicycle, as well as information obtained from the file.

The course of a traffic accident can be solved by mathematical-graphical analysis of vehicle movement and a cyclist processed by the PC Crash application program, version 12.1., which is designed to simulate the interaction of vehicles and bodies. The accuracy of the speed outputs is with respect to the input quantities within a tolerance of ± 5%. Based on the performed analysis of traffic accidents, it is subsequently possible to determine appropriate preventive measures in order to reduce traffic accidents, as well as to reduce the negative consequences of traffic accidents [4].

2. Safety of Cyclists as Road Users

Act of the National Council of the Slovak Republic no. 8/2009 Coll. on Road Traffic, as amended, regulates the basic concepts related to road traffic, road traffic rules, the rights and obligations of non-motorized participants, the competence of public administration bodies in the area of road traffic management organization, vehicle management and registration, administrative offenses for violating this law. Special provisions on cyclists are defined in the said Act, §55, par. 1-9. These are, for example, the rules of cycling, obligations before entering the passage, the obligation to wear a safety helmet, etc. [8].

It is a base for cyclist safety and the important role of mandatory bicycle equipment. Bicycles must be equipped with at least safety features, which are the brakes, lights (lit continuously or intermittently in front of white light and rear light of red light) and bells. With reduced visibility, it is essential that cyclists visibly wear reflective elements or reflective safety clothing. For the safety of cyclists it is important to move along marked routes, bike lanes and sidewalks [5].

An important factor influencing the safety of cyclists is the consumption of alcoholic beverages. A cyclist who drinks alcohol is at risk of falling off a bicycle or colliding with a motor vehicle and then colliding. It has been valid in
the Slovak Republic since 2017, that cyclists may consume alcoholic beverages up to 0.5 per mille (0.24 milligrams of ethanol) before cycling. This exception applies only in the built-up area of the village and on the path for cyclists. Outside these zones, alcohol is not tolerated by cyclists. Zero alcohol tolerance is only valid if those cyclists do not cause an accident or become a participant [8].

3. Development of Traffic Accidents with the Participation of Cyclists

The development of traffic accidents in the territory of the Slovak Republic (hereinafter referred to as the Slovak Republic) is analysed by means of detailed statistical data on traffic accidents, in which not only the current number of accidents is monitored, but also the negative consequences associated with them. Attention is first paid to road users, which are divided into drivers, pedestrians, motorcyclists and cyclists, as well as the number of road users killed in road accidents. Statistical data were processed in the period 2013 - 2019. In the mentioned period, the development of traffic accidents in the number of killed road users had a fluctuating tendency. Drivers accounted for the largest share, accounting for up to 54% of the total number of road users killed. This was followed by pedestrians as non-motorized road users (26%) and motorcyclists (12%). Cyclists had the smallest representation in the number of fatalities killed and accounted for 8% of the total [6].

The following table shows a more detailed development of traffic accidents with the participation of cyclists according to the number of traffic accidents and individual consequences of injuries in the period 2013 - 2019.

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Number of traffic accidents</td>
<td>481</td>
<td>499</td>
<td>493</td>
<td>452</td>
<td>466</td>
<td>514</td>
<td>471</td>
</tr>
<tr>
<td>minor injuries</td>
<td>346</td>
<td>349</td>
<td>327</td>
<td>337</td>
<td>301</td>
<td>344</td>
<td>338</td>
</tr>
<tr>
<td>serious injuries</td>
<td>65</td>
<td>75</td>
<td>87</td>
<td>67</td>
<td>92</td>
<td>105</td>
<td>62</td>
</tr>
<tr>
<td>killed cyclists</td>
<td>16</td>
<td>24</td>
<td>16</td>
<td>12</td>
<td>18</td>
<td>10</td>
<td>14</td>
</tr>
</tbody>
</table>

According to Table 1, it follows that in 2018 the largest number of traffic accidents with the participation of cyclists was recorded (up to 514 cases) and the smallest number was in 2016 (452 cases). The highest number of traffic accidents with the consequences of minor injuries of cyclists was in 2014 (349 cases) and at least in 2017 (301 cases). The largest proportion of traffic accidents with the consequences of serious injuries to cyclists in 2018 (up to 105 cases) and the smallest representation was in 2019 (only 62), which represents a decrease of 43 cases. The period 2015-2019 can be considered a successful trend in the development of traffic accidents involving killed cyclists, as the number of cyclists killed in 2014 was no longer exceeded. Within the framework of the identification of areas with the highest traffic accidents, the distinction according to regional differences represents a more concise view, at the level of self-governing regions. Development of traffic accidents with the participation of cyclists according to individual self-governing regions in the territory of the Slovak Republic in the period 2013-2019 is shown in Table 2.

<table>
<thead>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bratislava</td>
<td>56</td>
<td>51</td>
<td>50</td>
<td>58</td>
<td>53</td>
<td>49</td>
<td>46</td>
</tr>
<tr>
<td>Banská Bystrica</td>
<td>39</td>
<td>31</td>
<td>41</td>
<td>30</td>
<td>40</td>
<td>42</td>
<td>34</td>
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<td>Košice</td>
<td>48</td>
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<td>46</td>
<td>49</td>
<td>43</td>
<td>64</td>
<td>40</td>
</tr>
<tr>
<td>Nitra</td>
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<td>67</td>
<td>74</td>
<td>80</td>
<td>55</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>Prešov</td>
<td>43</td>
<td>49</td>
<td>47</td>
<td>35</td>
<td>45</td>
<td>51</td>
<td>65</td>
</tr>
<tr>
<td>Trenčín</td>
<td>59</td>
<td>61</td>
<td>73</td>
<td>80</td>
<td>66</td>
<td>79</td>
<td>65</td>
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<tr>
<td>Trnava</td>
<td>81</td>
<td>98</td>
<td>75</td>
<td>57</td>
<td>82</td>
<td>64</td>
<td>80</td>
</tr>
<tr>
<td>Žilina</td>
<td>76</td>
<td>91</td>
<td>85</td>
<td>63</td>
<td>80</td>
<td>97</td>
<td>71</td>
</tr>
</tbody>
</table>

In Table 2 you can notice the development of traffic accidents with the participation of cyclists by individual self-governing regions in the period 2013-2019. The decrease in the accident rate of cyclists was recorded in 2016 in Banská
Bystrica (only 30 cases) and the Prešov Region (only 35 cases). An increase in cyclist accidents has been recorded in 2018, especially in the Žilina Region (up to 97 cases), followed by Trenčín Region (79 cases) and the Nitra Region (68 cases).

The most frequent traffic collisions occurred when drivers considered roads for their priority territory and cyclists did not respect. Tensions are rising, aggressive to reckless behavior, drivers restrict or endanger cyclists and cyclists restrict vehicle drivers. The turning of the vehicles to the right was also problematic, when crossing a road with a cyclist. In this case, the driver is obliged to give preference to the cyclist, which did not happen in many cases. It was similar to turning the vehicle and the cyclist to the left. In this case, the cyclist turns on the left side of the vehicle, but it must allow him to rejoin after turning to the right side of the road. Another cause of the collision situation was the failure of the driver to keep a sufficient distance when circling the cyclist [5, 6].

Cyclists, as road users, often crossed roads in dark places, without reflective elements on clothes, did not respect the traffic lights, were under the influence of alcohol, they did not notice the unsatisfactory condition of the road or underestimated the weather situation and poor visibility [6].

The topic of security and consideration on the roads is very topical due to the expansion of a number of other alternative modes of transport (bicycles, electric scooters). For driver safety and cyclists are the most important mutual consideration, sufficient lateral distance when overtaking, early warning of a change of direction and their full concentration.

4. Accident of Cyclists as Participants in Road Traffic

4.1. Traffic Accidents and their Peculiarities

In order to successfully solve some types of traffic accidents with the participation of cyclists, it is very important to monitor the behavior of cyclists in dangerous sections, or in sections where a traffic accident has already occurred. Such an observation reveals:

- the way cyclists ride at the scene of the accident
  When inspecting the scene of an accident, the way cyclists ride is monitored, as well as their transverse distance from the edge of the road (passing the bicycle through the monitored section).
- entry of a cyclist to the main road
  If a cyclist enters the main road, he usually does not look around and enters the main road from the side road, even when a vehicle is coming along the main road.
- an obstacle in front of the cyclist
  The analysis of a traffic accident checks whether there has been a change in the direction of the cyclist's ride due to the avoidance of an obstacle. Obstacles can be fixed (canal, stationary vehicle, pothole), unstable (pool, shadow appearing pothole) and movable (pedestrians, animals, single-track or multi-track vehicle).
- the cyclist's position at the obstacle
  An important point is also the correct determination of the mutual position of the bicycle and the vehicle at the moment of their first contact, as it is then possible to judge the pre-accident movement of the cyclist [2].

4.2. The Most Common Types of the Relative Positions of the Vehicle – Bike

- collision of the vehicle with the bicycle from behind
  The mutual angle of the longitudinal axes of the bicycle and the vehicle can be determined on the basis of the deformation of the bicycle (rear fork, wheel) or on the basis of the deformations of the vehicle. Deformations on the vehicle - the point of first contact of the bicycle with the vehicle and the point of contact of the body with the vehicle (eg headprint on the windscreen) can be checked at a known vehicle speed to ensure that the relative position of the bicycle to the vehicle is correct (relative to bicycle speed).
- impact of the vehicle on the bicycle from the front
  The mutual angle of the longitudinal axes of the bicycle and the vehicle can again be determined on the basis of the deformation of the bicycle (front fork or front wheel or on the basis of the deformation of the vehicle). Based on the deformation on the vehicle, the point of first contact of the bicycle with the vehicle and the point of contact of the body with the vehicle (eg headprint on the windscreen), it is possible to check at a known vehicle speed whether the relative position of the bicycle to the vehicle is correct (relative to the bicycle speed).
- collision of the vehicle with the bicycle from the side
  If it is possible to identify the imprint of the bicycle frame on the vehicle, it is obvious that the angle of the longitudinal axes of the bicycle - vehicle was approximately 90 ° at the moment of impact. However, if the frame imprint on the vehicle is smaller than the actual bicycle frame, then the angle of the longitudinal axes was other than 90 °. As a rule, a short, very faintly visible skid trail remains on the road surface of the bicycle wheel that first contacted the vehicle. In some cases, a friction mark on the rim, fork, or pedals remains on the road. From these tracks it is possible to determine very precisely the place of collision and the exact transverse position of the vehicles at the place of collision.
- indirect clashes
  If the vehicle and the cyclist did not contact each other at all, but due to the very small lateral distance vehicle -
bicycle, the cyclist could not perform a typical trajectory - irregular wavy line in the transverse direction (towards the vehicle) and there is a change of direction and subsequent fall, eventually there will be a collision with an obstacle, resp. another vehicle. The transverse distance between the cyclist and the vehicle at which the cyclist of psychological restraint is to perform an irregular wavy line (towards the vehicle) is approximately 0.5 m and is conditioned by psychological factors. [2]

4.3. Example - Vehicle - Cyclist Accident with Reduced Visibility

The course of an accident of a traffic accident (variant A, variant B) of the type personal motor vehicle - cyclist on a bicycle with reduced visibility is shown by means of a traffic accident simulation in the PC Crash simulation program. The overall traffic situation, the position of the vehicle and the cyclist in the individual stages of the accident is shown in Fig.1.

Characteristics of the accident (variant 1):
In a traffic accident, a vehicle collided with a cyclist, with reduced visibility, on a section outside the village. The driver was moving with the dipped beam headlights on, at a speed (approx. 59 km/h) in the section with a maximum permitted speed of 90 km/h. The cyclist was moving on a bicycle, without active lighting and without reflectors, in the opposite lane, at the edge of the road.

Characteristics of the accident (variant 2):
In a traffic accident, a vehicle collided with a cyclist, with reduced visibility, on a section outside the village. The driver was moving with the dipped beam headlights on, at a speed (approx. 59 km/h) in the section with a maximum permitted speed of 90 km/h. The cyclist was moving on a bicycle with active lighting and reflectors, in the opposite lane, at the edge of the road.

![Fig. 1 The course of the accident - simulation of a traffic accident in PC Crash [3]. Legend: 1 – mutual position of the vehicle and the cyclist at the moment of the beginning of the driver's reaction; 2 – position of the vehicle at the moment of the beginning of the braking effect of the vehicle; 3 – position of the vehicle at the moment of the beginning of full braking effect of the vehicle; 4 – and bicycles; 5 – position of the vehicle at the moment of stopping](image)

Accident evaluation (variant 1):
The driver was moving at a speed lower than the speed appropriate to the driver's view and at the same time at a speed lower than the speed appropriate to the supervision of the cyclist. The driver responded to the collision situation in time. A sudden obstacle was created for the driver of the vehicle. Even with the correct driving technique, the driver could not stop in front of the crash site, because the cyclist, with his movement in the opposite lane, shortened the driver's distance to the crash site.

Accident evaluation (variant 2):
The driver was moving at a speed lower than the speed appropriate to the driver's view and at the same time at a speed lower than the speed appropriate to the supervision of the cyclist. The driver reacted late to the collision situation. In this case, it can be stated that the driver of the vehicle was not suddenly obstructed. With a timely reaction, the driver could stop in front of the crash site or create a safe side distance.

By clarifying the analysis of the accident of a simulated traffic accident of the vehicle - cyclist type, it can be stated that at present it is very important to deal with factors such as traffic, vehicle, road user in the interest of reducing traffic accidents and its consequences.
5. Analysis of a Selected Traffic Accident with the Participation of a Cyclist

As part of the analysis of the accident event of a selected traffic accident with the participation of a cyclist in reduced visibility the overall situation at the scene of the accident is assessed, vehicle driver and cyclist's driving technique and speed, as well as deformations on the vehicle and bicycle. From a technical point of view, the cause of a traffic accident is determined. For both road users, the possibilities of preventing a traffic accident are also evaluated. The accident in question occurred between a personal motor vehicle and a cyclist on a bicycle, with reduced visibility, in the village section, at the crossroads of local roads. In this section, the maximum permitted speed was 50 km/h. The cyclist suffered severe injuries (skull fracture, brain haemorrhage, abrasions and head bruises).

At the time of the inspection, the quality of the two-lane road was flawless, the road surface was dry and unpolluted (coefficient of friction between road and tires $\mu = 0.8$), the curb was in good condition, without guide bar. Driving priority is not indicated by traffic signs, follows from the rules of the road. Weather conditions were not aggravated, the road was lit by public lighting, the viewing conditions were good. Based on the documents, a plan was prepared from the place of the accident taking into account its real directional and width parameters. On its basis, the simulation of the accident was subsequently performed by the simulation program PC Crash, which was necessary to determine the relative position of the vehicle and the cyclist on the bicycle at the time of impact (Fig. 2).

![Fig. 2 The course of an accident over time from collision to final positions shown in a time interval of 0.20 s - without taking into account the light conditions - 3D view (A - beginning of the accident, B continuation and end of the accident) [7]](image)

Damage analysis (evaluation of bicycle and vehicle damage correspondence) was performed in order to determine the relative position of vehicles at the time of their collision. These deformations must correspond to each other within the species size and relative position at the time of collision [1]. Damage and traces of contact on the right part of the front bumper of the vehicle occurred during a collision with the front wheel of the bicycle, on the right front fender of the vehicle were created during a collision with bicycle handlebars. Damage to the right exterior mirror on the vehicle was caused by the vehicle colliding with the cyclist's body. Traces of contact on the right front door of the vehicle originated during a collision with bicycle handlebars. Damage to the front wheel of the bicycle has occurred in the event of a wheel collision with the right front wheel of the vehicle [7].

According to the performed analysis of the course of the accident, it follows that the driver of the vehicle was moving in the section in question at an operating speed of approximately 37 km/h, while the driving speed for the given section of the maximum permitted was 50 km/h. The driver of the vehicle reacted to the development of the traffic situation at the moment of the collision with a cyclist, which can be considered from a technical point of view for the delayed reaction. The cyclist was moving on a bicycle on the sidewalk in the section in question, operating a speed of approx. 23 km/h. At the time of the collision with the vehicle, the cyclist was moving on a bicycle at a riding speed of approx. 22 km/h [7].

In determining the cause of the accident, it can be stated that that the technical cause of the accident was incorrect cycling technique, who made a collision entrance to the road from the sidewalk without to make sure that he does not force the driver of the incoming vehicle to change direction or speed. When riding a bicycle in times of reduced visibility, the cyclist did not use any bicycle lighting, nor any reflective elements, making it significantly more difficult for other road users to recognize it. The concentration of ethyl alcohol in the cyclist's blood was determined with an FID detector to be 1.81 g/kg per mille [7]. The driver of the vehicle was not obliged to assume the riding of an unlit cyclist and did not
have to adapt his riding technique so that to stop the vehicle in front of the corridor of the movement of an unlit cyclist without reflective elements.

As part of the assessment of the possibility of the participants in a traffic accident to prevent it, it is possible to assume the following. If the driver of the vehicle were moving in the section in question at a speed of (calculated) 35 km/h and would react earlier to the development of the traffic situation, after the reaction time has elapsed, the vehicle would brake using maximum deceleration, this would prevent an accident by stopping the vehicle in front of a cyclist moving corridor. It should be noted that this cannot be required of the driver of the vehicle, because the cyclist was at that time with a bicycle on the sidewalk, in an area of hidden view. A cyclist moving on a bicycle on the sidewalk had the opportunity to prevent an accident by that before entering the road from the area of obscured view for moving vehicles first convinced whether he can do so without danger and in the given situation would do not enter the road, respectively, he would stop with the bicycle in front of the vehicle corridor. It should be noted that the vehicle had lights on while driving, which must have been visible to the cyclist.

6. Conclusions

Cyclists - drivers as road users in many cases cause unnecessary traffic collisions. The big problem is not only the very low level of mutual consideration, but the presence of alcohol is often confirmed, as well as non-compliance with road traffic rules. Development of traffic accidents with the participation of cyclists on the territory of the Slovak Republic during the period 2013-2019 was processed using available statistics. It can be stated that this trend had a fluctuating tendency. Cyclists as road users had the smallest representation in the number of participants killed. The positive trend of reducing the number of traffic accidents resulting in the death of cyclists has been since 2015.

In the present article, an analysis of the accident event of a selected traffic accident was performed with the participation of a cyclist on a bicycle in reduced visibility. The origin and course of the traffic accident were assessed, vehicle and cyclist driving technique and speed, from a technical point of view, the cause of the accident was determined and the possibilities of the participants in the accident were also evaluated to avert it. In the analysis of the accident of traffic accidents with the participation of cyclists, it is important to focus on the specifications of road accidents (way of riding cyclists at the place of the accident, obstacle in front of the cyclist, position of the cyclist at the place of the obstacle, entry of the bicycle to the main road). One of the most common types of vehicle-bicycle relative positions is the impact of the vehicle on the bicycle from behind, front, side and indirect clashes. As part of the explanation of a practical example, a vehicle-cyclist accident in reduced visibility the course of the accident was characterized in two variants through the simulation of a traffic accident in the simulation program PC Crash. In order to reduce traffic accidents and their consequences, it is therefore necessary to pay attention to the following factors, namely communication, vehicle, road user.

Acknowledgement

Article created with the support of the scientific research project VEGA 1/0159/19 Evaluation of the level of resilience of key elements of land transport infrastructure.

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Field Tests of an Intelligent Video Monitoring System Installed on Freight Wagons

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Abstract

The article presents the results of field tests of the intelligent video monitoring system of railway wagons, own name IMW. The IMW device was created as part of a project financed by the National Center for Research and Development, under Measure 4.1 of the Intelligent Development Operational Program 2014-2020 POIR.04.01.04-00-0157 / 17-00. The goal of the project is to develop a demonstration installation and validate the technology leading to an innovative product in form of an intelligent monitoring system for railway wagons. This system, through vibration diagnostics and a network of sensors (bearing temperature sensors, gas pressure sensor in the tanker), enables: detection of faults in freight wagons (e.g. flat surfaces, flat wheel, …). The article presents the recording of vibration acceleration signals for the defect of a flat wheel located on the outer axis of one of the wagon cart, using the intelligent video monitoring system (IMW). Vibration comparisons were made for an operational wheelset, on the basis of which an analysis was carried out using appropriate algorithms. The research was carried out for two ways of implementing the drive at different speeds: pulling and pushing.

KEY WORDS: diagnostics, vibration, wheelset

1. Introduction

Railway Institute participates in many innovative and novel national and international projects. The Automation and Telecommunications Laboratory participates in several research projects. The most important of them is the project „Intelligent video surveillance of containers” financed by the National Center for Research and Development, under Measure 4.1 of the Intelligent Development Operational Program 2014-2020 POIR.04.01.04-00-0157 / 17-00. The leader of the project is MobileMS company, whereas the Railway Institute in cooperation with other consortium partners i.e. STIPENDIUM Institute of Science and Technology, Kodegenix carries out various research and development works. The main objective of the project is to develop a demonstration plant and technology validation leading to an innovative product with the IMW's own name in the form of an intelligent railcar monitoring system (Fig. 1) that allow to:

- Intelligent monitoring data analytics for risk assessment and service cost forecasting. Uses real-time freight wagon condition data and associated geolocation data, automatic fleet observation, automatic alerts, downtime, entry/exit into/out of zone, data analytics, accurate wagon routing;
- Detection of defects on freight wagons (flat surfaces, flat wheels, stickers, overlaps) through vibration diagnostics and sensor network.

![Fig. 1 Functional structure of the system](image-url)
Railway Research Institute participates in research and development works both at the stage of laboratory tests using accredited test stands and at the Experimental Track Operation Centre in Żmigród [1]. The facility, which is nearly 8 km long, enables to carry out tests in conditions closest to the real intelligent container video monitoring system. The possibility to carry out experimental studies at the Experimental Track Operation Centre in Żmigród allows for regular improvement of the IMW product in order to avoid unexpected system faults in the target operation. The infrastructure of the facility allows for conducting tests in extreme operating conditions. Products created as a result of the project will allow to obtain unique functions of the whole solution, not available in the current solutions on the market.

The paper presents design assumptions and an algorithm for detection of wheel set defects in freight cars developed within the project. The algorithm creation is based on numerous tests and field researches in which Railway Institute actively participated. There were realized tests using wagons with flat wheel defect and healthy ones, in order to compare received results and to verify correct work of algorithm or possible corrections in system operation. Correctness of operation of the intelligent video surveillance of containers is controlled online, using a special platform to which defined measuring devices installed on the wagons send data by GSM signal (Fig. 2).

2. Flat Wheel Defect Detection

The flat spot effect on the wheel is observed through accelerometer signals of periodic impacts with similar characteristics. Passing through turnouts has the character of a group of frequently occurring pulses. For the detection of this type of event, detection of exceeding the acceleration level threshold is sufficient, since the impact signal will be higher than the background noise resulting from normal driving [2]. The method of adaptive threshold determination, consists in calculating the average of the absolute value of the variable component of the current acceleration signal, and then assuming that the "impact" threshold is, for example, n times the value of this average, or standard deviation. In this way, even if during the period of counting the average, the wheel overcame the rail joint it will still be about 1/1000 of the collected samples, so it will not overestimate the threshold calculated in this way.

The distinction between rail joints, turnouts and flat spots is made by distinguishing the time between their occurrences. The following features were observed as a result of field measurements conducted as part of the NCBiR project:

- Rail splices cause a pronounced peak in acceleration values at larger interval values,
- Railroad turnouts cause small accelerations, occurring in immediate succession because they occur infrequently, and generate characteristic sounds corresponding to a physical path from about 40-50cm to 15-20m (i.e., from about 0.2 wheel circumference to 5-7 wheel circumferences),
- Flat spots give shorter intervals (corresponding to the time it takes to travel one circumference of the wheel). The histogram of a wheel with a flat spot will have 2 distinct maxima - one from the flat spot and one from the rail joints.

If there is no impulse detection (tapping) within a time longer than the one corresponding to the wheel rotation frequency (e.g. there are no taps within 2 seconds, which means rotation at the speed of 5km/h) then the wagon is either standing or riding on a seamless track. The statement that a wagon is running on a seamless track and at the same time
has a flat wheel defect requires the knowledge of certain parameters:
  • Knowing the velocity to calculate whether the pulses correspond to sections of wheel circumference or rail
    length. The speed value can be obtained by:
    – GPS readout (energy intensive);
    – Estimation from the lowest FFT peak that will account for even the smallest wheel centricity defects
      (potentially low accuracy);
    – Estimation from integral of acceleration, e.g. with Kalman filter (loses convergence after a short time
      (e.g. several seconds).
  • Operation of devices from different wagons in a train and sharing the information about registered impulses -
    if the defect is in one wagon, the wagons further from it will not detect the impulses coming from it, but if the route has
    rail joints all the wagons having sensors will detect those joints.

3. Algorithm for Detecting Railroad Contacts and Turnouts

The algorithm is based on a worst-case scenario assumption resulting from the above properties and the band. In
the worst-case scenario, consisting in the bandwidth available from the sensor, the impact signal received by the device
on the railcar, generated by the occurrence of a flat wheel, will have amplitude (envelope) properties in the time domain and
a spectral character similar to that of a rail joint signal. The features that distinguish the occurrence of a flat spot from a rail joint are visible in the frequency spectrum of their occurrence and are quantitative rather than qualitative.

Wheel flat spot signal occurrence parameters:
  – Presents with a frequency equal to the rotational speed of the wheelset;
  – The impact frequency is proportional to the travel speed, e.g. for a travel speed of 20 km/h (= 5.5 m/s) of a
    wheelset with a typical diameter of 1.20 m (circumference equal to 3.77 m) the impact frequency is 1.474 Hz (recurring
    impact every 0.679 s).

Fig. 3 Raw ideal signal (from 48000Hz, 16bit reference recordings) - [g] blue. Signal gRMS value - red. Crest factor of
the signal - black. Length of gRMS and crest factor window: 1500 samples (corresponds to about 74.6 cm at
86 km/h).

Fig. 4 Simulated signal from the sensor on the carriage (sample rate 1kHz) - [g] light blue. Signal gRMS value - red.
Crest factor of the signal - black. Length of gRMS and crest factor window: 9 samples correspond to 215 mm
path at 86 km/h.
Parameters for the occurrence of a busbar coupling signal:
- It occurs with a frequency corresponding to the length of the rail sections, (several tens of meters on the contact track). Relatively low frequency compared to the frequency of car wheel rotation;
- When passing turnouts and crossings, they occur in groups of several to a dozen signals, in short intervals, corresponding to a 1m 50m path;
- The length of the on-board buffer available on the wagon is limited to the level of kilobytes, then it is assumed that the algorithm will operate on the corresponding data packets (current window).

Since speeds in real railcar operation range from a few kilometers to tens of kilometers per hour, also the envelope features and distances between recorded events are proportional to speed. The algorithm must take this issue into account. For this purpose, access to information about the instantaneous speed of the wagon, extracted from the GPS device, is provided. Based on the speed, a scaling of the parameters that are used in the detection algorithm is performed. This is realized using some assumptions to perform the calculations. The pulse from a wheel defect has a small length relative to the circumference of the wheel, so the size of the current data window of the algorithm is assumed to be proportional to the physical size of the path (length on the wheel). Within such a window, calculations are performed, in particular the RMS windowing.

Example results from the raw ideal signal and simulated on the RMS and crest factor are shown in the graphs – Fig. 3 and 4. Crestfactor is the ratio of the amplitude of the instantaneous pulse to the RMS value of the signal. The Crestfactor is calculated in the current window (which means that the RMS value it uses is also calculated in the current window).

4. Functional Principle of the Algorithm

The essential operation of the algorithm is presented in several dependent steps. The input data is analyzed using a crestfactor, which is sensitive to instantaneous pulses in the current amplitude of the signal being compared relative to the mean squared value of the signal preceding the pulse. The length of the current window is chosen based on the wheel speed calculated from the travel speed read from the GPS signal. A window corresponding to approximately 1/3 of the wheel rotation is assumed. The logic of operation is as follows: if within a limited section of wheel rotation (corresponding to 1/3 of the length) a sudden impulse occurs, which may mean:
- impulse originating from the rail (irregularity or discontinuity of the rail: e.g. splice, turnout crossing, etc.);
- impulse coming from a bump on the wheel (i.e., a flat spot or nalep).

At the next stage, candidate events are selected on which the analysis of time dependencies is performed. Candidate impulses lie in certain time intervals from each other, and the length of these intervals is a characteristic that allows to divide the impulses into groups, by comparing them with the expected time of wheel rotation, as follows:
- flat wheel type damage usually occurs early one at a time on a given wheel, so the interval between two such pulses will be equal to the period of wheel rotation;
- the remaining impulses coming from rail joints or turnouts will occur at irregular, often much longer time intervals. The typical circumference of a wagon wheel is ca. 2.9-3.14m, while the typical distances of joining rail segments are from several to several dozen metres on the contact track, similarly to the distances from turnout joints to crossings, etc.

### Table 1

<table>
<thead>
<tr>
<th>Lp</th>
<th>Wheel base [mm]</th>
<th>Tenon spacing [mm]</th>
<th>Wheel diameter [mm]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1800</td>
<td>--</td>
<td>920</td>
<td>Railroad carriage Y25Lsi(f)-C (ELH, DE)</td>
</tr>
<tr>
<td>2</td>
<td>2000</td>
<td>6800</td>
<td>920</td>
<td>Tanker of type 406R</td>
</tr>
<tr>
<td>3</td>
<td>2000</td>
<td>6800</td>
<td>920</td>
<td>Tanker of type 405RTM</td>
</tr>
<tr>
<td>4</td>
<td>1800</td>
<td>8000</td>
<td>920</td>
<td>Tanker of type 438</td>
</tr>
<tr>
<td>5</td>
<td>2000</td>
<td>7200</td>
<td>1000</td>
<td>Tanker of type 29R</td>
</tr>
<tr>
<td>6</td>
<td>2000</td>
<td>7000</td>
<td>920</td>
<td>Railroad platform type 401Z</td>
</tr>
<tr>
<td>7</td>
<td>1800</td>
<td>7500</td>
<td>920</td>
<td>Hopper wagon type 426Vb</td>
</tr>
<tr>
<td>8</td>
<td>2300</td>
<td>11100 - 14020</td>
<td>920</td>
<td>Intermodal (combined) transport wagons IPS TABOR</td>
</tr>
<tr>
<td>9</td>
<td>--</td>
<td>5000</td>
<td></td>
<td>Short dump wagon type 204V</td>
</tr>
<tr>
<td>10</td>
<td>1800</td>
<td>9000</td>
<td>920</td>
<td>Railcar type 448W (carbonizer)</td>
</tr>
<tr>
<td>11</td>
<td>1800</td>
<td>--</td>
<td>1000</td>
<td>Bogie car with spacing 1800 and wheels with a diameter of 1000mm. (theoretical case)</td>
</tr>
</tbody>
</table>

For most wagons, the axles are mounted in pairs in the bogie, where the axe distance is between 1.8-2 m, this means that on the wagon body the accelerometer will pick up each pass of the wagon along the rail joint several times. Nominally there should be 4 pulses, in two pairs corresponding to the bogies. Within each pair the pulses will be
separated by the time resulting from the distance between bogie axles, while the time distance between pairs of pulses will result from the length of the wagon, specifically from the distance between bogie pivots. The assumption made is that the impulses of passage after joining the rails by neighboring wagons are strongly attenuated and are negligible compared to the own impulses of the wagon on which the measurement is conducted [4].

In typical carriages, the interval of the rail joining signal from adjacent axles in the bogie is 0.62 to 0.79 times the wheel rotation time.

The situation in which it is potentially easiest to accidentally count a rail-junction crossing impulse as a flat spot impulse could occur under the following conditions:

- for strollers with smaller wheels and a longer stroller, such as No. 8;
- in case of high speed measurement error from GPS, or wheel wear reducing its diameter.

Example: The car in item No. 8 in the Table 1 has a wheelbase of 2300 mm, which is 0.79 of the 920 mm diameter wheel circumference of 2890 mm. If there was a speed measurement with an error worse than 20.4%, overestimating the speed measurement, this would cause the algorithm to calculate the time length of one revolution as 20.4% shorter on this basis. This means that instead of the time corresponding to a path of 2890 mm at a given speed, it would get 2300 mm, which is the same distance that corresponds to the physical interval between the pulses of the rail connection traversed by the axles of the same carriage. For this reason, it is recommended that the tolerance parameter vtol not be greater than +/- 10%, i.e. 20% (the default value). Thus, if a 20% tolerance is specified, the algorithm will classify as wheel rotation events those that are preceded by an interval lying between the lower and upper limit of the wheel rotation period, where the upper limit is 1.1 and the lower limit is 0.9 wheel rotations.

The result of the algorithm’s operation on the input data is a single number denoting the rate of finding a defect in the wheelset. This indicator is the ratio of the number of counts of events lying above the upper tolerance limit (1.1) to the number of events lying between the limits, i.e., in the range 0.9-1.1.

Result index:

- \( P < 1 \) – normal state, i.e., low proportion of pulses related to wheel rotation from the analyzed data;
- \( P \geq 1 \) – the defect of the wheel set, i.e., the high proportion of pulses associated with wheel rotation from the analyzed data.

5. Examples of Test Results

A Hilbert transform was used to analyze the test results to highlight signals from impacts associated with track joints and the presence of a flat spot on the wheel [3]. The results were read from fully operational cars and damaged wheelsets moving at different speeds. Fig. 5 shows the measurement results in the form of histograms.
6. Conclusions

During the measurements it was noticed that the overlapping bar graphs representing the results of the analyses of the readings of the measurements taken from the wagons with defective wheelsets tend to assume a shape close to that of the normal distribution graph. On the other hand, the overlapping bar graphs presenting the results of analyses of measurement readings obtained from wagons with a functioning wheelset tend to accumulate on the left side of the graph. Multiple datasets in our possession were analyzed and it was concluded that this is a regularity that can be considered a signal marker.

Acknowledgement

Work performed under the project „Intelligent video surveillance of containers” financed by the National Center for Research and Development, under Measure 4.1 of the Intelligent Development Operational Program 2014-2020 POIR.04.01.04-00-0157 / 17-00 are in the development stage. Laboratory and field tests are conducted on both IMW devices and innovative temperature sensors that will be integrated into the IMW system in the following months of the project.

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E-beam Modified Engine Oil

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Abstract

The paper focuses on combustion engine oil modified by e-beam. The article compares the properties of conventional and irradiated engine oil by high-energy electrons. There were used several radiation doses for comparison. The energy of accelerated electrons is 5 MeV. Researched oil properties were physical and physicochemical, mainly kinematic viscosity, viscosity index, total base number, etc. The article preferred comparisons of kinematic viscosity, oxidation and total base number as parameters that complement each other. Major changes in viscosity index and alkaline reserve were observed.

KEY WORDS: engine oil, e-beam, electron, irradiation, TBN, viscosity

1. Introduction

Particle accelerators represent modern technology for various applications in science and industry. Among the most used in industry are electron accelerators. The accelerated electrons energy application has recently seen a dynamic increase in polymer production and development. This technology is not used yet commonly in the oil industry, despite its potential.

Nowadays combustion engines continually push the boundaries of technology and engineering. They are smaller and more efficient, with as low as possible sacrificing performance. Advanced combustion engines challenge the oil with increased pressures. These intense pressures cause higher friction, which can waste up to 10 % of an engine’s performance. The most of engine wear happens while engine warms up. Serious interest in the properties of combustion engine oils is friction coefficient, chemical stability and optimal kinematic viscosity as the engine start, so it could flow in a shorter time through critical engine parts. Secondary the most important at this point is a higher viscosity index, so the engine oil kinematic viscosity should be independent of temperature. There are many significant engine oil properties, because engine oil is undoubtedly the most technologically complex oil product, whose properties are given by a number of often conflicting technical requirements. All kinds of combustion engine oils have inhibitors and additives for various reasons. All these oil enhancements are methods of the chemical way for raise up engine oil classification. The aim of this paper is to point out the possibility of physical modification in addiction to subsequent chemical additivation.

The article focuses on the investigation of data for electron radiation applied on combustion engine oils. It has already been shown, that electron radiation can change the kinematic viscosity of combustion engine oils and base oils [1, 2]. Therefore, research continues to explore other physical and physico-chemical properties of engine oils.

2. Materials and Methods

Presented study was realized on combustion engine oil Castrol EDGE, SAE 5W-40, ACEA C3, API SN/CF, VW 505.01 with Fluid Titanium Technology. The main reason for choosing stated engine oil was impossibility of purchase any type of base oil. Base oils are raw material from which engine, transmission and hydraulic oils are produced by various manufacturing methods and adding additives. Mentioned engine oil was chosen for primary research done [2] on similar product of the same oil manufacturer, for possibility of continuing research on older combustion engine with “PD” injection and for its affordability.

For continuous primary research it was done irradiating of 10 samples, each at the same irradiating parameters, volume, packaging and height. Every sample consist of 60 ml of mentioned engine oil poured in petri dish with 90mm in diameter and 15 mm in height. Every petri dish was cleaned by N-heptane 96% before applying each oil sample. Petri dish with sample is positioned in centre of steel container. Steel container has 1 mm thick walls and 100 mm walls height. 10 mm polystyrene pad was used under petri dish to prevent the effects of bremsstrahlung. Breaking radiation is generated in steel container moving on a conveyor under accelerator window. Each petri dish is opened – without lid part, except of two samples – 34 and 37 kGy. These two samples are for comparison with 33 kGy sample. 34 kGy sample was pour in shipping container in 7 minutes after irradiation and in another room. This sample had contact with only very small amount of air, oxygen and ozone which were under petri dish lid. 37 kGy sample had lid removed right
after irradiation process. Samples set for irradiation are shown in Fig. 1, Fig. 2 and Fig. 3.

Fig. 1 Oil sample prepared for irradiation process   Fig. 2 Oil sample detail with positioned dosimeters

For detecting radiation dose was used radiochromic films B3. At all positions were a pair of detectors. Each pair of detectors were both sides coated by duct tape to ensure oil proof and to prevent depreciation. Dosimeters were fixed at the bottom of petri dish and at top level they float. Radiation dose of tested samples were calculated as arithmetic mean of bottom and top-level detectors. Accelerated electrons energy was set to 5 MeV ± 5% and other irradiation parameters was clusters frequency of 240 Hz, scanning frequency 5 Hz by 40 cm, beam current 110 ± 3 μA, dose rate 0,21 kGy.s⁻¹ at all samples with various conveyor speed. Distance of conveyor from accelerator window were set to 52 cm.

Fig. 3 Samples with absorbed radiation dose of 12, 50 and 144 kGy in shipping container

3. Results and Discussion

For determine kinematic viscosity it was used gravimetric capillary method. Gravimetric capillary has oil-temperature controlled system through temperature of capillaries positioned in oil filling. Mentioned method fulfils the requirements of ISO 3104 and was used for both 40°C and 100°C. Results of each sample are shown in Fig. 4 and Fig. 5. The viscosity index was calculated by ISO 2909 method, based on obtained kinematic viscosity data. Viscosity index results are shown in Fig. 6.

In irradiation process, at higher radiation doses, is cross-linking potential as seen on samples 34 kGy and higher radiation doses. The result of researched samples cross linking is chemical chains connecting to longer chains. The longer chemical chain is, the greater shear stress must be overcome for the flow of fluid. 34 and 37 kGy sample representing oil without petri dish lid demonstrate fact, that amount of oxygen and ozone has not significant effect on kinematic viscosity. At 40°C it is desirable for the engine oil to have a lower kinematic viscosity and at 100°C conversely, for the oil to have a higher kinematic viscosity. By these requirements it is characterized engine oil with higher viscosity index. The kinematic viscosity at 100°C is not changed from unirradiated oil up to a dose of 37 kGy. The kinematic viscosity at 40°C is not changed from unirradiated oil to a dose of 12 kGy, where it undesirable
increases. Paradoxically, the kinematic viscosity at 40°C of the 33 kGy sample decreased, thereby increasing the viscosity index. Given the value of the viscosity index, 33 and 3.8 kGy appear to be suitable values of the absorbed radiation dose for further investigation in practice. It is necessary to make other experiments at much more irradiated samples to compare suitability of these radiation doses.

The base of combustion engine oils are hydrocarbons. Mentioned oils contain saturated bonds in addition to unsaturated hydrocarbons. Unsaturated ones are more sensitive to the effect of the electron beam than saturated bonds. This is due to the lower dissociation energy of hydrogen in the unsaturated bond \( \text{Rx - CH = CH - Ry} \), compared to the saturated bond \( \text{(RxRy) C - H2} \). When irradiating hydrocarbon materials by an electron beam, the primary step is the interaction of the electrons with the hydrocarbon, which results in the excitation of the C-H bond and the subsequent formation of radicals [3]. In the propagation phase of radical reactions there occur degradation effect which results in tearing hydrocarbon bonds into the shorter fragments. The decrease in molar masses in the phase of propagation of radical reactions appears as a decrease in kinematic viscosity. The cut-off point of this phenomenon appears in the region of 34 kGy. Terminally inactive radical products can have different chain lengths and bonds. The flow of cross-linked structures with a comparable chemical chain length to that of a linear chain is obstructed by the formation of more physical knots with other chains. If a bifunctional radical is formed on a chain upon initiation phase, it may recombine with two other radicals from two different hydrocarbon chains. This creates a crosslinked structure that does not allow independent movement of the connected chains and thus increases the kinematic viscosity values. In the extreme case, so many crosslinked chains can form difficult-to-see gel particles (so-called gel spot) in the engine oil, which can lead e.g. to clogged the capillary of the viscometer [2].

![Fig. 4 Kinematic viscosity at 100°C](image1)

![Fig. 5 Kinematic viscosity at 40°C](image2)

![Fig. 6 Viscosity index of measured samples](image3)

Infrared spectrometry was used for determining amount of water, bubbles, oxidation and sulfation value and total base number. Infrared oil analyse provides direct quantitative measurement of a lubricant’s properties via IR spectrum of sample. Results of each sample are shown in Fig. 7 to Fig. 11.

Fig. 7 represent number of bubbles in researched samples and Fig. 8 shows amount of water dependence on the absorbed dose. As can be seen from figure, the amount of water is stable after irradiation, independent of absorbed radiation dose. Possible reason is the exposure of the oil to the air humidity, meant by the time of opening the original container to the time of measurement. Non-irradiated sample was measured right after opening the original package.
Oxidation is a reaction between oxygen from the air and engine oil molecules, mostly between oxygen and hydrocarbons. Oil oxidation is supported by temperature. The higher the oil temperature is, the faster the oil oxidizes. Because oxidation is promoted by elevated temperature, there is often talk of thermo-oxidative aging of the oil, in which the oil undergoes certain thermal changes in addition to oxidation. The oil also comes into contact with flue gases, which affect the entire oxidation process. The best known is the nitrination of the oil, which usually accompanies the oxidation. During fuel combustion, the atmospheric nitrogen is converted to nitrogen oxides (NOx), which then come into contact with the engine oil in the flue gas. Nitrination is subsequently occurred due to the action of nitrogen oxides on the oil. The product of nitrination are organic nitrates. Therefore, the measurement of oil nitrination is highly recommended in the engine oil in operation. Oxidation of oil (hydrocarbons) produces a number of oxidation products, such as aldehydes, ketones, acids, esters and others. All these substances have a polar character (as opposed to the non-polar engine oil) and as such also affect the properties of the engine oil. If the oil is depleted by oxidation, its lubricating properties deteriorate. If the extent of oxidation is already greater and the oxidation products gradually accumulate in the oil, they may react with each other and cause an increase in the viscosity of the oil. 

Mentioned factors lead to a deterioration of mainly the low-temperature viscosity characteristics, an increased kinematic viscosity and a deterioration in the pumpability of the oil. Neutralization of alkaline additives in the engine oil leads to the formation of sulphates. As it could be seen, while sulphates have declining trend, the oxidation is raising and kinematic viscosity is decreasing too. It follows that, the oxidation is affected by the air oxygen only. By this fact it is relevant to irradiate engine oils in inert atmosphere. Inert atmosphere will reduce the formation of radicals, as described upper.

Acidic substances are not desirable in combustion engine oil and, in the worst case, can cause severe engine corrosion. Therefore, every combustion engine oil contains alkaline compounds that neutralize the action of acidic substances. The higher the TBN of the oil, the longer it will take to neutralize acidic substances. During oil operation, the acidity increases and at the same time the alkalinity of the oil decreases. In order for the combustion engine oil to function properly and to protect the engine from corrosion in addition to perfect lubrication, it is important that the TBN value is always higher than the TAN value during operation. If the TBN drops below 30%, the oil is usually considered as acidic and need to be replaced.

Total base number changes are shown in Fig. 11. The acidity and alkalinity of engine oils are not very often mentioned properties. Even so, the alkaline reserve and acidity of the oil are very important in assessing its quality and exhaustion during oil - engine operation. Base oils as such are always neutral - neither acidic nor alkaline. However, a certain amount of acidic substances also occurs in the new engine oil. The acidity of new engine oils comes from certain additives which, even because they are slightly acidic, have the properties we require from the additive. Other acidic substances are formed during the operation of the engine and come from the combustion of the fuel and are also
formed in the oil itself during its oxidative degradation. Some sources of acidic substances are the condensation of the moisture in contact with the oil and the acids formed by the reaction of sulphur with moisture.

4. Conclusions

The e-beam accelerator can be used for combustion engine oils properties modification. The influence of container or packaging material of engine oil during irradiation was described as well as radiation depth profile with chemical changes in hydrocarbons, oxidation, water content and total base number [4]. A significant step was reached in the research of combustion engine oil kinematic viscosity, viscosity index, oxidation and TBN. After extended research it is possible to add another method into manufacturing engine oils. By incorporating e-beam irradiation into the oil production process by pre-additivation of the base oil, the adverse effect of potentially increasing oxidation and water concentration could be reduced. In case of confirmation and improvement of positive results, base oils can be physically modified by radiation and subsequently additivated. This one extra step in production can prominently increase the quality and classification of oils as products.

Results of the research can be used for subsequent experiments in which is admissible to examine more tests in the same container, at the same settings and irradiation parameters with vary irradiation doses up to 34 kGy.

Ongoing research is oriented to operating characteristics realization of other kinds of combustion engine oils by e-beam. It is necessary to measure radicals. Information about these high reactive molecules can precisely solve chemical changes that arise. High probability is expecting in modifying stability of kinematic viscosity, viscosity index and alkalinity reserve in combustion engine operation.

Given the value of the viscosity index, 33 and 3.8 kGy appear to be a suitable values of the absorbed radiation dose for further investigation in practice.

It will be necessary to compare the kinematic viscosity stability of a conventional combustion engine oil with an irradiated one during engine operation. Determining the impact of TBN content on mileage will also be a fundamental basis for further studies. TBN is one of many factors influencing the usability of combustion engine oil, the lifetime of rubber parts in the engine, engine overall life, the chemical composition of the flue gas and thus combustion engine emissions.

Acknowledgement

The presented study has been prepared with the support of the Ministry of Defence of the Czech Republic, Partial Project for Institutional Development, K-202, Department of Combat and Special Vehicles of the University of Defence, Brno in cooperation with PROGRESA FINAL SK.

References

Assessment of the State of AtoNs System on the Hazardous Navigation Section of the Dnieper River

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Abstract

The modernization of ports and fairways, as well as the latest progress in science in the elaboration of new processing and the increasing requirements for marine services, make it necessary to dynamically remodel and strengthen the system of aids to navigation. The existing real prospect of an increase in freight traffic served by river transport in Ukraine requires an assessment of the current AtoN system. Knowing the weaknesses and problems of the current system is paramount for the purpose to eliminate it and upgrade services. To achieve this goal, the work analyzed the location of physical floating warning signs and their range of visibility, especially in bad weather conditions. A method was proposed to solve the identified problems in order to achieve European standards to ensure an appropriate level of safety of navigation.

KEYWORDS: AtoN system, safety assessment, shipping

1. Introduction

Reliable aids for navigation are very important for providing a vessel’s safety, efficient operation, and for prevention of environmental disasters. Particular importance has questions concerning reliable, high-precision control over the position of the vessel, especially during navigating in the coastal zone, on approach routes, in narrow channels, and in the port water areas, where the consequences of a vessel accident are constrained with the risk of human casualties, environmental pollution, damage to hydraulic structures, etc.

Requirements for the availability of visual AtoNs (Aids to Navigation) are mandatory on IWW (Inland Waterways). However, in inauspicious weather conditions, especially in low visibility, the level of navigational safety is essentially reduced. Thus, the main goal of the article is to analyze the main parameters of the actual AtoN system on the example of a hazardous dangerous section of the Dnieper River.

The objectives of the study included the following tasks: to determine the meteorological range of visibility on which AtoNs become invisible for the eye of the observer during navigation in the fairway; compare of the obtained data with the requirements for the minimum range of visibility of light in accordance with IALA Recommendations; analyze of the level of safety taking into account location of navigation marks; offering a solution for identifying hazardous areas.

It was taken into account the standards of safety, security, and environment of maritime transport. IALA Standards are issued by the International Maritime Organization (IMO), which encourages innovation and efficiency in practice [1].

2. Research

Regardless of the vessel position changing relative to the navigation mark or lite, AtoN characteristics must remain permanent. The main requirement for the navigation mark is to ensure appropriate visibility of the corresponding purpose both during the day and at night. However, there are situations in maritime practice, particularly, in bad weather conditions, such as fog, when the limited visibility of the navigational safety mark can lead to adverse consequences.

As an example, consider the dangerous section of the navigation area, which is located between Zaporizhzhya HPS and Bilenke village [2]. There are the following hazards on the selected area: limited visibility and insufficient depth, underwater rocks, shoals, rocky bottom, the bridge under construction.

To analyze the safety of the AtoN location, it is necessary to assess the parameters that are standardized for all IALA Member States. One of the most important characteristics of a light signal is its range of visibility, which indicates the maximum distance where light from the buoy is conspicuous. For this purpose in navigation it is used the light range ($D$), which is determined as the maximum detection distance of the light beam, taking into account the meteorological visibility ($V$) and the nominal range ($NR$) required for the observer's eye [3]:

$$D = V \times NR$$
The nominal range (NR) is the maximum distance on which the lite can be seen in meteorological visibility equivalents 1852 meters. The meteorological optical visibility range is related to the transparency of the atmosphere by the following formula [4]:

\[ V = d \log \frac{0.05}{\log T_m}. \]  

(2)

In quantum mechanics the transparency coefficient \( T_m \) is determined by the following formula [5]:

\[ T_m = \exp \left( \frac{2m}{\hbar} \sqrt{2m(E-U)} \right). \]  

(3)

Where \( x_1 \) and \( x_2 \) are turning points at which the total energy \( E \) becomes equal to the potential and the momentum of the particle is zero.

Luminous flux is a quantity measured by the amount of energy emitted by a light source per time unit:

\[ F = \frac{E}{t}. \]  

(4)

The value measured by the amount of energy supplied per unit surface area in one second is called the illuminance (\( E \)), measured in lux. Illumination can be expressed as a function of the meteorological visibility range \( V \) and the distance to the observer (\( d \)) according to Allard’s law [6]:

\[ E(d) = \frac{I \cdot T_m}{d^n}. \]  

(5)

Light intensity (\( I \)) is the magnitude of the flux indicated in a specific course and calculated as the ratio between the luminous flux and the radiation angle and also can be found in accordance with Allard’s law (measured in units of light - candelas):

\[ T_m = \exp \left( \frac{2m}{\hbar} \sqrt{2m(E-U)} \right). \]  

(6)

Based on the foregoing, we will enter the actual illumination generated by each AtoN lite in three different visibility conditions: good, medium, and bad. It is necessary to check the effective visibility of the AtoN using the inequality:

\[ E_d > E_R. \]  

(7)

Calculations were made for AtoNs in the selected area. Obtained dates concerning insufficient results of visibility of lights are summarized in Table.

<table>
<thead>
<tr>
<th>№ buoy</th>
<th>( d ) [km]</th>
<th>( E(d) ) [lx]</th>
<th>( E_R ) [lx]</th>
</tr>
</thead>
<tbody>
<tr>
<td>“114a” r</td>
<td>1.6483</td>
<td>6.2×10^{-11}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“116” r</td>
<td>1.7594</td>
<td>1.03×10^{-11}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“120” r</td>
<td>1.852</td>
<td>2.3×10^{-12}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“130” r</td>
<td>1.0762</td>
<td>7.7×10^{-7}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“151” g</td>
<td>1.2038</td>
<td>9.7×10^{-8}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“157” g</td>
<td>1.6668</td>
<td>5.1×10^{-11}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“161” g</td>
<td>2.4632</td>
<td>1.4×10^{-16}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“165” g</td>
<td>1.6112</td>
<td>1.1×10^{-10}</td>
<td>2×10^{-7}</td>
</tr>
<tr>
<td>“169” g</td>
<td>1.2964</td>
<td>2.2×10^{-8}</td>
<td>2×10^{-7}</td>
</tr>
</tbody>
</table>

Table

AtoNs which illuminance is not appropriate for navigation at night in bad visibility
Illumination of the floating mark must be greater than or equal to the minimum detection range by a navigator. Calculations which were carried out indicate potentially dangerous areas of the fairway, where light of buoys with appropriate transparency of the atmosphere are hardly visible to the observer in night time ($E_r = 2 \times 10^{-7} \text{lx}$).

Fig. 1 shows areas of increased danger, where the visibility range of the AtoNs is insufficient in foggy weather.

![Fig. 1 Potentially dangerous areas for navigation in the fairway](image)

The results are effective in all situations, except for situations with poor visibility, which makes the system insufficiently relevant to provide an appropriate level of security. It was decided that in order to solve this problem, it is necessary to use synthetic and virtual aids to navigation equipment in areas where the visibility of the buoys is limited in bad weather conditions.

3. Conclusions

It can be concluded that the light of the real AtoNs does not provide the possibility of timely detection of the mark at night in fog weather. Thus, the probability to identify navigation marks and avoid danger in time is reduced.

The visibility range of marks must create a continuous zone around the hazard and overlap with each other at least 30%. This requirement will be fulfilled in case of adding virtual AtoNs in hazardous sections for a period of bad weather conditions. Using AIS AtoN messages in conjunction with real buoys can be profitable for both navigators and administrations.

However, it is necessary to consider that some vessels are not sufficient equipped for displaying AIS AtoNs. In addition, the availability and reliability of AIS information cannot be guaranteed in all cases. The usefulness of such a combined solution must be investigated and decided on a case-by-case basis as it depends on the local situation and conditions.

Furthermore, it is necessary to obtain experience regarding the security risk and reliability of the entire system, customized solutions can be implemented locally using synthetic and virtual AIS AtoNs.
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Finding Ways of Building Sustainable Trails Cargo Transportation Using Optimization Methods and Computational Tools

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Abstract

The study is devoted to the search for new approaches to determining the optimal model of cargo transportation in a changing volume of orders from customers. At the same time, the construction of the model takes into account the parameters of production capacity of manufacturers in relation to the volume of orders from customers to gain a competitive advantage. The study of theoretical principles allows to state the existence of certain problems in determining the rational parameters of freight routes. A methodical approach to determining the optimal schemes of cargo transportation uses the principle of network optimization taking into account certain external influences. The components of influence on the general indicator of transport work are defined and characterized. On the example of network optimization problems, namely, when using spreadsheets for mass use of MS Excel, a dynamic model is built that allows you to assess the risks and benefits for the carrier. Schemes of the constructed routes at minimization of operational expenses by the carrier and maximization of benefit for customers are visualized.

KEY WORDS: routing, carry routes, node, flow optimization

1. Introduction

The role of road transport is certainly not exaggerated and freight transportation in its application is described as the most mobile way of delivering goods from the manufacturer to customers. Thanks to the use of vehicles, consumers can receive the ordered goods on time and in the required amount. According to many scientists in pricing in the production of various products, the transport component occupies on average 30%. This is a very important indicator and manufacturers, competing with each other, are trying to find a way to reduce the conditional weight of the transport component in the cost of production. Road transport is playing an increasingly important role due to the advantages, which include: the ability to deliver goods at the appointed time ("just in time"), delivery from the warehouse of the sender to the warehouse of the recipient ("door to door"), excluding intermediate transshipment of goods; high speed of cargo delivery, which reduces the need for working capital and accelerates the capital turnover of manufacturers; the ability to transport small consignments in accordance with the wishes of the consumer [1-3]. In today's economy, the most effective way to organize the rational delivery of goods is the routing of transportation [4]. The correct choice of the required type of transportation route is the key to improving many economic indicators of the enterprise. Routes can be both pendulum, ring and prefabricated. For delivery of small consignments, generally used carry routes, which are types of ring routes [5, 6]. The authors of publications [7] note that the task of routing is extremely important even in comparison with the rational loading of vehicles. Indicators for assessing the effectiveness of the use of certain delivery routes are quite diverse. However, they can be most thoroughly assessed using a set of factors that will help to obtain certain results. These can be technical, operational and economic indicators such as the level and degree of mechanization of loading and unloading operations, the average complexity of the operation, the cost of transportation and profitability of the adopted technology, productivity, unit costs and reliability of results [8].

In the attempt to reduce the cost of the cargo delivery process, the carrier tries to plan efficient routes and choose a rational vehicle that will ensure the stability of the transport system. Regarding the optimality of the parameters of production resources in modeling and determining the level of stability of transport systems, the authors propose to use different efficiency indicators, which allows to qualitatively carry out the process of freight planning, even with the interaction of different modes of transport [9, 10]. The sphere of cargo transportation is quite conflicting. One of the areas of establishing relationships between the cargo owner, carrier and customer is the intersection of vectors of their strategies, which creates an optimal point, which can be guaranteed by creating effective route networks [11, 12].

So, as we can see, there are different opinions about improving the efficiency of the cargo delivery process in different industries. Each case of construction of a route is characterized by the organizational features, but, even under identical conditions of functioning of transport networks, decisions concerning the organization of effective transport process can be various.

2. Presentation of Main Material

Today, the effectiveness of many industries depends on transport. This is especially true of agricultural production, which plays an important role in Ukraine economy. Up to 15% of gross value added is created in this area. Over 30% of
all Ukrainian exports are provided at the expense of agricultural products [13]. Despite the annexation of the Autonomous Republic of Crimea and hostilities in parts of Donetsk and Luhansk regions, as a result of which the area of agricultural land in the country has decreased, the industry maintains a positive dynamics of development. Therefore, it is very important to provide logistical support to intensively developing industries. One of the options for providing such support is to increase the efficiency of transportation of agricultural products by optimizing routes in the direction of reducing the time lag of its delivery and cost. As you know, the tasks of transportation routing include determining the set of points included in the route, and the optimal sequence of detours of these points, while achieving the principles of minimizing the cost, distance and time of transportation using modern information systems [14, 15]. This can be done with modern software, which in many cases is very expensive. Given its significant cost, the task of finding other ways to justify the optimal transportation routes is relevant.

One of the ways to solve complex transport problems is to use MS Excel. In [16] the example of modeling of practical optimization problems, in particular the solution of the problem "Salesman" in MS Excel is considered. But certain restrictions on the number of 10 points, with a much larger number of customers, are accompanied by the search for additional ranking methods, which greatly complicates the modeling process. Therefore, there is an urgent need to solve modern problems of cargo transportation using precise methods, but without requiring significant resources to find a rational route of transportation. One of such ways is application of models of stream optimization by means of MS Excel.

The methodological approach presented in [17-20] gives grounds to determine that in some practical situations for planning various processes, in particular transport, for clarity it is convenient to use schemes (graphs), which consist of nodes and arcs and can determine certain connections, and characteristic assessments. In the directional graph, the arcs have the form of arrows that show the direction of communication between the nodes. An oriented graph with weighted arcs is called a network, and it in turn gives a clear idea of the solution of transport problems with supply nodes, consumer nodes and intermediate nodes, where the directed arcs in the form of arrows between them determine possible routes.

Using this methodological approach, consider an example of creating optimal routes for the transportation of agricultural products, namely feed to customers in the regional connection. When planning the process of creating routes, we set the following parameters: 2 large enterprises for the production of feed and 3 small, with which you can add the required amount of feed when transporting it to the customer. Also, accordingly, we specify that there are 13 customers whose order volumes are known. The first way to find the optimal route is to determine the distances between delivery points. To distribute between feed delivery points, it is necessary to determine the coordinates of the points and the corresponding lengths between them. The author suggested using the MS Excel package for this purpose. To determine the coordinates of points (nodes of the transport network) on the map is formed a rectangular coordinate system, where the horizontal axis X is determined by column numbers, and the vertical axis Y - row numbers. Having the coordinates of the points (in the cells), calculate the distances between certain pairs of nodes according to the rules of the Pythagorean theorem (on the line connecting them) and knowing the size of the map and PC monitor screen (cm) and map scale (km / cm), in this coordinate system it is approximate to calculate the distances between pairs of points in km [17]. After these procedures, an array of data is formed that can be used for further calculations.

According to the authors [17-20], flow models are built on the principle of preserving the flow in the node, according to which the output flow takes into account the input and potential of the node. The principle is implemented in procedures, an array of data is formed that can be used for further calculations. The methodological approach presented in [17-20] gives grounds to determine that in some practical situations for planning various processes, in particular transport, for clarity it is convenient to use schemes (graphs), which consist of nodes and arcs and can determine certain connections, and characteristic assessments. In the directional graph, the arcs have the form of arrows that show the direction of communication between the nodes. An oriented graph with weighted arcs is called a network, and it in turn gives a clear idea of the solution of transport problems with supply nodes, consumer nodes and intermediate nodes, where the directed arcs in the form of arrows between them determine possible routes.

With restrictions for nodes: \( p(i) = j \), \( \sum_{k(i) = j} x_k \leq \pi_j \), for node 12 (Resurrection) are as follows:

\[
x_{12} = d_1 x_1 + d_2 x_2 + \ldots + d_{15} x_{15} \rightarrow \min.
\]

With restrictions for nodes:

\[
\sum_{p(i) = j} x_i - \sum_{k(i) = j} x_k \leq \pi_j
\]

for node 12 (Resurrection) are as follows:

\[
\sum_{p(i) = j} x_i - \sum_{k(i) = j} x_k \leq \pi_{12} \Rightarrow (x_{26} + x_{27} + x_{28} + x_{29}) \geq (x_{15} + x_{22}) \leq 1.
\]

(1)
Here is an explanation of the formation and computer implementation of restrictions on the example of the node Voskresenske. The node Voskresenske in the list has №12, the potential of the node (1, offer), this node includes 2 arcs from the nodes Nova Kakhovka (arc №15) and Knyazivka (arc №22), because the ends of only these arcs are called Voskresenske; 4 arcs go from the Voskresenske node to Mykhailivka (arc №26), Vozsiyatske (arc №27), Stantsiine (arc №28) and Snihurivka (arc №29), only the beginnings of these arcs are called Voskresenske (Table).

Consider the implementation of the problem in MS Excel.

\[ = \text{SUMMIF} (\text{Ends}; \text{Node}; \text{Threads}) - \text{SUMMIF} (\text{Beginnings}; \text{Node}; \text{Threads}) \leq \text{Potential}. \]

The result after the calculations:

\[ (x_{AB} + x_{BC} + x_{AC}) - (x_{MB} + x_{MB}) \leq \sigma_B (3 + 0 + 0 + 0) - (0 + 2) = 1. \]  

In the table for nodes (Fig. 2, a) we enter in random order the names of nodes (settlements) and their potentials: with a minus – demand, with a plus – supply (this is the right part of the restrictions). Immediately using the SUMMIF (range; condition) we determine the sum of supply and demand, because the problem has a solution when the sum of supply is not less than the sum of demand. We enter headings and we pass to formation of the table for arcs. 

In the table for arcs (Fig. 2, b) you need to enter the names of the beginning and end of each arc, as well as the length of these arcs. Enter the headings of other columns, determine the range of searched unknowns – Stream (X), calculate the values of values \( (d, x) \) and their sum (OF). After that in the table for nodes it is possible to specify restrictions, using function for input streams: \( = \text{SUMMIF} (\text{Ends}; \text{Node}; \text{Threads}) \), for source streams: \( = \text{SUMMIF} (\text{Beginnings}; \text{Node}; \text{Threads}) \). Next, determine the difference between Input-Output (this is the left part of the constraints) and the remainder (Demand / Supply – Input/Output).
Using the "Solver" command in the "Data" menu of MS Excel, specifying certain restrictions, namely $I3\leq I37$ = whole; $I3\leq I37 \geq 0$; $Q3\leq Q20 \leq N3\leq N20$ and the parameters sought to determine the objective function, we obtain the solution of the problem (Fig. 3). It is determined that the optimal transportation plan corresponds to the minimum total transport costs of 5631.88, which are presented in the form of transport work.
The obtained transportation plan is optimal, because the overall indicator of transport work to meet demand is minimal according to the given initial data. The introduction of additional restrictions can take into account certain external influences on the organization of transportation, for example, to impose restrictions on the capacity of arcs, variable demand, fluctuations in production, and so on.

This method does not guarantee the optimal order of detour points within the route. Therefore, after receiving the delivery and assembly routes, it is necessary for each of them to solve the problem of optimal detour of points in the route in order to reduce the total mileage on the route. One of the simplest approximate methods for solving the problem of rational detour of points in the route is the known method of sums. As a result of calculations we receive optimum routes with a certain order of detour of points (Fig. 4).

3. Conclusions

The solution of the optimization multi-stage transport problem using linear programming allows to distribute the volume of feed delivery to customers under load at two main production plants and three auxiliary, the total production of which meets the demand from customers. According to the conditions of the problem, the production units, auxiliary small productions, customers and arcs that characterize the length between the points are identified. The minimum value of the target function is obtained, namely 5631.88, which characterizes the optimally performed transport work when transporting feed to customers.

It is proved that the implementation in practice of this approach to optimize the multi-stage transport problem allows to solve complex problems of forming routes of transportation of agricultural products, with the location of enterprises of different productivity and customers in an extensive network. The use of compound routes allows you to dynamically assess the process of delivery of the necessary orders with changing demand for products and different production volumes at different enterprises.

References

519


Analysis of Possibilities of Integrating Cargo Bikes into Urban Space

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Abstract

The paper analyses current various ways of use cargo bikes and defines the resulting demands on urban planning. Although the infrastructure for cycling has been developing successfully in recent years, the existing infrastructure does not always meet the specific needs of cargo bikes (e.g. parameters of clearance profile, parking space). The requirements of different groups of cargo bike users may also vary, e.g. depending on the cargo bike type used. When the cargo bikes use common infrastructure with other transport means, it can affect the traffic flow in cities, both in terms of safety and capacity. Based on the analysis, the article defines the possibilities for sustainable integration of cargo bikes into the urban space.

KEY WORDS: cargo bike, traffic flows, urban planning, sustainable transport

1. Introduction

Cargo bikes have gained popularity in recent years in both the commercial and private spheres, especially in Europe and North America. They are mainly used as an alternative transport mode which complements car transport. Exploiting the potential of cargo bikes in an optimal way can contribute to sustainable urban mobility. The reduction of emissions and savings of fossil fuels are the main benefits. Initial surveys suggest that during the Covid 19 pandemic, there has been an increase in interest in cycling including the use of cargo bikes, especially for delivery purposes [6, 15].

Some research studies show that the cargo bike can be more time-efficient than a car in densely populated agglomerations under optimal conditions [3, 9]. Setting the right conditions is crucial, as the movement of cargo bikes in regular traffic can also have negative effects, such as congestions and traffic safety deterioration.

The article focuses on defining the factors influencing the integration of cargo bikes into urban space. The number and structure of cargo bike users are expanding along with the availability of different types of cargo bikes. The behavior of these users in traffic can affect the traffic flow in the city to varying degrees. Each user may have different preferences, which also depend on local conditions. as shown in [2, 7, 13]. E.g. the courier service will prefer faster routes and bikes with larger capacities. In contrast, a parent who takes a child to kindergarten is likely to choose the safest possible route and bike. Based on the analysis, this article specifies also the influence of the cycle traffic with cargo bikes on the capacity and traffic safety in urban space.

2. Analysis of Users of Cargo Bikes

Users of cargo bikes can be divided into two main groups - commercial users and private users. Both of these groups can be divided into subgroups of users who share certain common features. The group of commercial users includes:

- courier service providers (mail and parcel delivery);
- delivery services (e.g. food, groceries, flowers);
- specific delivery services (e.g. blood samples);
- mobile sales;
- municipal waste collection.

The main goal for courier and delivery services is to serve a given number of customers as quickly as possible. In this case, the couriers move in regular traffic. They can use cycle paths and roads together with motorized vehicles. Delivery routes can be predetermined in the case of serving a constant group of customers in a given area. When the group of customers is variable, it is possible to use software applications for dynamic route planning. [10, 14].

Commercial cyclists have very limited possibility to adapt the route and timing of the ride to current conditions, such as weather or traffic. Because of this, e.g., it may happen that the commercial cyclist may be at increased risk of collisions and injury during peak-times of traffic [5]. Mobile bicycle shops are usually moved to the point of sale in the morning, where they offer their services during the day and they return to the home depot after the sale ends. They can also change the point of sale during the day. Therefore, they move for a shorter time in regular traffic, partly at peak times. Cargo bike for mobile sale often has a unique shape and dimensions and, depending on the type of load, can move more slowly, which can also affect the traffic flows. Waste collection service usually uses predetermined routes with predetermined points of service, which are served in given times. In this case, it is possible to schedule the system
to avoid peak times of traffic.

_Private users_ use cargo bikes:
- for the transport of children (to kindergarten, school, leisure activities…);
- for shopping (food and consumer goods);
- as a transport mean for people with reduced mobility.

What all private users have in common is that they can easily choose another mode of transport in case of unfavourable conditions (e.g. weather). The user who takes children to kindergarten is likely to prefer the safest possible routes. The timing of the ride depends on the purpose of the trip (e.g. school times) and it is therefore not always possible to avoid peak-times of traffic. It is difficult to generalize the preferences of users who use cargo bikes for shopping. In this case, the experience and personality of the cyclist will be largely decisive. These users have a very good possibility to plan a ride outside of peak-times of traffic. The group of people with reduced mobility is relatively diverse [8] and can use the cargo bike as a means of transport, but also for shopping. This group of users will pay attention to safety and will move slowly. At the same time, this group of users has a very good possibility to plan its ride according to current conditions. A specific group of cargo bike operators/users consists of providers of cargo bike sharing systems and cargo bike rental systems.

3. Cargo Bike Choosing Criteria and Variants

3.1. Criteria

The commercial operator of a cargo bike system can use multi-criteria analysis for selecting a suitable bike. The goal is to select a suitable cargo bike type based on a predefined service model. The private user also usually assesses the variants according to the selected criteria, but the evaluation is mostly intuitive. The procedure for evaluating variants is given by the following steps:

**STEP 1:** Setting the goal → selection of a suitable type of bike.

**STEP 2:** Determining the set of variants \( X = \{X_1, X_2, \ldots, X_n\} \) → available types of cargo bikes (including the possibility of customization).

**Simplifying the set of criteria** \( Y = \{Y_1, Y_2, \ldots, Y_k\} \) → cargo bike requirements.

**STEP 3:** Partial evaluation of all variants (sorting) according to individual criteria.

**STEP 4:** Aggregation of partial evaluations into the final overall evaluation and selection of the optimal variant.

The advantage of this approach is the possibility to consider the weight of individual criteria. Based on the analysis of user groups, we determined a set of criteria that can influence the selection of the cargo bike for all user groups (Table 1).

<table>
<thead>
<tr>
<th>Group of criteria</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic</td>
<td>Initial investment.</td>
</tr>
<tr>
<td></td>
<td>Method of purchasing the bike (cash, instalments, leasing…).</td>
</tr>
<tr>
<td></td>
<td>Energy consumption of e-bikes.</td>
</tr>
<tr>
<td></td>
<td>Operating costs (e.g. maintenance and repairs, battery replacement).</td>
</tr>
<tr>
<td>Cargo bike parameters (dimensions, load capacity, weight, number of wheels).</td>
<td></td>
</tr>
<tr>
<td>Drive ability (stability, manoeuvrability, steering control…).</td>
<td></td>
</tr>
<tr>
<td>Steering design (gears, brakes, handlebars…).</td>
<td></td>
</tr>
<tr>
<td>Drive type (mechanical or electric).</td>
<td></td>
</tr>
<tr>
<td>Lifespan.</td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td>Availability of service (maintenance and repairs).</td>
</tr>
<tr>
<td></td>
<td>Driving distance on one charge for e-bikes.</td>
</tr>
<tr>
<td></td>
<td>Resistance to damage (e.g. due to weather conditions, driving on uneven surface…).</td>
</tr>
<tr>
<td></td>
<td>Operating characteristics (operating conditions, routes…).</td>
</tr>
<tr>
<td>Transportation</td>
<td>Cargo bike design (location of cargo space, weather protection…).</td>
</tr>
<tr>
<td></td>
<td>Cargo type.</td>
</tr>
<tr>
<td></td>
<td>Dimensions and volume of cargo space.</td>
</tr>
<tr>
<td></td>
<td>Ergonomics.</td>
</tr>
<tr>
<td></td>
<td>Possibility to secure cargo and bike against theft.</td>
</tr>
<tr>
<td>Logistic</td>
<td>Specific requirements arising from the purpose for which the bicycle is used (e.g. thermal insulation for food distribution, fitting of safety belts for passenger transport…).</td>
</tr>
<tr>
<td></td>
<td>Used transport unit (dimensions, shape and storability).</td>
</tr>
<tr>
<td></td>
<td>Parking options.</td>
</tr>
<tr>
<td></td>
<td>Equipment with navigation and tracking systems.</td>
</tr>
<tr>
<td>Legislation</td>
<td>Legislation terms and regulations (e.g. e-bike definition in legislation, maximum speed…).</td>
</tr>
<tr>
<td></td>
<td>Fees and exemption from certain fees (e.g. taxes, insurance, fees required by the municipality…).</td>
</tr>
</tbody>
</table>

Table 1

Set of criteria for select a suitable cargo bike
3.2. Variants

The offer of various cargo bike types on the market is currently relatively wide with good possibilities for the production of custom-made bikes. The load capacity of the cargo bike is up to 300 kg. The width ranges from 60 cm for a two-wheel cargo bike to approx. 100 cm for a multi-wheel cargo bike. Two- and three-wheel variants are available with both electric and mechanical drives. For multi-wheel variants, the electric motor is standard equipment. Table 2 summarizes the most common types of cargo bikes and their properties that may affect their integration into urban space [1, 4].

<table>
<thead>
<tr>
<th>Cargo bike design</th>
<th>Suitable especially for</th>
<th>Drive ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of wheels</td>
<td>Cargo space</td>
<td></td>
</tr>
<tr>
<td>two</td>
<td>front and rear</td>
<td>private users, courier and delivery services</td>
</tr>
<tr>
<td></td>
<td>front</td>
<td>courier services, specific delivery services</td>
</tr>
<tr>
<td></td>
<td>rear</td>
<td>courier services</td>
</tr>
<tr>
<td>three</td>
<td>front</td>
<td>private users, mobile sales, specific delivery services</td>
</tr>
<tr>
<td></td>
<td>rear</td>
<td>courier and delivery services, mobile sales, people with reduced mobility</td>
</tr>
<tr>
<td>four</td>
<td>rear</td>
<td>courier and delivery services, mobile sales, people with reduced mobility</td>
</tr>
<tr>
<td>multi-wheel</td>
<td>rear (trailer)</td>
<td>courier services, waste collection</td>
</tr>
</tbody>
</table>

4. Integration of Cargo Bikes into the Urban Space

4.1. The Impact of Cycle Traffic with Cargo Bikes on the Safety and Traffic Flows

The design and size of cargo bikes, especially their width, can significantly influence the possibility to use standard cycle paths. This could be a limiting factor for using a cargo bike in so-called associated transport space (space for pedestrians and cyclists).

Many cities in the Czech Republic are already actively applying a strategy for the integration of bicycle transport into the transport system. However, the infrastructure they build respects the needs of standard passenger bicycle transport. The width of the lanes for cyclists is often at the limit of the minimum possible width even due to the insufficient width of the street space. The infrastructure in the associated space is therefore accessible to cargo bikes with a small to medium capacity, i.e. bikes with two, or three wheels. Separate paths for cyclists with two-way traffic are the exceptions. But this type of path is rare in continuously built-up areas in the Czech Republic.

Large cargo bikes will thus mainly move in the main transport space (space for motorized transport), where they can use the infrastructure for cyclists. But their driving profile in many cases will exceed the width of the protective or reserved lanes. The width of cargo bikes can therefore be the cause of the "reluctance" to accept them by other users of the main transport space.

In the Czech Republic, there are currently ongoing discussions on the safety of bicycle operations in the main transport space. On 14 April 2021, after some postponements, the Czech Chamber of Deputies voted for an important change in the rules for overtaking cyclists. The law, which regulates the traffic rules on roads, proposes a more precise definition of the safe lateral distance when overtaking a cyclist. Safe lateral distance when overtaking a cyclist means the distance between the nearest edges of the motor vehicle, trailer or load and the bicycle, bike trailer or cyclist. If this proposal goes through other legislative steps, drivers will have to maintain a lateral distance of at least 1.5 meters between the car and the bike. A minimum safety distance of 1 meter will apply in sections with the permitted maximum speed of 30 km/h. The Czech Republic will thus join other countries where this rule is already regulated by law. Safety distances are specifically set by law e.g. in Germany, France, Spain, Portugal or Belgium. The police control and enforce the safe distance even in countries where it is not precisely defined, such as the United Kingdom.

The concern about the flow of road traffic is a frequent objection to approving this distance. In the built-up area, the width of the road of two-way roads with low traffic is 5.5 meters, but often 6.5 meters or more. Narrowing the road...
to the minimum possible width is also a consequence of traffic-calming measures, especially where parking lanes are a part of the main transport space. Even so, two cars can pass by (avoid) on all two-way roads. There is therefore a presumption that it is possible to overtake a cyclist on these roads, even on a cargo bike. The width of cargo bike is usually up to 1 m. The width of the standard lane should be enough for overtaking, or the vehicle driver can also cross into the opposite lane when overtaking. Quite exceptionally, it is also possible to design a two-way road with a width of 3.5 meters, e.g. in residential areas. On these roads, vehicles can pass by each other only in points designated for this purpose (every 80 to 100 meters). The speed on such roads is usually limited to the maximum permitted speed of 30 km/h, which is already very close to the speed of cyclists. Even here, however, overtaking a cyclist on a truck should be possible.

Table 3 shows the differences in the passage times of road sections of a certain length when the speed of the vehicle is reduced and the cyclist cannot be safely overtaken. These values show that possible slowdown has no significant effect on travel time or on the flow of road traffic.

### Table 3

<table>
<thead>
<tr>
<th>Speed reduction [km.h⁻¹]</th>
<th>Difference in the passage time according to length of road sections [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 m</td>
</tr>
<tr>
<td>from 50 to 30</td>
<td>0,48</td>
</tr>
<tr>
<td>from 50 to 20</td>
<td>1,08</td>
</tr>
<tr>
<td>from 50 to 10</td>
<td>2,88</td>
</tr>
<tr>
<td>from 30 to 20</td>
<td>0,6</td>
</tr>
<tr>
<td>from 30 to 10</td>
<td>2,4</td>
</tr>
</tbody>
</table>

When assessing travel time and traffic flow, it is also necessary to consider other factors that affect the traffic flow, or causes the effect of the congestions. These factors include e.g. preference for pedestrians at crosswalks or delays at intersections.

### 4.2 The Impact of Cycle Traffic with Cargo Bikes on the Capacity

The design of intersections and sections between intersections is to be solved as a whole in terms of safety and usability of the infrastructure for cyclists. In particular, the spatial possibilities of intersections will influence, and usually predetermine, the possibilities of designing the sections between intersections.

In the Czech Republic, calculations of intersection capacities are regulated by the methodology published in the so-called Technical Conditions [11]. However, they do not currently sufficiently cover the impact of cyclist traffic. For all types of intersections, the composition of traffic flows is considered by recalculating individual types of vehicles (including bicycles) into unit (recalculated) vehicles. The question is whether the current coefficients are also applicable to cargo bikes. For uncontrolled intersections and small roundabouts, the further consideration of cycle traffic, on the capacity of the junction already depends on the individual solver. This can reflect the cycle traffic in the parameters that affect the capacity of intersections, especially within the gaps in the superior and subordinate traffic flows. For intersections controlled by traffic lights, the cycle traffic is considered by determining the so-called split times, i.e. the intervals from the end of the green-light time on the traffic light for one direction to the beginning the green-light time on the traffic light for the direction in collision course. In the case of gaps, parameters depend on the subordinate traffic flows, and in the case of split times, indirectly on the possible start-up or acceleration of the vehicle. It is important to note that in the case that cycling integration measures are not implemented on the road, cyclists must be allowed to move in intersections in joint traffic with other vehicles. Cycle traffic at intersections is regulated by Technical Conditions “TP 179 Design of Roads for Cyclists” [12].

In the case of uncontrolled intersections or junctions, it is appropriate to implement cycling measures primarily for the direct direction, or and other directions that need to be preferred with regard to the cycling routes. These are mainly the "Pictograms corridor for cyclists", a protective or reserved lane for cyclists, a separate shift lane, etc. These measures do not depend on whether they are used by cyclists on passenger or cargo bikes. Properly implemented, these measures can significantly increase traffic safety at an intersection. In superior traffic flows, these measures do not usually affect the capacity of the intersection. These measures can be similar to turn- and through lanes for other vehicles in the assessment of the capacity of individual entrances. At larger intersections, the lower speed of cyclists in superior traffic flows may affect the usability of gaps in superior traffic flows. In the case of absence of any measures for cyclists (vehicles should not overtake cyclists or ride with them at the same time), thanks to the lower speed of cyclists, these gaps will increase. This will increase their usability for vehicles from subordinate traffic flows. Conversely, when using measures, cyclists may ride and overtake at the same time. The gaps in the superior traffic flows will thus decrease with higher intensity of cyclists.

The Technical Conditions “TP 179” [12] recommend the construction of smaller and more compact roundabouts...
in municipalities with regard to the safety of cyclists. If cyclists move in the main transport space, they do not have a significant effect on the capacity of mini and small roundabouts with an outer diameter up to about 30 m. Bikes usually move at roundabouts at a comparable speed as motor vehicles. Other vehicles move on a roundabout behind bikes, so it does not depend on whether it is a passenger or cargo bike. Roundabouts with an outer diameter above approx. 30 m, small roundabouts with a traffic intensity of more than 10,000 vehicles / 24 hours or with a higher share of buses and trucks in the traffic flow, turbo roundabouts and roundabouts with more lanes at the entrance and the circuit are not suitable for guiding cyclists in the main traffic area with regard to traffic safety. If cyclists move in an associated transport space, they may affect the capacity of the intersection if a separate cycle path is connected to the roundabout. The inclusion of another entrance to the intersection will create additional collision points in the intersection, which will affect the size of critical gaps. In certain cases, the capacity of the intersection may be reduced, especially at the previous and subsequent entrances to the intersection.

In the case of intersections controlled by traffic lights, the different speeds and nature of the movement of bicycles and motor vehicles may give rise to requirements for partial or more extensive modifications to take account of cycling traffic, especially at larger junctions. It can be either the creation of separate measures for bicycles or the adjustment of the control of traffic lights and split times for movement in common traffic, etc., depending on the needs of a given intersection. Due to the lower speed of cyclists, the cycle traffic at larger intersections can increase the split times and thus reduce the capacity of the intersection. For this reason, it is appropriate to consider such measures as separate bicycle traffic lights at the entrance to the intersection or an internal transverse line connected to the signal in the area of the intersection, which will allow to shorten the necessary split times. However, cycling measures that are implemented "inside" such large intersections must respect the size of the bicycle, in this case also the length. This could create a problem for cargo bikes and make it impossible to use such measures.

5. Conclusions

It follows from the above that the size of the bike does not affect the capacity of the intersection, except for measures "inside" the intersection controlled by a traffic light. It does not matter whether the cyclist moves on the standard or cargo bike at the intersection. However, capacity can be affected by bike speed. This depends on the cyclist's behavior, but also on the load on the cargo bike and its design. Therefore, not only the dimensions of cargo bike (the possibility of using it in associated transport space) but also its operating parameters (speed, acceleration) are important for choosing a suitable cargo bike with regard to traffic flows in urban areas.

References

Risk Assessment in Glider Flights as a Stage of Developing an Integrated Safety Management Method in General Aviation

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Abstract

Gliding is very often a first step in the aviation career of many pilots. On the one hand, there are many incidents caused by the poor experience of young pilots, on the other hand there is also a routine of experienced instructors, that causes unwanted events. Thus, risk management should be available and commonly used by all pilots, regarding age and skills. The article presents a risk assessment in a model glider flight. On the basis of European and Polish regulations, aviation incidents reports and interviews with sailplane pilots, the list of hazard sources was created. Hazards were identified and areas requiring special attention were indicated. Based on the following analyses, a risk assessment method, common to all General Aviation flights will be constructed.

KEY WORDS: risk assessment, General Aviation, gliders

1. Introduction

A glider is a special kind of aircraft that has no engine, thus there are only three forces acting on it: lift, drag and weight. To generate lift, the glider has to move through the air. In order to fly, it trades altitude for velocity. According to very efficient construction and using thermals during flight, the glider can stay aloft for hours. However, it requires great skill and experience from the pilot. In order to confirm his abilities, the sailplane pilot has to get a license, that is issued by the Civil Aviation Authority (CAA). There have been three categories of licenses in Poland since 2011: Light Aircraft Pilot License (Sailplane) – LAPL(S), Sailplane Pilot License – SPL and Pilot License (Glider) – PL(G). The PL(G) licenses expired in 2015 [12, 13]. Nowadays, only LAPL(S) and SPL are in use. The main difference between them is that the SPL makes it possible to fly for renumeration. The number of all sailplane pilot valid licenses together is increasing steadily (Fig. 1).

Fig. 1 Number of valid sailplane pilot licenses in Poland from 2011 to 2018 [own study based on 12]

With a growing number of airspace users, the risk assessment of sailplane flights is needed to be carried out, in order to provide an acceptable risk levels. The area of the analysis consists of the model pilot flying single form model aerodrome with SZD-50-3 Puchacz sailplane. Gliders are a wide group of aircraft differing in construction, lifting surface characteristics and take-off possibilities. There are several types of gliders: hang gliders, trikes (motorized hang gliders), paragliders, powered paragliders and sailplanes. Flying each of them requires a separate licenses and different skills. For the purpose of the article a glider is considered a sailplane. Another part of the gliders group will be analyzed in further research.
2. The Description of the Analysed Area

2.1. Pilot’s Characteristic

For the needs of the article, it was assumed that the aircraft is controlled by a model pilot. He is a man between 25 and 35 of age, has a valid Sailplane Pilot License (SPL). The choice is justified by the Polish Civil Aviation Authority (CAA) statistics, according to which over 90% of valid licenses belong to men (Fig. 2).

![Gender Distribution of Valid Sailplane Pilot Licenses](image)

**Fig. 2 Number of valid sailplane pilot licenses by gender in 2018 [own study based on 12]**

The privilege of the holder of an SPL is to act as Pilot-in-Command (PIC) on sailplanes. The sailplane license is very often the first step into flying, even before airplanes. Many of the airline transport pilots continue flying sailplanes during their commercial career and even when they are retired. This allows maintaining habits needed in emergency situations, when the pilot cannot rely on flight supporting systems. It is assumed that the model pilot has basic knowledge of aviation law, human capabilities and limitations, meteorology, communications, flight rules, operational procedures, navigation and general knowledge of the glider. After obtaining the license, he made over 30 starts as a PIC, so he can carry passengers [1]. He is authorized to winch launch and car launch. Additionally, the pilot has got an aerobatic rating possible to achieve after at least 40 hours of flight time and a radio correspondence certificate. The pilot is familiar with the aircraft flight manual (AFM). All the documents needed for the flight are in paper form.

2.2. Glider’s Characteristic

SZD-50-3 Puchacz (Fig. 3) is two-place, high-wing training aircraft made of composite. Half-shell wings, with a girder, are also made of sandwich composite. Single plate aerodynamic brakes on the upper and lower surface of the sash. In the model, the monorail chassis consists of three wheels (main wheel suspension, front wheel and tail skid). Pusher rudder drives, automatically connected [8]. The sailplane is used in aeroclub. Has a CoFa certificate of airworthiness and valid Airworthiness Review Certificate (ARC). Also, a valid radio license. It’s got 3000 h flight time. Due to its construction, SZD-50-3 Puchacz is prone to stalling, which is important when making turns during the approach to landing. It also has very effective aerodynamic brakes. They should not be removed too early, especially during the 4th turn of the airport circle. The glider is equipped with one instrument panel, located in the front cabin. On the board there are: speedometer, gyrometer, variometer, altimeter and compass. The upper edge of the instrument panel is used to assess the position of the glider relative to the horizon and the towing aircraft [4]. The aircraft is insured.

![SZD-50-3 Puchacz Sailplane](image)

**Fig. 3 SZD-50-3 Puchacz sailplane**

2.3. Environmental Situation

There are several types of air operations that can be performed on sailplanes. These include commercial
operations, competition flights, introductory flights, cross-country, flying display and aerobatic flights. For the purposes of the analysis, the considered area was narrowed down to cross-country flight understood as flight between a point of departure and a point of arrival following a pre-planned route, using standard navigation procedures. [1]. The analyzed flight takes place during the day [3]. A pre-flight check took place with all pilots to fly at the airport that day. Aerodrome Flight Information Service (AFIS) is provided at the model aerodrome. A grass runway length is 1000 m and width 150 m. The aeroclub holds Approved Training Organization (ATO) certificate.

3. Risk Assessment

3.1. Hazard Sources’ Identification

The article focuses on risk assessment as a connection of risk analysis, estimation and evaluation. There are many methods of risk assessment [2, 5]. One of them is Risk Score in which, the risk is estimated in four steps, based on three parameters \( r_1, r_2, r_3 \). The steps are:
1) Characteristic of the hazard area;
2) The identified hazards’ list;
3) Risk estimation (based on 1):

\[
R(z_i) = \prod_{k=1}^{3} r_k(z_i),
\]

where \( r_1 \) – risk component corresponding to the criterion of damage resulting from the hazard activation \( (S) \); \( r_2 \) – risk component corresponding to the probability criterion \( (P) \); \( r_3 \) – risk component corresponding to the exposure criterion \( (E) \).

4) Risk evaluation.

The characteristic of the hazard area was described in chapter 2 of this article. In order to obtain hazards list, information on hazards \( (H) \) and hazard sources \( (HS) \) during flight has to be collected. To do so, among others: engineering knowledge, brainstorming technique, conclusions from State Commission on Aircraft Accidents Investigation reports and sailplane flight instructions were used [4, 10]. To make a checklist, the analysed area was divided into several groups in order to make it clear and easier to analyse. It was assumed that the question groups of the hazard sources checklist about the occurrence of hazard sources are:
1) The pilot;
2) Aircraft’s technical state;
3) Environment;
4) Airspace and Air Traffic Services.

The source of hazards during the flight may be influenced by: the pilot (questions 1-45), which are marked orange; the sailplane (questions 46-61) which are marked blue; the environment (questions 62-81) – marked green, as well as airspace (questions 82-91) – marked purple. In total, 91 questions checklist was developed. Answers marked with some colour means, that if the answer (marked “✓”) coincide with the colour, hazard source occurs. It is assumed that the flight takes place in polish airspace. The check list for the selected area of analysis is presented in Table 1.

Table 1

<table>
<thead>
<tr>
<th>Question</th>
<th>Hazard Source</th>
<th>Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>37. Is it possible that the pilot is younger than 16 years old?</td>
<td>✚</td>
<td></td>
</tr>
<tr>
<td>40. Is it possible that the weather forecast wasn’t checked?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>41. Is it certain that the pilot knows the flight instruction of aerodrome?</td>
<td>✚</td>
<td></td>
</tr>
<tr>
<td>50. Is it certain that the sailplane is equipped in a radio?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>51. Is it certain that the sailplane is equipped in a transponder?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>61. Is it possible that the tow rope is not firmly mounted?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>62. Is it certain that there is always a place to land safely in the casual area?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>68. Is it certain that there will be no cross-wind during descent?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>78. Can there be an unmanned aerial vehicle flying nearby?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>79. Is it possible that the duty instructor has little experience?</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>85. Is vertical separation provided in the flight area?</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
The identification of hazard sources was based on a list of control questions. This was done by highlighting the answers to individual questions contained in it. Out of 91 questions in the checklist, 68 answers coincided with the “color square”. It means that 68 hazard sources were identified in the area of the analysis. Selected hazard sources are presented in Table 2.

### Table 2

<table>
<thead>
<tr>
<th>Nm.</th>
<th>Hazard sources description</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>Exceeded launching speed</td>
</tr>
<tr>
<td>70</td>
<td>Runway incursion (people, animals)</td>
</tr>
<tr>
<td>30</td>
<td>No habits caused by the constant repetition of aviation activities</td>
</tr>
<tr>
<td>59</td>
<td>Breaking the towing line down</td>
</tr>
<tr>
<td>76</td>
<td>Unmanned Aerial Vehicle collision with a sailplane</td>
</tr>
<tr>
<td>62</td>
<td>Pilot blinded by the sun</td>
</tr>
<tr>
<td>3</td>
<td>Lack of attention due to fatigue</td>
</tr>
<tr>
<td>6</td>
<td>Lack of attention due to alcohol presence in the body</td>
</tr>
<tr>
<td>87</td>
<td>Controlled zone incursion</td>
</tr>
</tbody>
</table>

Hazard sources were analyzed and on that basis hazards and unwanted events could be indicated.

### 3.2. Hazards Recognitions

According to the risk management algorithm, after identifying the hazard sources, they should be assigned to the hazards they generate. Individual hazard can come only from one or from several sources. When they occur simultaneously, it is enough to have one source to activate the hazard. Identification of some hazards is presented at Table 3.

### Table 3

<table>
<thead>
<tr>
<th>Hazard sources</th>
<th>Hazards</th>
<th>Unwanted events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid or sudden use of muscle strength &lt;5&gt;</td>
<td>Hazard of hitting objects in the cabin</td>
<td>Limbs fractures, tendon rupture, bruises, cuts</td>
</tr>
<tr>
<td>Lack of attention due to alcohol presence in the body &lt;6&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrectly fastened parachute &lt;12&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change flight parameters as a result of unwitting action &lt;22&gt;</td>
<td>Hazard of the pilot falling out of the cabin</td>
<td>External and/ or internal injuries, death</td>
</tr>
<tr>
<td>Not fastened seatbelts &lt;23&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damage to the pilot or part of the glider by unsecure objects &lt;26&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inaccuracy caused by rush &lt;39&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot’s seat backrest protection is broken &lt;52&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Components incorrectly mounted &lt;57&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The handle for opening the parachute is blocked &lt;10&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incorrectly fastened parachute &lt;12&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency scenarios for all phases of flight not prepared &lt;21&gt;</td>
<td>Hazard of the pilot falling out of the cabin</td>
<td>External and/ or internal injuries, death</td>
</tr>
<tr>
<td>Not fastened seatbelts &lt;23&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inaccuracy caused by rush &lt;39&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stall during making a turn &lt;56&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cockpit canopy stuck &lt;58&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on defined hazard sources, 13 hazards were identified in the area of the analysis: hazard of hitting objects in the cabin (9 HS), hazard of the pilot falling out of the cabin (7 HS), hazard of ground collision (37 HS), hazard of aviation obstacle collision (24 HS), hazards of cognitive overload (12 HS), hazards of eye overload (8 HS), hazard of mid-air collision (24 HS), hazard of sailplane – launcher unscheduled disconnection during take-off (16 HS), Hazard of hard landing outside the aerodrome (13 HS), hazard of glider part detachment on the ground (8 HS), hazard of glider part detachment in the air (11 HS), hazard of hard landing at the aerodrome (22 HS), hazard of no post-accidental medical assistance (5 HS).

### 3.3. Risk Estimation and Evaluation

In order to estimate the risk in display flight, Risk Score method was used. The specific way of assigning damage, probability and exposure to corresponding values was described in articles [6-8]. For the purpose of this article a change in an interpretation of exposure levels criterion was made. Most of the pilots doesn’t fly every day, so the scale
was changed in order to find an exposure during performing flights (Table 4).

<table>
<thead>
<tr>
<th>Exposure level (E)</th>
<th>Characteristic</th>
<th>Own interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Constant</td>
<td>Every flight</td>
</tr>
<tr>
<td>6</td>
<td>Every day</td>
<td>Every second flight</td>
</tr>
<tr>
<td>3</td>
<td>Every week</td>
<td>Half of the flights</td>
</tr>
<tr>
<td>2</td>
<td>Every month</td>
<td>Quarter of the flights</td>
</tr>
<tr>
<td>1</td>
<td>Few times a year</td>
<td>Few times in season</td>
</tr>
<tr>
<td>0.5</td>
<td>Once a year</td>
<td>Once in a season</td>
</tr>
</tbody>
</table>

Table 4
The exposure levels and their characteristic in Risk Score method with own interpretation

In order to gratitude the risk acceptance level, its evaluation is necessary. For negligible and low risk levels there is acceptable risk category. Tolerable risk category corresponds to important risk level and unacceptable to high or very high, risk level [9]. The categories of risk related to risk levels from Risk Score method is presented in Table 5.

<table>
<thead>
<tr>
<th>Risk level</th>
<th>Risk category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Low</td>
<td>Tolerable</td>
</tr>
<tr>
<td>Important</td>
<td>Tolerable</td>
</tr>
<tr>
<td>High</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>Very high</td>
<td>Unacceptable</td>
</tr>
</tbody>
</table>

Table 5
The risk levels and categories in Risk Score method

For each of the hazards defined in earlier variables were assigned, referring to: the level of damage generated by the activation of hazard (S), exposure to hazards (E), and the probability of damage (P). Below is an estimation of the risk during a display flight. For hazards with a risk category other than 'accepted', actions have been proposed to reduce the risk level, e.g.:

1) Hazard of hitting objects in the cabin
Variables: S = 1  E = 6  P = 1
Calculation of risk value: \( R = S \times E \times P = 1 \times 6 \times 1 = 6 \)
The risk level: negligible
Risk category: acceptable
Proceeding against risk: Caution and mounting check required

2) Hazard of ground collision
Variables: S = 15  E = 3  P = 10
Calculation of risk value: \( R = S \times E \times P = 15 \times 3 \times 10 = 450 \)
The risk level: high
Risk category: unacceptable
Proceeding against risk: avoiding rush, inaccuracy, routine, checking the sobriety of the pilot before every flight, checking towing rope every single time, preparing emergency scenarios
Variables after risk reduction: S = 15  E = 1  P = 1
Calculation of post risk value: \( R = S \times E \times P = 15 \times 1 \times 1 = 15 \)
The risk level: low
Risk category: acceptable
Proceeding against risk: Caution required

The risk assessment above is only a sample of the work done. The whole analysis included: 91 questions checklist, 68 identified hazard sources, 13 hazards defined. Every hazard unacceptable or tolerable were proposed corrective actions, for the unacceptable risk levels.

In the future, the analysis can be use in order to create a safety management system [11] aiding sailplane pilots in their tasks.

4. Conclusions

The aim of this article was to analyze and assess the risk, during a display flight using the sailplane. With the Risk Score method, calculations were made and risk levels were assigned to the relevant categories. Almost a half of the
hazards were assigned to the unacceptable category (collision in the air, separation of aircraft elements in the air, collision with the ground, collision with the aerodrome infrastructure etc.). Therefore, it was necessary to determine the risk management in order to reduce it. Avoiding rush and inaccuracy, checking the sobriety of pilots before the flight, using a short safety checklist, planning dangerous situations before they occur and not flying at all costs are recommended actions. The risk assessment method could be added to the electronic flight bag (EFB) in order not to burden the pilot with additional paper documents. EFB is a tool that includes flight planning, briefing, navigating and with special equipment also traffic, weather, weight and balance features are available. Due to the fact that a lot of unwanted events took place after a long pause in flying, or during the training process it is advisable to use simulation methods also in glider training. After risk reduction, all hazards have an acceptable level. Most of the risks are influenced by the accuracy of the human being in the performance of specific activities and norms. For this reason, many of the risk reduction measures proposed are directly related to the pilot. It should be remembered that the work refers to the model pilot, aircraft and aerodrome, which is why the analysis results in actual conditions may be different. Nevertheless, the risk in aeroclubs should be monitored at each stage.

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4. INSTRUKCJA UŻYTKOWANIA W LOCIE SZYBOWCA SZD-50-3 „PUCHACZ”. Szybowcowy zakład doświadczalny Bielsko-Biała [In Polish: Pilot’s operating handbook for SZD-50-3 Puchacz sailplane]


Comparative Analysis of the Results of Calculating the Stability of a Reinforced Subgrade with Geosynthetic Materials

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Abstract

The article presents the results of studies of the stress-strain state of the reinforced and unreinforced railway subgrade. This study compares changes in the distribution of stresses and displacements in a railway subgrade. Comparisons of stresses and displacements made it possible to obtain:

- comparative analysis of the work of the main site of the subgrade under increased load with reinforcement and without reinforcement;
- comparative assessment of the efficiency of the reinforced subgrade at increased load;
- isolines and isofields of displacements and stresses in the body of the embankment at an increased load.

KEY WORDS: roadbed, embankment, geotextile materials, stresses, displacements

1. Introduction

Deformations of the ground and the upper structure of the track significantly impede the speed of trains and increase operating costs. The main feature in the track's maintenance on which such speeds are realized, is the increased requirements to ensure the smoothness of the rail threads. One of the means of forecasting is a comprehensive analysis of stability based on mathematical and simulation modeling of the ground. The goal was to conduct a comparative analysis when calculating the stability of railway embankments when reinforcing embankment soils with geosynthetic materials using the finite element method.

2. Analysis of Achievements in this Area

One of the areas of improvement of methods for calculating the strength of the track and, in particular, the main site of the ground is as follows. Strength is estimated not only by the magnitude of the load but also by the number of its effects over the service life, i.e., it is proposed to take into account the load (the work of M.F. Verigo and V.S. Lysyuk). Until now, the rated voltages have been compared with the allowable from the action of a single load. It is proposed to assign allowable stresses considering the load stress, the specified standard service life of the track, the physical and mechanical properties of this element of the track, the allowable values of accumulated damage and deformation.

It is known that the assessment of the ground under trains with the study of only dynamic stresses (for the first group of limit states) is necessary, but in some cases an insufficient criterion to ensure its reliable operation as the basis of the railway track.

Theoretical calculation methods for estimating the stress-strain state of the railway ground are quite complex and have not yet received practical application. Therefore, the elastic work of the ground is evaluated, as a rule, experimentally.

There are several ways to assess the stress-strain state of the ground. These include:

- A method of determining the residual deformations of the ground, considering these deformations as a result of its work under the repeated influence of trains;
- A method of measuring the elastic subsidence of the rail track under the influence of mobile loading complexes (with the allocation in the total subsidence of the share of elastic deformations of the ground);
- Method of layer-by-layer measurement of elastic deformations of the soil along the depth of the subsoil using a downhole deformer.
- The method of determining the residual deformations of the soil.

It is assumed that the residual deformation of the subsoil is the end result of its elastic work under repeated cyclic influence of rolling stock.
3. Materials and Methods of Research

The model for the calculation is also adopted spatial based on three-dimensional finite elements (CE) to take into account the real characteristics of the object under study. All geometric and deformation characteristics of the ground are taken from the regulatory documentation. Thus, the developed spatial model is based on the real characteristics of the ground of the two-lane section, which were obtained during the construction of the existing embankment [1].

The total number of nodes of the scheme is 23,928 pieces. (about 70 thousand degrees of freedom), the number of finite elements - 20,867 pcs. SE in the scheme are accepted as compatible, ie all nodes of adjacent elements coincide, which has a positive effect on the accuracy of the solution. Dimensions of the model: length (base) - 55.7 m, width - 5.5 m, height - 12.5 m (of which the height of the ground - 12 m). Modeling of the entire height of the embankment, but the load on the main site from the rolling stock is local and reduces its impact at a depth of 4.5… 5 m, given the significant deformation properties of the ground [2, 4].

The dimensions of the CE range from 0.30 × 0.5 × 0.5, 0.35 × 0.5 × 0.5 to 0.5 × 0.5 × 0.5 m, ie the CE grid is adequate to the size of the presented model, as it is considered that the basic size of SE should not exceed 1/20 of the characteristic size of the model. The scheme uses both prismatic SEs with a triangular base (in the modeling of the slope) and parallelepipeds (in the modeling of the ground and the base). Prismatic SE with a triangular base are tested for degenerate and "needle" elements, the angles of the triangle are not less than 60°.

Boundary conditions are imposed on the scheme: at the bottom of the model there is a ban on movement on all three axes X, Y and Z, on the sides of the base - a ban on the X and Y axes, on the transverse sides of the model - a ban on the Y axis (flat deformation conditions). The top and slopes of the model are free from boundary conditions. [5-7].

Deformation characteristics are selected from the tables in accordance with the studied soils of the subsoil [3].

The locomotive (first pair), weight distribution and distance between axles were taken as the model load. The pressure on the axle is taken to be equal to the standard pressure from the locomotive \( P = 20 \text{ t} \) taking into account the dynamic coefficient \( \mu = 1.5 \), \( P = 30 \text{ t} \).

Three schemes of loading of the CE model were accepted:
1. scheme - the locomotive is on the same track with the addition of its own weight of the ground;
2. scheme - the locomotive is on two tracks with the addition of its own weight of the ground;
3. scheme - loading of the scheme only by own weight.

The 3rd load scheme is provided to control the displacements and stresses in the model, which are caused by the own weight of the ground, and the same factors from the train load.

In Fig. 1 shows the location of the loads of the 1st and 2nd schemes on the main site of the embankment. The load on the axle of the car is distributed over the width of the sleeper, which it accounts for, and it is distributed over 12 nodes SE, which are part of the geometric location of the sleeper and is 25 kN.

![Fig. 1 Location of loads on the upper structure of the track (UST): a – in the case of the 1st load scheme; b – in the case of the 2nd load scheme](image)

All geometric dimensions and total loads on the model are stored and controlled during the calculation, which is possible in the applied calculation complex.

In Figs. 2-5 shows the results of the calculation of the ITU of the ground with the train load.
Fig. 2 Isolines and isopoles of displacements and stresses in case of embankment of homogeneous material, 1st loading scheme: a – movement along the X axis (horizontal); b – movement along the Z axis (vertical); c – normal stresses along the X axis (horizontal); d – normal stresses along the Z axis (vertical)

Fig. 3 Isolines and isopoles of displacements and stresses in case of embankment with combined reinforcement by geosynthetics, 1st loading scheme: a – movement along the X axis (horizontal); b – movement along the Z axis (vertical); c – normal stresses along the X axis (horizontal); d – normal stresses along the Z axis (vertical)
Fig. 4 Isolines and isopoles of displacements and stresses in case of embankment of homogeneous material, 2nd loading scheme: 

- a movement along the X axis (horizontal);
- b movement along the Z axis (vertical);
- c normal stresses along the X axis (horizontal);
- d normal stresses along the Z axis (vertical)

Fig. 5 Isolines and isopoles of displacements and stresses in case of embankment with combined reinforcement by geosynthetics, 2nd loading scheme: 

- a movement along the X axis (horizontal);
- b movement along the Z axis (vertical);
- c normal stresses along the X axis (horizontal);
- d normal stresses along the Z axis (vertical)
4. Conclusions

The most informative results of the stability analysis were obtained by comparing the VAT parameters in the embankment of homogeneous material with the embankment with combined reinforcement by geo synthetics. Analyzing these results, we can draw the following conclusions about the stability of the high embankment.

The general picture of the distribution of displacements and stresses in a homogeneous embankment coincides with a qualitative analytical picture, which is the fact that proves the adequacy of the applied model to the real distribution of VAT. However, in the studied case, in addition to the action of the array’s own weight, the effect of train load is modeled, which makes some adjustments to the general state of VAT, which can be seen in the stress distribution in IBC (Fig. 2, d, e). The stresses from the train are also close to the analytical solution of the influence of the distributed load on the elastic space.

Comparing the displacement in the embankment's case of homogeneous material (hereinafter - Case 1) and in the embankment's case with combined reinforcement by geo synthetics (hereinafter - Case 2) we can show that the reinforcement of the ground with geo synthetic elements gave positive properties to the whole system. Thus, displacements (approximately 0.45… 0.5 mm) and normal stresses along the Z axis decreased slightly, and normal stresses along the X axis decreased significantly (1.75… 1.77 times). It should be noted that the placement of geo synthetics in the zone of active distribution of train load changed the picture of stresses not only quantitatively but also qualitatively (Fig. 4 and 5, v-d). Thus, in the case of normal stresses along the X axis, their distribution changed in such a way that the zone of increased stresses shifted from the IBC to the boundary of the geo synthetics (Fig. 3, c), and the value of maximum stresses of 0.498 MPa decreased to 0.282 MPa (1.78 times). Although visually the picture of the distribution of normal stresses along the X axis is much more complicated (there are two zones on the boundaries of the clamp of geo synthetics), but quantitatively their value is much lower than the limit of soil destruction.

A comparative analysis of cases 1 and 2 in the second loading scheme made it possible to estimate the change in the level of VAT when a train passes on two tracks. It should be noted that in both cases the vertical displacements changed slightly (by 0.02 mm), horizontal - by 0.3 mm, respectively. The stress state of the ground during the second load scheme became symmetrical and homogeneous in contrast to the first scheme, which was expected. It can also be shown that in this scheme in both cases at the boundary between the layers of gravel and metamorphic shale appeared a zone of some heterogeneity of normal stresses along the X axis (from -0.02 MPa in the ground to +0.014 MPa at the boundary, Fig. 4.-5), which may cause the formation of a landslide zone. However, the values obtained in mathematical modeling do not allow to indicate the presence of such a zone, and it should be noted that the model is based on the ideal deformation characteristics of the system elements and therefore cannot correspond to the actual ground completely. Thus, the studied model also does not reproduce the possibility of ballast pockets and bags, local disruption of the structure and the appearance of areas of increased fracture, which also reduces the adequacy of the results, but the reproduction of the above factors at this stage of mathematical modeling is almost impossible.

Since the ballast prism receives a significant part of the stress distribution, the ground without this element is analyzed, which is possible in the SCAD complex. Comparison of normal stresses along the X-axis in the subsoil shows that for the 1st load their level increased in the area of the geo synthetics, almost 10 times, although in WBC it decreased (Fig. 4 and 5, v-d). Thus, in the case of normal stresses along the X axis, their distribution changed in such a way that the zone of increased stresses shifted from the IBC to the boundary of the geo synthetics (Fig. 3, c), and the value of maximum stresses of 0.498 MPa decreased to 0.282 MPa (1.78 times). Although visually the picture of the distribution of normal stresses along the X axis is much more complicated (there are two zones on the boundaries of the clamp of geo synthetics), but quantitatively their value is much lower than the limit of soil destruction.


References
Author's Index

A
Abramović B., 262  
Afanaskou P., 402  
Aftaniuk V., 103  
Aharkov O., 136  
Alvarez H., 151  
Andrieiev V., 531  
Astaykin D., 510  

B
Ballay M., 332, 493  
Bartusevičienė I., 64  
Bartuška L., 30  
Beuš J., 359  
Bercely-Alvarez A., 151  
Berezovyi N., 316  
Bernát J., 411  
Bialek K., 499  
Blatnický M., 183  
Böhnm K., 108  
Bolibrků L., 199  
Bondarenko A., 510  
Bnejac N., 262  
Brodniansky M., 343  
Brzozowski K., 257  
Bulgakov O., 510  

C
Charmin R., 402  
Chocholáč J., 449  
Chuchumenko B., 284  
Ciszewski T., 140, 338  

Č
Čamaj J., 222  
Čulik K., 251  

D
Danilenko D., 103  
Dariimaa O., 391, 443  
Dedik M., 222  
Dizo J., 53, 183  
Dvořáková T., 467  
Dziewiątkowski M., 5  

E
Eiduks J., 26  

F
Fandáková M., 80  
Feszczyzn M., 22  
Fiačan J., 183  
Furch J., 505  
Fusar I., 477  

G
Galant-Golebiewska M., 525  
Gandramavičius M., 10  
Gavrilovs P., 26  
Gavuro T., 92  
Gerlitz L., 396  
Gill A., 22, 208  
Ginter M., 385, 525  
Gladkykh I., 268  
Golikov A., 268  
Goolak S., 455  
Gramza G., 171  
Gryschuk O., 406  
Groulová V., 487  
Guevara-Cedeño J., 151  

H
Haichenia O., 70, 477  
Hajzler O., 245  
Hakalová J., 297  
Hanzl J., 30  
Hashchuk P., 145  
Heine N., 396  
Henesey L., 396  
Himmetoglu S., 35, 86  
Hmelevska N., 47  
Hnenny O., 316  
Hoang A.D., 113  
Hovativuk M., 406  
Hruďaková K., 572, 251  
Hruška R., 449  
Hubar O., 531  
Husak M., 47  

I
Ievsieievi A., 188  
Ievsieieva O., 188  
Ilichev K., 188  
Ischuk I., 58  

J
Jakubauskaite V., 322  
Jelinek J., 505  
Jokubynienė V., 422  

K
Kalinichenko L., 188  
Kalivoda J., 158  
Kasanický G., 411, 434  
Kichkin O., 177  
Kichkina O., 177  
Kicova E., 163
Kobaszyńska-Twardowska A., 385
Kohút P., 493
Korbut M., 41
Korohods'kyi V., 284
Korovaichenko Y., 103
Kotoriũ M., 309
Kovtanets M., 350
Kozachenko D., 316
Kozyczkowski K., 396
Kozlov M., 203, 449, 487
Kraus J., 354
Krushtopa S., 481
Krykavskyy Y., 199, 371
Kubjatko T., 108
Kučera T., 203, 449, 487
Kudela P., 80
Kudriashov V., 278
Kulík K., 245
Kunicina N., 193, 391, 443
Kurhan D., 47
Kurhan M., 47
Kusznier M., 98
Kuzmenko S., 177
Lebid I., 278
Ledvinová M., 520
Leitner B., 290, 332
Lileikis S., 127
Litvinova Ya., 514
Liubarskyi B., 455
Loga-Księska W., 74, 257
Lomotko D., 58
Lupták V., 438
Lusкова M., 290
Luzhanska N., 278
Macurová L., 332, 493
Macleá N., 359, 461
Macleónková L., 359, 461
Makovec M., 203
Malashkin V., 316
Maliuha E., 70
Marchenko D., 177
Markul R., 531
Martikánová A., 92
Mazurenko O., 278
Medvedieva I., 70
Meyer C., 396
Mezitis M., 151
Mikhailov E., 183
Miller W., 208
Morgoš J., 251
Muhitovs R., 151
Nycz-Wojtan S., 199
Nikipchuk S., 145
Nõmmik A., 379
Novák A., 343
Nozhenko V., 350
Oyun-Erdene N., 391, 443
Ol'ynyk J., 268, 510
Oliskevych M., 416
Otošen Ō., 284
Otersone K., 131
Pająk M., 481
Pakulina H., 188
Palčák M., 80
Palochová M., 297
Patlins A., 193, 391, 443
Paula D., 108
Paulauskas D., 396
Paulauskas V., 396
Paulauskiene T., 10, 322
Pechenyuk Ą., 239
Pelio R., 416
Petrychenko O., 239
Petryk A., 406
Philipp R., 396
Pidopyr'gora L., 188
Pleninger S., 328
Polak K., 233
Polyakov V., 53
Polivyanchuk Ą., 284
Ponisciakova O., 163
Popov V., 131
Prosvirova O., 350
Psenková V., 297
Řehoř V., 467
Riabov Ie., 455
Saltyte-Vaisiauske L., 322
Sapronova S., 455
Schweiger H.-G., 108
Seidlová Ą., 520
Semakesiite V., 322
Semenov S., 183
Setlíková P., 228
Shandrivska O., 371
Shepel V., 70
Shevchenko Ą., 131
Shynkarenko N., 371
Contents

Preface

M. Dziewiński, D. Szpica. Comparative Study of Diesel and Compressed Natural Gas (CNG) Engine

M. Gandramavicius, T. Paulauskiene. Prediction of Liquefied Natural Gas Ageing at Klaipėda FSRU Terminal Independence

G. Velichko. Properties Study of the Harmonized Shape Transition Sections of the Railway Track Curves

M. Feszczyń, P. Smoczyński, A. Gill. Impact of Station Modernisation Projects on Railway System Resilience

P. Stankevics, P. Gavrilovs, J. Eiduks. Safety of Pneumatic Brake Systems of Rolling Stock

J. Hanzl, L. Bartuška. Road Safety at Intersections and Roundabouts: A Case Study

S. Himmetoglu. Validation of a Multi-Body Human Model for Efficient Rear Impact Simulations

D. Szpica, M. Korbút. Computational Evaluation of the Compression Ratio Impact on External and Economic Indicators of a Piston Pneumatic Engine

M. Kurhan, D. Kurhan, M. Husak, N. Hmelevska. Perspectives of High-Speed Train Traffic in Ukraine at the Stage of Integration with the European Network


O. Ischuka, D. Lomotko. Application of Logistic Information Flow in Customs Clearance of Cargo at Marshalling Station

I. Bartusevičienė, E. Valionienė. Smart Workplace: Students’ Opinion On Being Prepared to Meeting Digitalization Challenges

E. Maliuha, I. Medvedieva, V. Shepel, O. Haichenia. Development of Recommendations for Bypass of Storm Areas Based on North Atlantic Wind Repeatability Analysis

W. Loga-Księska, J. Sordyl. Mobile Road Condition Measurement as Support of RWIS in Urban Areas

P. Kudela, M. Palčák, M. Fandáková. Effect of Improving Railway Crossings Technology on the Occurrence of Traffic Accidents in the Slovak Republic

S. Himmetoglu. An Analysis of Head-on Frontal Collisions by Modelling Crash Tests

A. Martikánová, L. Socha, T. Gavura. Leadership in Air Transport

D. Szpica, M. Kusznier. The Proposal of Functions Describing the Opening and Closing Process of the Low-pressure Gas-phase Injector

V. Aftaniuk, D. Daniilenko, Y. Korovaichenko. The Simulation Model of a Multi-scrubber for Cleaning Gases Emitted by Marine Engines


V. Sukalova. Covid 19 as a New Risk Factor in the Work Safety Management of Professional Drivers

S. Lileikis, J. Zakrevskij. A Case Study of Digital Technologies in Intermodal Freight Forwarding

O. Aharkov, V. Tverdomed, L. Kushmar. An Investigation of Axial Load Influence on the Level of Contact Stresses in a Wheel-Rail Pair

W. Nowakowski, T. Ciszewski. The Use of COTS Technology in Building Reliable and Safe Railway Traffic Control Systems


A. Berbey-Alvarez, H. Alvarez, J. Guevara-Cedeño, M. Mezitis, R. Muhitovs. Economic Externalities of the Panama Metro Network

J. Kalivoda. Reduction of Guiding Forces in Curves - Comparison of Fundamental Solutions

O. Ponisciakova, E. Kicova. Use of Value Management Tools in Public Transport Companies

G. Gramza. Analysis of Possible Discrepancies Between the Public Transport Offer and Customers’ Expectations

O. Kichkin, O. Kichkina, S. Kuzmenko, D. Marchenko. General Formalization of the Intellectual System for the Control of the Train Thrust on the Traffic Section

J. Dižo, M. Blatnický, I. Fiačan, S. Semenov, E. Mikhailov. Engineering Design of a Tyre-rail Adapter for a Light Road-rail Vehicle


A. Patlins, N. Kunicina. How to Make Public Transport System Safer During the Pandemic and after


T. Kučera, M. Makovec. Smart City Approach in Logistics and Transport in the Czech Republic

W. Miler, A. Gill, P. Smoczyński. Train Driver Reliability Analysis with the Use of HCR and Train Simulation Program

O. Zabolotnyi. Moisture Content Control in Heavy Fuel During the Process of Emulsification with a Help of Capacitive Sensors


M. Šustr, P. Šohajek, P. Setliková, R. Soušek. Impact of the Pandemic Disease on the Railway Central Traffic Control Centers

E. Wawrzyn, K. Polak. HYPERNEX: Ignition of the European Hyperloop Ecosystem Project Within Horizon 2020

A. Pechenyuk, O. Petrychenko. Prediction of Safe Maneuvers in Restricted Waters as Problem of Navigation and Ship Hydrodynamics

O. Hajžler, K. Kulík, M. Strouhal. Fuel Saving Methods in an Airline

K. Čulík, K. Hrudkay, J. Morgoš. Operating Characteristics of Electric Buses and Their Analysis

W. Loga-Ksińska, K. Brzoźowski. Estimation of Environmental Footprint Caused by Freight Vehicles Using WIM Data in a Local Scale
K. Solina, B. Abramović, N. Brnjac. Market Liberalisation of Railway Freight Transport in Croatia

I. Gladkykh, A. Golikov, I. Vorokhobin, J. Oliynyk. AIS AtoN Network Simulation on the Dangerous Section of the Dnieper River

G. Zoidze, G. Tkhiiaishvili. Prospects of Intermodal Transportation and Logistics Channels Development for Georgia

I. Lebid, N. Luzhanska, O. Mazurenko, A. Kudriashov, I. Kravchenya. Improvement of Customs and Logistics Services in Ukraine

O. Osetrov, B. Chuchumenko, A. Polivyanchuk, V. Korohodskyi. Mathematical Modeling and Computational Study of a Passenger Car Dynamics During Acceleration

B. Leitner, M. Luskoa. Unmanned Aerial Vehicles as a Tool for Monitoring and Protection of Physical Infrastructure Systems

J. Hakalová, Š. Kryšková, M. Palochová, Y. Pšenková. Analysis of the Use of Electromobility by Business Entities in the Czech Republic from Accounting and Tax Perspective

L. Sokołowska. Simulation Research of All-purpose Interface Model Between Interlocking System and Block System

Ž. Stević, M. Kotorić, G. Stojić, S. Sremac. Selection of Delivery Vehicle Using Integrated Objective-subjective MCDM Model


S. Pleninger. The SSR Surveillance Coverage Mapping Based on Aircraft’s Replies Processing

M. Ballay, E. Sventeková, B. Leitner, L. Macurová. Mathematical – Graphic Analysis of Traffic Accident with the Assessment of Intervention Activities Fire Brigades

T. Ciszewski, W. Nowakowski. Selected Issues of Geographic Data Description for Infrastructure Elements in RailML

M. Brodniansky, A. Novák. Monitoring Communication Design System for UAV Detection

M. Kovtanets, O. Prosvirova, V. Nozhenko, T. Kovtanets. Method of Thermo-energy Gas Separation for Adaptive Temperature Regulation in Friction Contact of Railway Brakes

D. Urban, J. Kraus. Key Issues of e-ID UAS Integration

R. Madleňák, J. Beňuš, L. Madleňáková. Experimental Testing of the Vehicle-driver Interaction by Eye-tracking Technology in Laboratory Conditions

A. Toruň, L. Sokołowska. All-purpose Interface Model Between Interlocking System and Line Block System


V. Trasberg, A. Nõmmik. Public Financial Support to Aviation During the COVID-19 in the Baltic Countries

A. Kobaszyńska-Twardowska, M. Ginter. Hazard Sources’ Identification During Unmanned Medical Transport Flight


P. Afanaskou, R. Charnin. Estimation of the Residual Resource of a Dumping Wagon for Transportation of Bulky Cargo after Long-term Operation

O. Gryshchuk, A. Petryk, A. Kozlov, M. Holovatiuk. Justification of Technological Parameters of Transport Infrastructure when Construction of Specialized Terminals in Sea Ports

J. Bernát, G. Kasanický, P. Vertaľ. Pedestrian Vehicle Accidents and Design of a Test System for the Needs of Forensic Science


J. Liebuvienė, V. Jokubynienė. Research of the Impact of Road Surface, Tire Pressure and Automobile Speed on the Braking Distance

M. Sumila. Impact the Train Wi-Fi Systems on the GSM-R Network Service Availability

S. Stehel, P. Vertaľ, G. Kasanický. The Impact of the COVID-19 Pandemic on Traffic Accident Statistics in Slovak Republic

V. Lupták. Analysis of Transport Services of Regional Railway Transport in the Area of Šumava Railways


R. Hruška, J. Chocholáč, T. Kučera. Use of RFID Technology in the Logistic Process of Distribution with the Support of a Dynamic Simulation Software Tool


L. Madléňáková, R. Madléňák. Development of Electromobility in the Context of the Economic Situation of Selected Countries

T. Dvořáková, V. Řehoř, M. Svítek, P. Vittek. Health Protection Measures and Physical Distancing Model for Airports

M. Sumila. Hard and Soft Telematics Systems


T. Kučera, V. Groulová. Proposal of Suitable Control System and Measure in Internal Logistic Process

M. Ballay, E. Sventeková, L. Macurová, P. Kohút. Accident Analysis with the Participation of a Cyclist with Using a Dynamic Model of Traffic Simulation

A. Toruń, K. Bialek, P. Wętoszka. Field Tests of an Intelligent Video Monitoring System Installed on Freight Wagons

M. Zachar, J. Furch, J. Jelínek. E-beam Modified Engine Oil

J. Oliynyk, D. Astaykin, A. Bondarenko, O. Bulgakov. Assessment of the State of AtoNs System on the
Transport Means 2021
Sustainability: Research and Solutions
Proceedings of the 25th International Scientific Conference (PART I)

ISSN 1822-296 X (print)
ISSN 2351-7034 (online)

Design by Rasa Džiaugienė, Rolandas Makaras, Robertas Keršys, Saulė Kvietkaitė

Cover Design by Publishing House „Technologija“

Printing House “Technologija”, Studentų 54, LT-51424, Kaunas