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PREFACE

24[rth] international scientific conference TRANSPORT MEANS 2020 due to the COVID-19 pandemic in the world, for the first time was organized as a virtual event on 30 September - 02 October, 2020. It continues long tradition and reflects the most relevant scientific and practical problems of transport engineering.

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

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

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

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

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

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

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

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

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Proceedings of 24th International Scientific Conference. Transport Means 2020.

Analysis of Selected Functional Parameters of the Gas Supply System During NEDC and WLTC Cycles

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Abstract

Liquefied petroleum gas (LPG) supply systems are widely used in means of transport. Each vehicle sold as a brand new one must meet the legislative requirements according to the year of manufacture. In the course of legislation, standardized driving cycles are used, i.e. New European Driving Cycle (NEDC) or Worldwide Harmonized Light vehicles Test Cycle (WLTC). These are carried out under laboratory conditions, where mainly the vehicle's emissions are assessed. A slightly different approach was used in the study, because selected functional parameters of the gas supply system were analysed. Alternatively, the test vehicle is equipped with a multi-point LPG vapour phase injection system. The procedures contained in a load chassis dynamometer with an axle-supply function were used to achieve the intended purpose. In turn, a data recorder was used to record functional parameters. In this way, the mileages of selected parameters related to the operation of the gas supply system were determined, at the same time confirming the more demanding nature of the WLTC cycle in terms of energy demand. For a certain group of parameters functional relationships were determined.
KEY WORDS: *mechanical engineering, combustion engines, alternative fuel supply, testing, passenger car*

1. Introduction

Currently, all vehicles sold as brand new must meet the requirements of the legislative test regulations [1]. If an additional alternative power supply system is installed in the vehicle, it must meet the legislative requirements according to the year of vehicle production referring to the original power supply system [2, 3]. The legislative provisions concern the composition of exhaust gases, and additionally, the emission of CO_2 (carbon dioxide) may be translated into fuel consumption. From a formal point of view, tests of this type are carried out in two variants. In the first one, under laboratory conditions, in standardized driving cycles such as the New European Driving Cycle (NEDC) [4] or Worldwide Harmonized Light vehicles Test Cycle (WLTC) [5]. In the second one, in conditions of real traffic Real Driving Emissions test (RDE) [1, 6]. In laboratory conditions, chassis dynamometers are used for load mapping, which are able to additionally power the vehicle's axles simulating artificially higher inertia. In real traffic conditions, the route and traffic volume conditions are determined. The emissions of road vehicles are determined in g/km and therefore it is necessary to use exhaust gas analysers with this type of measuring function. In addition, it is required that the analysers are capable of identifying as many compounds in the exhaust gas as possible and that they are mobile for the RDE cycle. Portable Emissions Measurement System (PEMS) analysers are commonly used in stationary or mobile versions. A separate group in the legislative evaluation are engines of off-road vehicles and commonly used working machines [7, 8], where the emission is determined in g/(kW·h). A detailed description referring to the legislative issues of vehicles equipped with internal combustion engines is given in [9-11]. The main differences in NEDC and WLTC cycles concern acceleration [12], specific power [13], total energy demand [14], as well as chassis dynamometer settings [15].

One of the most popular alternative fuels used in transport is liquefied petroleum gas (LPG) [16, 17]. Apart from few cases [18], engines can be easily adapted to this type of power supply [19]. The LPG supply system is an additional fuel system built from scratch and its operation in the case of injection systems is based on the use of control keys for petrol injectors and a few own components and sensors [20]. Algorithms of LPG systems control are constantly modified, as a result of which it is possible to supply the LPG liquid phase with direct injection [21] or to use a combined system in the latest solution [22]. Apart from some emission problems of the engine fuelled with LPG in the poor mixture mode [23], the range of stoichiometric mixtures results in reduced emission of PM (particulate matter), NOx (nitric oxide) and HC (hydrocarbons) with comparable emission of CO (carbon monoxide) [24, 25].

As already mentioned, LPG is the most popular alternative fuel. While LPG sequential multipoint systems are one of the most popular alternative fuels supply solution. The main problem in this type of power supply systems is the fact that it is necessary to deliver a larger volume of gaseous fuel in relation to the original fuel - petrol [26]. In many cases, the accuracy of execution of gas injectors is also not conducive to this, which results in uneven [27] and non-repeatability of fuel dosage [28]. Continuous searches for the ways to solve the problems with fuel dosage by gas injectors tend to use the piezoelectric drive [29, 30].

The driving cycles developed for legislative purposes provide an opportunity to assess the emissions of vehicles. The recently introduced WLTC cycle gives a more real picture of engine operation than the previously binding NEDC cycle [31, 32]. Some of the studies concern gaseous alternative fuels [33, 34]. It should be stressed that the exhaust gas emission is a result of the operation of the power supply system and cooperating systems. A lack of comprehensive studies on the analysis of operating parameters of the gas supply system during the implementation of various single cycles was noted, which could be the basis for confirming the differences in their nature. Therefore, an attempt was made to compare functional parameters of the gas supply system during the implementation of the NEDC and WLTC.

2. Object of the Research

The subject of the research was a Hyundai vehicle, model i20 (Fig. 1). The engine of this vehicle is a 4-cylinder naturally aspirated power unit originally equipped with Kappa II multi-point petrol injection (Table 1). The vehicle is equipped with an alternative LPG vapour phase supply system in the configuration shown in Table 2.

Fig. 1 The research object – Hyundai i20

Table 1

The technical data of the Hyundai i20

Vehicle:	
- year of the manufacture	2018
- mileage	1080 km
Engine:	R4 / 16V
- engine displacement	1.248 cm^3
- max. power at engine speed	86 kW at 6000 r./min
- max. torque at engine speed	122 N·m at 4000 r./min
- injection system	MPi
- respect to emission	Euro 6d
- fuel	RON 95
- exhaust system	TWC(2 NBO sensors)
Gearbox:	Manual 5 gear

Table 2

The basic elements of the LPG system

LPG ECU	STAG AC QNEXT PLUS
reducer-evaporator	STAG AC R02
LPG vapour injector	Matrix HD 544
pressure sensor	STAG AC PS04
tank	Toroidal Elpigas 43 L
multivalve	AC M01

Before starting the tests, the vehicle was checked for the function of the components, the tyre pressure and the condition of the operating fluids. In addition, the alternative LPG supply system was statically and dynamically calibrated. The injection times of gasoline and LPG injectors were compared and the multiplier value.

2. Research Methodology

As the tests were of a comparative nature under the conditions laid down in the NEDC and WLTC legislative provisions, it was necessary to use a device enabling the implementation of these cycles. For this purpose, a chassis-type load-brake with the Maha MSR 1000 axle drive function was used. It enables the mapping of road conditions through quasidynamic load adjustment. In addition, the internal software of the dynamometer allows the realization of driving cycles programmed by the manufacturer, or in its own configuration. The software allows for continuous recording of traffic parameters and load during tests. In the tests the procedures of NEDC and WLTC cycles contained

in the dynamometer were used.

The AC data recorder (Fig. 2) was used to record parameters related to the operation of an alternative LPG supply system. This device operates on the principle of "black box", which during the tests records the parameters of the gas supply system in continuous mode, from the moment the application connects to the Engine Control Unit (ECU) gas. It is possible to signalize unplanned events by using the button, which is stored in the measurement results.

Fig. 2 AC data recorder

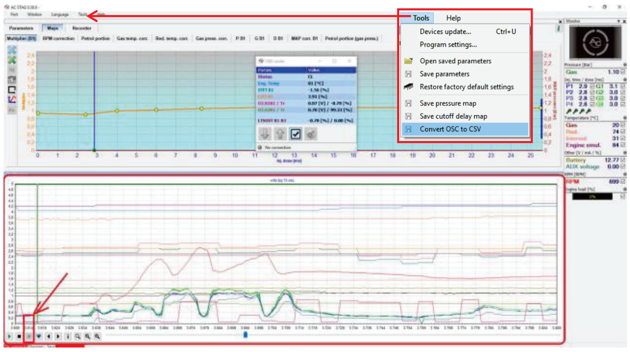

Fig. 3 Program window for reading parameters from the recorder

The values of LPG system parameters are stored on the memory card installed in the AC data recorder. The results can be directly reproduced via a communication cable in dedicated software using a PC (Fig. 3). The data is saved as *.osc file which can be played back in this software. For the purpose of the analysis it was necessary to convert the results into *.csv file.

4. Results and Discussion

The tests were carried out in a controlled laboratory climate on one day. Attention was drawn to the necessity of lowering the engine temperature to the conditions required at the beginning of the cycles (25 ± 5°C for NEDC and 23 ± 1°C for WLTP). The necessary load coefficients of the chassis dynamometer resulting from the vehicle's own weight, air resistance and rolling resistance were calculated and left as constant input data for both analysed cycles.

As the tests were of a comparative nature under the conditions laid down in the NEDC and WLTC legislative provisions, it was necessary to use a device enabling the implementation of these cycles. For this purpose, a chassis-type load-brake with the Maha MSR 1000 axle drive function was used. It enables the mapping of road conditions through quasidynamic load adjustment. In addition, the internal software of the dynamometer allows the realization of driving cycles programmed by the manufacturer, or in its own configuration. The software allows for continuous recording of traffic parameters and load during tests. In the tests the procedures of NEDC and WLTC cycles contained in the dynamometer were used.

When comparing the vehicle speeds (Fig. 4, a), a longer duration and a higher maximum engine speed for the WLTC cycle is visible. The vehicle speed is the resultant of the engine speed and the transmission ratio used at the time, so it is appropriate to compare the engine speed for both cycles (Fig. 4, b). Comparison of engine speed indicates lower fluctuations for the initial phase of the NEDC cycle, while higher fluctuations occur throughout the WLTC cycle. The temperature ranges of the motor (Fig. 4, c) and the reducer-evaporator unit (Fig. 4, d) are very similar. In case of NEDC cycle the temperature has a higher gradient. The LPG pressures for both analysed cycles remain at a similar level (Fig. 4, e), outside the initial phase up to approx. 100 s. Differences in LPG temperature are visible in turn (Fig. 4, f), where in the WLTC cycle the increase is smaller. This may be due to the fact that there is a higher demand for LPG, as a result of which it heats up less after a phase change in the evaporator. The ECU of the tested engine had the option to determine the momentary load, which is very helpful in analysing the "aggressiveness" of the tests. Higher load oscillations are visible (Fig. 4, g) in the case of the WLTC cycle, which confirms a more correct representation of the actual driving conditions [9, 32]. It is similar with the injection times for the I cylinder (Fig. 4, h), where significantly higher oscillations occur in the WLTC cycle. The injection time is a reaction to the momentary energy demand necessary to overcome the resistance to motion, i.e. load. The adjustment of the injection time to the current load conditions can be evaluated after the Short Term Fuel Trim (STFT), where there is a compatibility in both tests (Fig. 4, i) outside the range (700...1200) s for the NEDC cycle, where STFT oscillates above the maximum WLTC values. The interval indicated is the part of the NEDC cycle referred to as EUDC. On the other hand, Long Term Fuel Trim (LTFT) corrections do not go beyond the maximum ranges of both cycles (Fig. 4, j).

To evaluation of functional parameters of the gas supply system during NEDC and WLTC cycles it was decided to use a spread chart. They show the load (Fig. 5, a), injection time of the first cylinder (Fig. 5, b) and STFT correction (Fig. 5, c). The load is a result of movement resistance, the injection time is a reaction to the load and STFT correction is the correct choice of injection time to the current load state.

On the basis of the results of the research, the equations of linear functions describing the relations presented on Fig. 5. The results were obtained accordingly have been presented in Table 3.

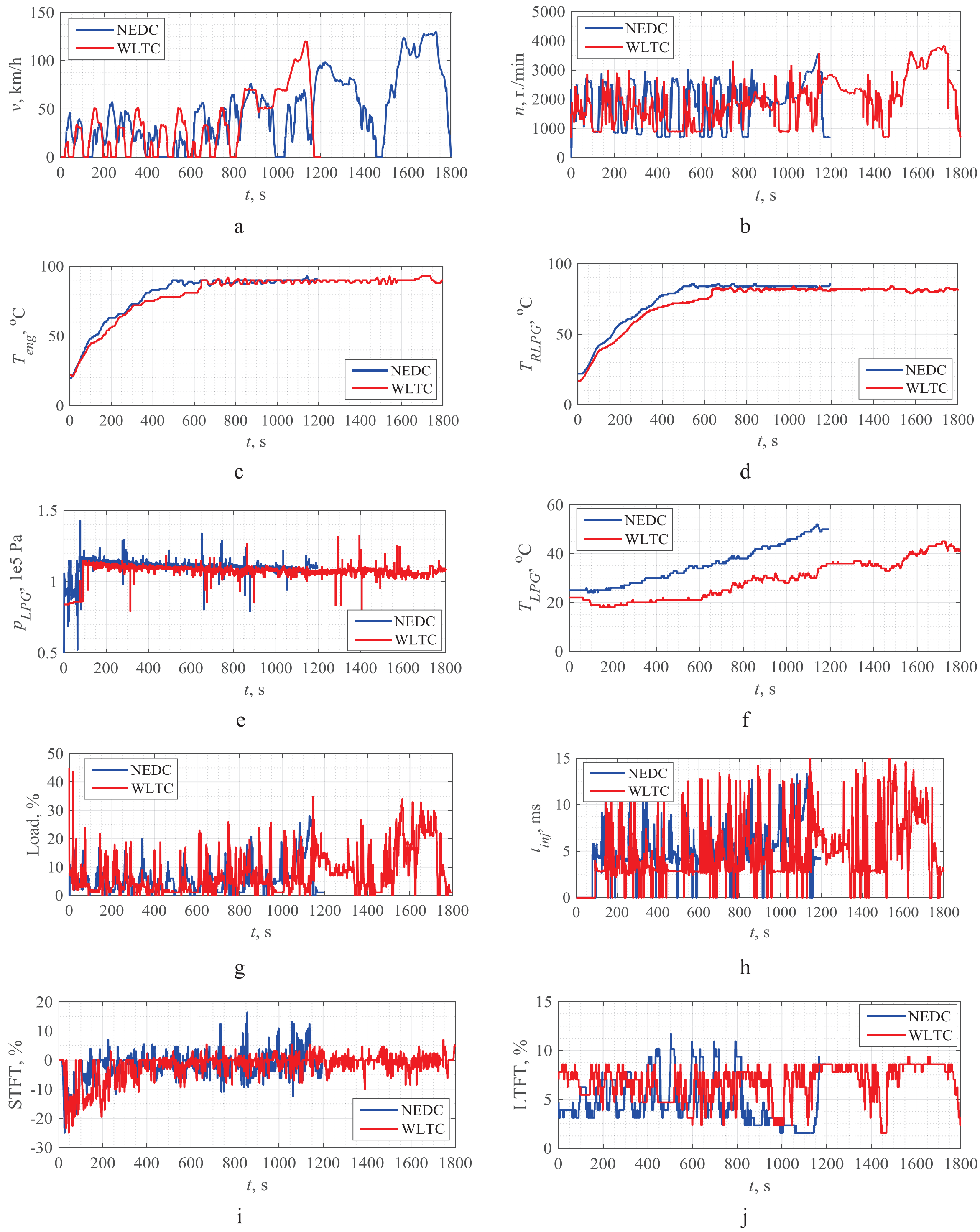

Fig. 4 Results of the research (description in main text)

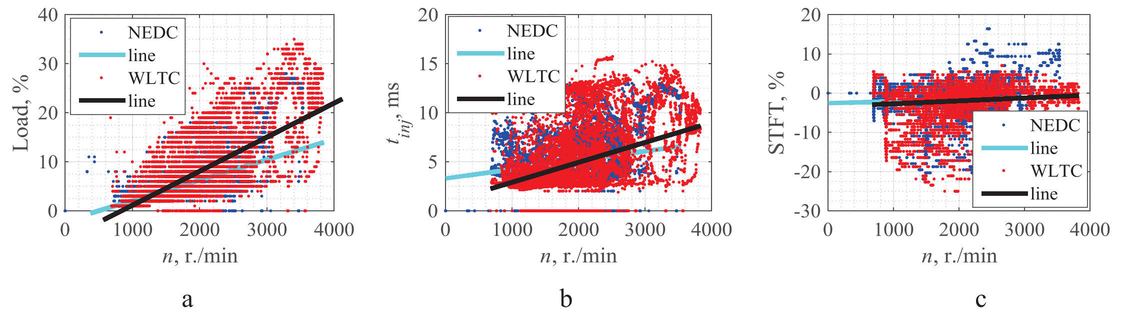

Fig. 5 The ECU-determined engine load (a), injector and cylinder injection time (b) and short-term correction (c) against engine speed for NEDC and WLTC cycles

Table 3

The linear functions describing the relations

Parameter	Function
load	$\text{Load}_{\text{NEDC}} = 4.169\text{e}-3 \cdot n - 2.067$ $\text{Load}_{\text{WLTC}} = 6.947\text{e}-3 \cdot n - 5.809$
injection time	$t_{inj\,\text{NEDC}} = 9.253\text{e}-4 \cdot n + 3.305$ $t_{inj\text{WLTC}} = 2.032\text{e}-3 \cdot n + 0.8798$
STFT	$\text{STFT}_{\text{NEDC}} = 4.295\text{e}-4 \cdot n - 2.554$ $\text{STFT}_{\text{WLTC}} = 7.369\text{e}-4 \cdot n - 3.434$

Based on the straight directional coefficients in Table 3, it was found that:

– the load calculated by the engine ECU over the WLTC cycle is 66.6% higher than in NEDC;

– in response to the load, the injection time (in this case represented by the I cylinder) over the WLTC cycle is 119% higher increments than in NDEC;

– the evaluation of the combustion process in the form of STFT has shown an incremental trend in the WLTC cycle 71.6% higher than in NEDC.

Thus, the information on higher energy demand during the WLTC cycle, published in literature reports, was confirmed [12, 13, 32]. By referring the test results to the roadside driving in non-standard vehicle cycles with a different engine [35], a closer correlation of the WLTC cycle than NEDC is visible.

5. Conclusions

The main aim of the study was to compare functional parameters of the gas supply system during NEDC and WLTC cycles. A vehicle equipped with a dual-fuel engine was used for this purpose. Originally equipped with multi-point petrol injection and alternatively with multi-point LPG vapour phase injection. In the organization of the tests, the procedures contained in the load chassis dynamometer with the function of powering the axle were used. In turn, a data recorder was used to record functional parameters. The conclusions are as follows,

– lower engine speed fluctuation was recorded for the initial phase of the NEDC cycle against the WLTC;

– the temperature waveforms of the motor and the reducer-evaporator are very similar;

– the LPG pressure for both cycles under consideration remains at a similar level;

– higher load, injection timing and STFT oscillations have been found for the WLTC cycle, which confirms a more accurate representation of actual driving conditions;

– functional relationships were determined for load, injection time and STFT in both tests.

In summary, the article presents an analysis of selected functional parameters of the gas supply system. Presented test results and functional dependencies of selected parameters allow to assess the character of NEDC and WLTC cycles. They are also the basis for the assessment of the correctness of engine adaptation to alternative power supply and model analyses. In the next stage, a deeper analysis of a larger number of functional parameters of the gas supply system operation and their relation to the petrol supply is planned.

Acknowledgment

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Analysis of Trip Generation Parameters Comparing Different Household Survey Samples Size

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Abstract

The household survey is the most complex survey in the traffic demand modeling process in terms of time, required sample size, costs and data analyzing. The household survey collects socio-economic data, vehicle ownership, household size and structure, and trip rates of residents. The significant problem of a household survey is related to collecting the required sample and achieving a good representation of the whole population. Often residents of the study area refuse to respond to a survey that is being conducted. This paper will analyze the impact of reducing the required household survey sample on errors in determining household daily trip rates. Based on the collected household survey in the urban area of the City of Slavonski Brod in Croatia, the authors will compare the results and differences of the total sample and the reduced samples.
KEY WORDS: *household survey, sample size, trip generation, trip rate*

1. Introduction

Traffic data is a basic and indispensable component of traffic modeling. Data collection is a very demanding activity in terms of finances and the time required to collect specific data. It is necessary to precisely plan activities to minimize the costs and period time for preparation and collection of data, while maximizing the accuracy and effectiveness of data. Errors in the input data will create errors in the output data of the model [1]. The data is used for three main purposes (i) to describe the current situation, (ii) for the development and use of the transport model, (iii) to monitor the effects of strategy implementation, policy and investment in the transport system.

The basic data used in traffic modeling can be divided into two categories:

1. traffic supply data:
   a) capacity of transport infrastructure and transport means;
   b) speed of transport means;
   c) traffic flow management;
   d) timetables.
2. traffic demand data:
   a) number of passengers (goods);
   b) travel costs and travel time;
   c) attributes of transport system users (socio-economic, age, household size, employment status, trip purposes).

Various transport demand models are used, but the most commonly used model is a four-stage model consisting of:

- trip generation. In the first step of the four-stage transport model, the total number of trips generated and attracted by each zone in the analyzed area is estimated. This can be achieved in several ways, by analyzing the trips of each individual or household within the zone and directly from the attributes of each zone: population, employment, number of cars, etc;
- trip distribution. Origin and destination, as well as the total number of trips in a certain period time is distributed between the zones and is shown by the origin-destination matrix or OD matrix;
- modal distribution. This step determines the type or mode of transportation. The choice of mode or type of transport is certainly one of the most important steps in the classic transport model since it has a significant impact on traffic planning and traffic policy of a particular city;
- trip assignments. In the final step of the classical transport model, there is a merge of transport demand and transport supply and optimal routes are defined.

The main weakness of the mentioned model is the lack of characteristics of the transport network in trip generation sub-model [2, 3].

The aim of this paper is to evaluate the trip generation parameters of different household survey samples and to check whether a smaller sample could achieve satisfactory parameter values as in the full sample. The research was

made based on paper [4] in which the authors analyzed 6000 household surveys in the full sample and reduced samples from 2400, 1000 and 750 households, but without a clear explanation of how they defined and determined the reduced samples. The rest of the paper is organized as follows: Chapter 2 describes the most common survey methods of transport planning, Chapter 3 describes the analysis and results of the research, and Chapter 4 summarizes the main conclusions of this research.

2. Travel Surveys Methods

Integrating various types of data into computer programs is a common thing. The most well-known computer programs for multimodal transport modelling PTV VISUM and AIMSUN, allow the import of various types of data, such as GIS data [5, 6]. Importing GIS data into computer programs significantly reduces the time required to create a traffic network, ie traffic supply (type of road, type of intersection). Unlike transport supply, collecting data on transport demand is a long-term activity that requires significant financial resources and time. When developing a multimodal traffic model, various research on data collection is conducted with the aim of obtaining OD matrices [6].

The household survey is the primary survey for collecting data on daily household trips. The household survey involves several methodologies, such as a direct interviews („face to face“), telephone interviews, computer-assisted personal interviews (CAPI) and computer-assisted telephone interviews (CATI). Other surveys, such as the cordon survey, can serve as an addition to the household survey or to verify data obtained from the household survey. A household survey as direct interview is the most expensive and complicated survey, but it gives the best results on the household trip pattern. It is estimated that conducting a survey by direct interview is three to ten times more expensive than other methods of data collection (for example by telephone), but the response rate to this survey ranges from 75% to 85% compared to self-completed surveys.

When conducting a direct interview survey, interviewers can give more detailed explanations in terms of the meaning of the question or the way it needs to be answered. Because these surveys can be quite lengthy and tedious, the interviewer can maintain the interest of the respondents and ensure that the entire household survey is completed without skipping questions and giving ambiguous answers. By noticing the interest of survey participants, and the way they answer questions, the interviewer can assess the veracity of the answers. Some of the shortcomings, apart from the cost of conducting the survey, are manifested in the time required to prepare the survey itself and to require trained staff that is geographically close to the survey location [7, 8].

Unlike a direct interview, self-completion of the survey takes place without the presence of a trained interviewer. The advantages of self-completion surveys are certainly lower costs compared to the direct interview, higher geographical coverage and ensuring impartiality because the interviewer does not influence the answers of the respondents. The biggest disadvantage of the self-completion survey is the low response rate, ie not returning the survey. It is estimated that the response rate to this survey ranges from 20% to 50%, which is significantly less than when conducting a direct interview survey. The survey form must be extremely well thought out and designed, and the questions must be very clear and unambiguous [7, 8].

An online household survey is financially cheaper than a traditional direct interview survey. Free applications can be used for the needs of the internet survey, in which case researchers only spend their time designing the survey form. There are no costs for interviewers who would do a classic survey using the direct interview method, nor the cost of printing a survey form. The problem is that Internet surveys are filled out by a certain group of the population (mostly the younger generation) [8].

Call Detail Records (CDR) are data generated by the physical movement of mobile phones. Mobile phone position information is required for the proper functioning of the network on the mobile device. Von Morner [9] lists several possible applications of CDR in the transport system: (i) public urban transport, (ii) individual transport, (iii) non-motorized transport. Rutten et al. [10] compared vehicle travel times between data collected using CDRs and detectors on motorways and urban roads in the Netherlands. Maerivoet and Logghe [11] compared CDR data with data collected on detectors and GPS data in the urban area of Antwerp (Belgium). The research showed similar results in travel time between the mentioned data sources. In [12], the authors developed a methodology for determining OD matrices using mobile data and Call Details Records, and by counting traffic at certain intersections. This methodology was validated using 2.87 million CDR records in Dhaka (Bangladesh).

GPS surveys are often used to collect household data and serve as a supplement to the household surveys. GPS devices enable obtaining very precise data on the origin and destination of travel, travel time, route and traffic conditions while driving. In some cases, the trip purpose can be determined if there is a land use attribute of the area in the GIS application. Although the use of GPS devices can introduce bias into passenger behavior, their use complements insufficient trip data from self-completing travel survey. Such surveys are used to make various analyses such as travel time analysis, modal trip distribution, and travel distribution models [13, 14]. One of the main problems of research using GPS devices is a weak signal in certain circumstances (tunnels, dense forests). An additional problem may be the cost of the survey, given the unit price of the GPS devices and the fact that each survey participant must be equipped with one device. This disadvantage can be eliminated by using "smartphones" with GPS. There is no equipment cost in this approach, as participants use their own mobile phones. Data collected using a mobile phone can be forwarded to the database in real time. Participants are required to enter the mode of transport, trip purpose, travel or parking costs for each GPS movement recorded through the application.

3. Analysis of Different Household Survey Sample Size

The household survey was conducted as part of the development of the Sustainable Urban Mobility Plan of the Urban Area of the city of Slavonski Brod, (Croatia). It was conducted on a random sample of households, by direct interview, on representative days, in October and November 2019. A total of 5% of the total number of households in the study area was surveyed. The survey was conducted in the household where trained interviewers asked questions related to general household data and all trips of each household member that occurred the previous day.

The study area is divided into traffic analysis zones (TAZ) where a specific household sample was collected in each traffic zone. Households were selected at random. The study area is divided into 93 zones, of which 76 zones are within the city of Slavonski Brod (residential zones, industrial zones, shopping centers, markets, etc.), nine zones are located outside the city, and eight zones represent external zones that are not located in the coverage area.

A total of 752 household surveys were collected in 36 residential zones. Based on the household survey, a comparative analysis of six samples was conducted. The following household survey samples were taken into account: total sample and reduced samples by 10%, 20%, 30%, 40%, 50% and 60%. (Fig. 1). The analysis of the full sample and reduced samples was performed using the SAS Studio program [15]. Representative reduced samples were determined in SAS Studio using the *Select random sample* menu containing the *Sample size* and *Specify the random seed* options. Reduced samples were stratified by zones (TAZ) so that in each zone, a specific percentage of the household was defined at random. *Specify the random seed* option specifies the initial "seed" to generate random numbers. If the specified "seed" is not defined, the program automatically determines the "seed" based on the system clock of the computer. This ensures randomness in the selection of samples.

Figure 1 shows the parameter values in the full sample and the reduced samples. The average number of trips generated by a household in the total sample is 5.8763, with a standard deviation of 3.1202. The median of the total sample, reduced sample by 10%, 20%, 50% and 60% is five trips, while the median of the reduced sample of 30% and 40% is six trips. The first quartile (Q1) of all samples is four trips, while the third quartile (Q3) is eight trips, so it is concluded that the interquartile range of the full sample and reduced samples is four trips, which means that 50% of households generate between four and eight trips per day. It can be seen that the maximum whisker in all analyzed samples is 14 trips, and all values above this value were determined as outliers. Also, it can be seen that the data on all samples are positive skewness, which means that the data are not symmetrically distributed around the median.

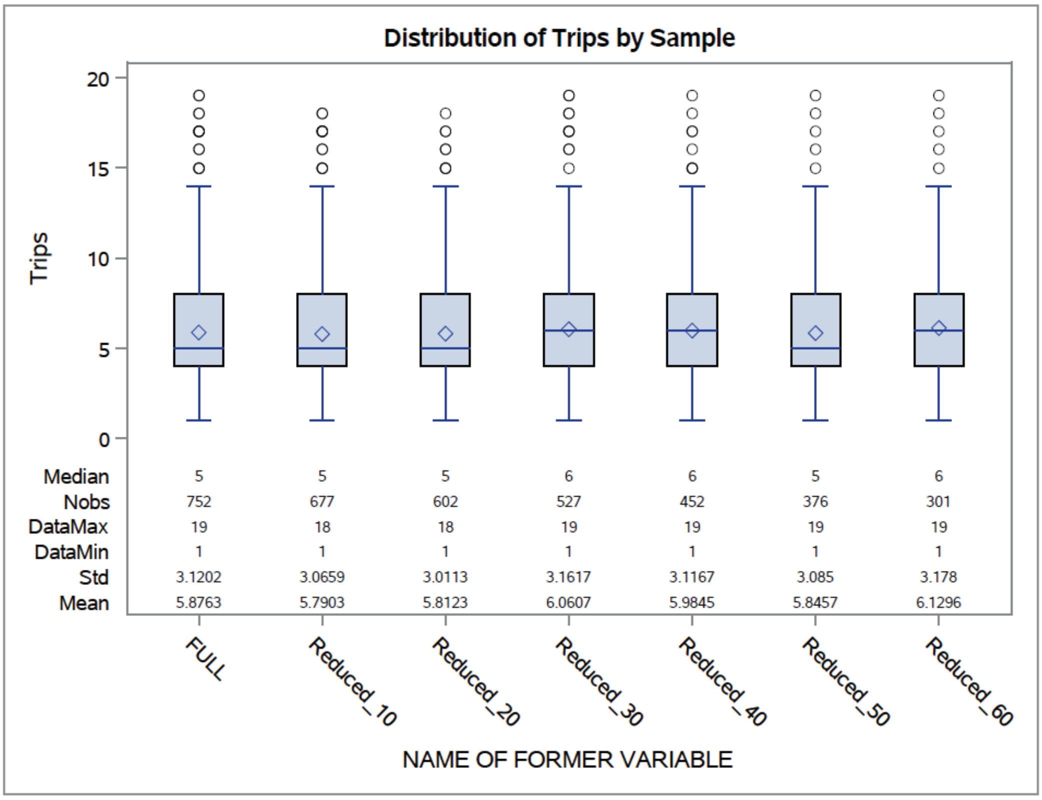

Fig. 1 Distribution of trips by sample size

The largest relative error was 4.31%, and was recorded on a sample that was reduced by 60%, and the minimum error was -0.52%, and it was recorded on a sample that was reduced by 50%. The relative error for the sample reduced by 10% is -1.46%, for the sample reduced by 20% is -1.09%, for the sample reduced by 30% is 3.14%, and for the sample reduced by 40% % is 1.84%.

The analysis of trip generation parameters was made for six travel purposes. Fig. 2 and Table 1 show the values

of the trip generation parameters of the total and reduced samples for the six purposes of the trip, namely return to home, work, education, leisure, shopping and others.

Fig. 2 Trip rates of full and reduced household sample

Table1

Trip rates of full and reduced household sample

Variable	FULL	Reduced_10	Reduced_20	Reduced_30	Reduced_40	Reduced_50	Reduced_60
return to home	2,654	2,623	2,618	2,734	2,710	2,649	2,784
work	0,985	0,982	0,942	1,042	0,998	0,920	1,113
education	0,394	0,368	0,375	0,429	0,425	0,431	0,455
leisure	0,387	0,383	0,370	0,383	0,398	0,407	0,359
shopping	0,657	0,654	0,679	0,670	0,655	0,636	0,631
other	0,799	0,780	0,824	0,803	0,799	0,803	0,784

The relative errors in Table 2 were calculated as a comparison between the trip generation parameters calculated for the whole sample and the trip generation parameters of the reduced samples. The largest relative errors were achieved for two purposes of travel: education and going to work. In other cases, the errors are below 10% which is satisfactory. Nevertheless, it can be concluded that, in general, the travel generation rates obtained from the reduced sample are close to those from the full sample.

Observing the parameters of a trip generation of reduced samples (Table 2), the largest relative error is 15.63%, and was achieved on the sample that was reduced by 60% and the trip purpose "education", while the smallest relative error is -0.20% in a sample which is reduced by 50% and the trip purpose is "return to home". It should be noted that in the sample reduced by 60% a deviation of more than 10% was obtained, so it can be concluded that in further analysis with reduced samples greater than 60% this error would be even greater.

Table 2

Trip rates percentage error of full and reduced household sample

Variable	FULL	Reduced_10	Reduced_20	Reduced_30	Reduced_40	Reduced_50	Reduced_60
return to home	2,654	-1,16%	-1,37%	3,02%	2,11%	-0,20%	4,89%
work	0,985	-0,31%	-4,42%	5,72%	1,26%	-6,61%	12,95%
education	0,394	-6,56%	-4,62%	8,95%	7,92%	9,46%	15,63%
leisure	0,387	-1,14%	-4,27%	-0,95%	2,91%	5,15%	-7,28%
shopping	0,657	-0,39%	3,42%	1,97%	-0,31%	-3,24%	-3,91%
other	0,799	-2,41%	3,09%	0,43%	-0,07%	0,50%	-1,90%

4. Overview and Conclusion

The household survey by direct interview is still considered the primary way of collecting data when developing a multimodal transport model. Other methods of data collection (GPS, CDR, Internet, smartphones) have great potential due to the development of network technologies, but a major drawback is the protection of personal data.

In this paper, certain travel generation parameters in the total household survey sample and six reduced samples (reduced by 10%, 20%, 30%, 40%, 50%, and 60%) were also analyzed. The average number of household trips of the total sample and the reduced samples were analyzed and compared. The relative errors of the average number of trips of all reduced samples were less than 5% in relation to the total sample, which is very acceptable.

Observing the relative errors of the trip generation parameters by a purpose that were analyzed in the paper. It can be concluded that the reduced samples have satisfactory results because the deviations are less than 10% in relation to the total sample. A sample that is reduced by 60% has deviations greater than 10% for two trip purposes which are work and education. If further analysis would use data from reduced samples of trip generation parameters whose relative errors are greater than 10% of the full sample, there is a possibility of obtaining erroneous results in the further process of making a traffic model, and thus making wrong conclusions.

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Vehicle Structure Related Design Criteria and Restraint Performance for Vans in Full-Width Frontal Impacts

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Abstract

In the preliminary design of a vehicle, some nominal values for the design parameters are required. The design criteria are the nominal values for the design parameters to obtain a vehicle with good crashworthiness. A group of 8 vans with different mass and brand, are selected from the crash test database of the National Highway Traffic Safety Administration (NHTSA). These vans which were manufactured between 2012 and 2017, earned four or five star rating in full-width rigid barrier (FWRB) frontal impact test. The values of the design parameters are statistically analysed and the corresponding design criteria and restraint performance are specified. Acceleration-based injury risk parameters and restraint performance metrics are defined. This paper presents design guidelines for a van with good crashworthiness and low injury risk which can be useful in the preliminary design of a van.
KEY WORDS: *vehicle safety, frontal impact, design criteria, restraint performance*

1. Introduction

The injury risk of an occupant is affected by the following main factors which include the mean acceleration of the occupant compartment, the shape of the crash pulse, the performance of the restraint system, the deformation of the car and the amount of intrusion into the occupant compartment [1-4]. In order to obtain a car with good crashworthiness, a set of design criteria has to be established. In crash tests, dummies record data for several injury measures, such as neck forces, chest deformation, chest and head accelerations, which are used in the formulas of injury criteria to assess injury risk to occupants [9]. Apart from the data measured by dummies, there are load cells and accelerometers that record the structural response of the car. In the preliminary design of a car with good crashworthiness, an engineer needs to know the nominal values for the design parameters related to the vehicle structure such as the acceleration, deformation and stiffness of the vehicle.

The National Highway Traffic Safety Administration (NHTSA) conducts full-width rigid barrier (FWRB) frontal impact tests using instrumented dummies under the New Car Assessment Program (NCAP). In these tests, the rigid barrier (i.e. wall) is composed of load cells measuring the crush forces and/or moments acting on the car; there are also several accelerometers attached to the car structure. The data collected for each car is presented in the website of NHTSA along with a crash test report. For FWRB frontal impact tests, these crash test reports include acceleration and compression of the dummy chest, maximum value of the HIC (head injury criterion), the neck injury criteria *Nij*, upper neck and femur forces, and deformation of the car. However the data, which are not available in the crash test reports, can be processed to obtain values for the design criteria that are critical to obtain a car with good crashworthiness in frontal impacts.

Turkey is a major producer of vans. In this paper, FWRB frontal impact test data of 8 vans with different mass and brand, were downloaded from the website of NHTSA [5]. These vans were manufactured between 2012 and 2017, and they earned four or five star rating (highest rating) in FWRB frontal impact test. The sensor data collected from these tests are filtered and further processed to obtain vehicle structure related design parameters which are not included in the crash test reports. These design parameters which are extracted from crash sensors, are maximum deformation of the car front in the deformation phase (i.e. dynamic crush), mean/peak accelerations of the occupant compartment using both accelerometers and load cells, maximum force sustained by the car structure, stiffness of the car front, and stiffness over mass ratio of the car.

The values of the design parameters extracted from crash sensors, are statistically analysed and the corresponding design criteria are suggested. Additionally, three metrics are defined to assess restraint performance of the tested vans. This study derives design criteria for the design parameters which are related to the van structure and restraint performance metrics which are not readily available in the crash test reports.

2. FWRB Frontal Impact Tests and Test Data Processing

In FWRB frontal impact tests, cars impact a fixed rigid barrier (i.e. rigid wall) with 100% overlap at a fixed impact speed of 56 km/h as shown in Fig. 1. The aim of this test is to obtain information about vehicle crashworthiness and the performance of the restraint systems. The rigid wall is composed of load cells measuring the crush forces and moments acting on the car. In these tests, a 50th percentile male Hybrid III dummy and a 5th percentile female Hybrid III dummy

are placed in the driver seat and the front passenger seat, respectively. The dummies are belted and equipped with tri-axial accelerometers, potentiometers and load cells. Several accelerometers are also attached to the vehicle structure such as the rear sills, rear seats and engine.

Fig. 1 FWRB frontal impact test [5]

One of the aims of this study is to derive vehicle structure related design criteria which can be obtained by processing the crash sensor data. In the NCAP FWRB frontal impact test, the total barrier force (i.e. crush force or wall force) and vehicle accelerometer data are filtered according to the Society of Automotive Engineers (SAE) Recommended Practice J211-1 [6]. The occupant compartment linear accelerations are expressed in the x and z directions of the global coordinate system shown in Fig. 1. The linear displacement of the undeformed occupant compartment in the global x-direction is used to estimate the deformation of the vehicle.

After having processed the sensor data as described above, the total barrier force is plotted against the displacement (or deformation) of the occupant compartment to obtain the overall force versus deformation characteristics of the structural elements of the vehicle in frontal impact. The curve in Fig. 2 presents an exemplar of force versus deformation characteristics derived from NCAP FWRB crash test data. It can be seen that the deformation of the car structure is predominantly plastic. The FWRB impact involves two phases which are the loading phase followed by the unloading phase. The loading phase starts from the first contact of the car with the wall and ends when the deformation of the car becomes maximum as seen in Fig. 2. In the unloading phase, a very small portion of the absorbed energy is returned to the vehicle due to spring-back of the vehicle structure. Since the deformation is close to being plastic, the loading phase is the dominant phase.

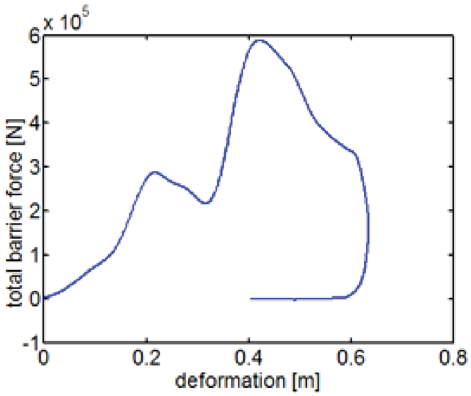

Fig. 2 Typical car-structure behaviour in FWRB test

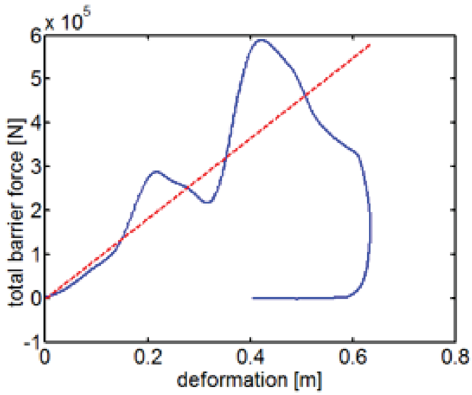

Fig. 3 Barrier-force-work based loading stiffness

3. Design Parameters for FWRB Frontal Impact Test

A set of design parameters is constructed which are known to be related with the crashworthiness of cars and injury risk of occupants. Table 1 presents this set of design parameters whose values are obtained directly from the crash test reports (OCR) or calculated from the analysis of sensor data (CSD). Among these design parameters, the acceleration of the occupant compartment is known to affect occupant injury risk with higher accelerations leading to higher restraint forces on the occupant [2-4, 7, 8]. The acceleration of the occupant compartment is related to the mass and the stiffness of the car. Apart from the mass of the car, the stiffness and the geometry of the energy-absorbing structures are the key parameters that determine the crash pulse experienced by cars in collisions. Therefore, in designing the occupant restraint systems, the stiffness of the energy-absorbing structures needs to be known. The total barrier force on the car is an important value that is required to design the structure of the car to withstand the impact.

The design parameters given in Table 1 also include injury criteria (HIC, *Nij*, chest compression and chest acceleration) whose values are measured by the sensors in the dummies. HIC is the head injury criterion which is based on the resultant acceleration of the centre of gravity of the head and its maximum value is recorded [9]. The maximum HIC value recorded in NCAP FWRB tests is calculated over a time interval of 15 ms hence it is also denoted by HIC15. The normalized neck injury criterion Nij is used to evaluate the risk of neck injuries in frontal impacts. Nij is based on a formula which combines the axial force and bending moment at the connection between the head and neck; in this formula

axial force and bending moment values are normalized by their corresponding critical values [9]. The limit or threshold values for the injury criteria are displayed in Table 2.

Table 1
Design parameters (OCR: obtained from crash test report, CSD: calculated from sensor data)

m	mass of the tested car including dummies and instrumentation (OCR)
k_{Lbf}	barrier-force-work based loading stiffness (CSD)
x_{max}	maximum deformation of the car (CSD)
F_p	peak total barrier force on the car (CSD)
F_{mw}	work-based mean total barrier force for the loading phase (CSD)
F_{mt}	time-based mean total barrier force for the whole crash (CSD)
ω_n	natural frequency of the car ($\sqrt{k_{Lbf} / m}$) (CSD)
t_r	estimated crash-pulse duration (CSD)
t_L	duration of the loading phase (CSD)
a_m	mean acceleration of the occupant compartment (OC) (CSD)
a_{mL}	mean acceleration of the OC during the loading phase (CSD)
a_{mt}	mean acceleration of the OC based on F_{mt} (CSD)
a_{mw}	mean acceleration of the OC based on F_{mw} (CSD)
a_{m25}	peak moving average (25ms) acceleration of the OC (CSD)
a_{m50}	peak moving average (50ms) acceleration of the OC (CSD)
a_p	peak acceleration of the OC (CSD)
a_{hmx}	maximum head resultant acceleration of the driver (OCR)
HIC_d	head injury criterion (HIC) value for the driver (OCR)
Nij_d	normalized neck injury criterion (Nij) value for the driver (OCR)
cc_d	maximum chest compression for the driver (OCR)
ca_d	maximum chest resultant acceleration for the driver (OCR)

Table 2
Limit values for the injury criteria in the crash test reports

	Driver (50th % male dummy)
$HIC15$	700
Nij	1
Max. chest compression	63 mm

As shown in Table 1, there are various design parameters whose values are calculated from crash sensor data. The first one is the barrier-force-work based loading stiffness k_{Lbf} which is determined by equating the area under the barrier force versus deformation curve in the loading phase (see Fig. 3) to spring energy as shown in Equation 1. In this equation, the terms x_{max} , F and x represent the maximum deformation of the car, the total barrier force and the deformation of the car, respectively. x_{max} is estimated from double integration of the accelerometer data and it is different from the permanent deformation of the car measured after the crash test. In Fig. 3, the dashed straight line whose slope is k_{Lbf} , is a linear approximation of the barrier force versus deformation behaviour of the car structure. The natural frequency ω_n of the car structure is defined in Eq. 1 as well. The peak total barrier force on the car F_p is calculated from load cell data.

The time at which the loading phase ends is t_L and it is calculated from accelerometer data. When time equals t_L, the velocity of the car becomes instantaneously zero and at this time the maximum deformation of the car occurs. t_r is the crash-pulse duration and it is also the time at which the car loses contact with the barrier. The velocity at which the car loses contact with the barrier, is called the rebound velocity V_r . The crash-pulse duration t_r is estimated with the aid of Fig. 3 and it corresponds to the time instant at which the barrier force first becomes zero in the unloading phase. With V_0 being the initial impact velocity of the car, Eqs. 2-4 are constructed to define the parameters given in Table 1 in which F , x and t represent the total barrier force, the deformation of the car and the time, respectively.

$$\frac{1}{2}k_{Lbf}x_{max}{}^{2} = \int_{0}^{x_{max}} F dx\,;\;\; \omega_n{}^2 = k_{Lbf} / m\,; \tag{1}$$

$$a_m = \left(V_r - V_0\right)/t_r\,;\;\; a_{mL} = \left(0 - V_0\right)/t_L\,; \tag{2}$$

$$F_{mt} = \int_{0}^{t_r} F dt / t_r\,;\;\; F_{mw} = \int_{0}^{x_{max}} F dx / x_{max}\,; \tag{3}$$

$$a_{mt} = F_{mt} / m\,;\;\; a_{mw} = F_{mw} / m\,. \tag{4}$$

Moving average acceleration of crash pulses was shown to better represent crash severity [1]. The calculation of moving average acceleration involves the mean value of acceleration within a specified moving time interval. This moving time interval can be chosen to be 25 ms or 50 ms [1, 10]. For instance, a time interval of 50 ms is swept throughout the crash pulse duration to calculate moving average accelerations for all 50 ms time intervals. For a given crash pulse (i.e. acceleration versus time history), the maximum (or peak) value of the moving average accelerations for the whole duration of the crash pulse is reported [10].

The injury risk of the occupant depends on both the crash severity (i.e. crash pulse) and the performance of the restraints (seatbelt, airbag, energy absorbing steering column and knee airbag). The metrics defined in Table 3 are defined to evaluate restraint performance. Lower values of these metrics indicate better restraint performance. The head/chest acceleration factors are basically the ratios of head/chest acceleration over occupant compartment acceleration hence they show how well the restraints (especially the seatbelt and airbag) limit head/chest accelerations for a given amount of occupant compartment acceleration.

Table 3

Definitions of restraint performance metrics (See also Table 1)

Head acceleration factor	$rh50 = ahmx / am50$
Chest acceleration factor	$rc50 = cad / am50$
Overall acceleration factor	$ro50 = rh50\, rc50$

The 8 vans which received four or five stars (the highest rating), are the only vehicles manufactured between 2012 and 2017 in the NHTSA database. In Tables 4 to 6, the mean values of the design parameters and restraint performance metrics (with standard deviations in parentheses) are given for these 8 vans. Apart from the individual values of mass and stiffness, the values presented in Tables 4 to 6 are the design criteria values to construct a van with good crashworthiness and low risk of occupant injury.

Table 4

Car structural properties, mean and standard deviation

m [kg]	k_{Lbf} [kN/m]	ω_n [rad/s]	x_{max} [m]	F_p [kN]	F_{mw} [kN]
2212.5 (98.0)	1217 (96.8)	23.46 (1.17)	0.717 (0.039)	1014.2 (141.3)	434.5 (13.0)

Table 5

Occupant compartment acceleration parameters, mean and standard deviation

t_r [ms]	t_L [ms]	a_m [g]	a_{mL} [g]	a_{mt} [g]	a_{mw} [g]	a_p [g]	$am25$ [g]	$am50$ [g]
132.68 (11.16)	75.77 (4.19)	-13.71 (1.26)	-21.11 (1.07)	-14.13 (1.40)	-20.05 (0.99)	-36.94 (5.30)	-29.94 (2.19)	-26.62 (1.94)

Table 6

Injury criteria values and restraint performance metrics with mean and standard deviation (driver)

HIC_d	Nij_d	cc_d [mm]	ca_d [g]	$rh50$	$rc50$	$ro50$
204.0 (83.3)	0.3 (0.05)	20.4 (3.2)	41.8 (4.7)	1.83 (0.29)	1.57 (0.13)	2.89 (0.61)

4. Discussion

The design criteria values for the design parameters in this study are presented in Tables 4 to 6. The results indicate that in order to obtain a good performing van in FWRB frontal impacts, the vans should have a natural frequency ω_n (i.e. square root of stiffness over mass) of 23.46 rad/s with a standard deviation of 1.17 rad/s, a mean deceleration (a_{mL}) of 21.11 g for the loading phase with a standard deviation of 1.07 g, a mean deceleration (a_m) of 13.7 g for the whole crash with a standard deviation of 1.26 g and a mean moving average deceleration (a_{m50}) of 26.62 g with a standard deviation of 1.94 g. The results indicate that vans require a frontal deformation of 0.717 m on average with a standard deviation of 0.039 m to absorb the crush energy and limit occupant compartment deceleration. The peak force F_p that the van has to endure by keeping the occupant compartment intact is 1014.2 kN on average with a standard deviation of 141.3 kN. The restraint systems of these good performing vans produce maximum head accelerations and maximum chest accelerations which are 1.83 times and 1.57 times the peak moving average (50ms) acceleration of the occupant compartment.

Occupant injury risk and the values of the injury criteria (HIC_d , Nij_d , cc_d) are affected by both the mean acceleration of the occupant compartment (OC) and the restraint (airbag, seatbelt, load limiter, pretensioner, energy absorbing steering column, knee airbag) properties. Thus, an optimised restraint system is essential for a car with good crashworthiness. In order to rate the vans regarding their injury risk in FWRB impacts, an overall injury risk parameter $R = |a_{m50}| \cdot r_{h50} \cdot r_{c50} = |a_{m50}| \cdot r_{o50}$ can be used. It can be seen that the overall injury risk parameter R is an acceleration-based metric. Table 7 presents the ratings received by the analysed vans in the US NCAP FWRB tests and the corresponding overall injury risk parameters. Table 7 indicates that 4 star vans have higher injury risk parameter R values except the 8th van which should have experienced considerable occupant compartment intrusion and/or ineffective knee airbag interaction (leading to lower-extremity injuries) which is not taken into account by the parameter R. It should also be noted that the number of data is only 8 since these are the only vans which received four or five stars (the highest rating), and manufactured between 2012 and 2017 in the NHTSA database. As a future work, the correlations between acceleration-based injury risk parameters (R, a_{hmx} , ca_d) defined in this study and the injury criteria (given in Table 3) will be explored.

Table 7

Correlation between vehicle rating and the overall injury risk parameter R

Van	1	2	3	4	5	6	7	8
Rating	5 star	5 star	5 star	5 star	5 star	4 star	4 star	4 star
a_{m50}	-23.31	-26.63	-26.45	-24.99	-26.46	-29.72	-27.18	-28.24
r_{o50}	2.280	2.805	3.306	3.312	1.915	3.728	3.250	2.544
R [g]	53.13	74.69	87.44	82.77	50.68	110.8	88.35	71.83

5. Conclusions

Eight vans which received four or five star rating (highest rating) in NCAP FWRB frontal impact test, are analysed. The experimental data of these best performing vans with different mass and brand, can help to obtain design criteria values for the design parameters which are known to affect the crashworthiness of vehicles and injury risk of occupants. The design parameters which are presented in Table 1, are either obtained from crash test reports or calculated by processing the sensor data. The most recent van models are analysed hence the presented design criteria values belong to the state-of-the-art van design. Occupant injury risk is determined by the combined effect of crash severity (measured by mean acceleration) and restraint properties. In this study, acceleration-based injury risk parameters are used and an overall injury risk parameter is defined which takes into account the combined effects of crash severity, restraint effectiveness and vehicle structural performance. This paper presents design guidelines for a van with good crashworthiness and low injury risk which can be useful in the preliminary design of a van.

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Logistics Approach to the Organization of Unbalanced Freight Transportation in Transport Networks

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Abstract

In the process of freight transportation, there often arises a situation when the volume of freight delivery from its suppliers exceeds its consumers` warehouse capacity. In this case, there is a need to use intermediate points for excess freight temporary storage and, as a consequence, we face a multi-stage transportation problem. The transport mobility plan for suppliers, consumers and intermediate points is often not explicitly specified, and simply a map of their location is introduced, that is, the transport problem is set using a transport network. It is given a description of the logistics approach, which, through the use of transport technology, solves the problem of unbalanced freight transportation organization in transport networks.
KEY WORDS: *freight transportation, transport network, multi-stage transportation problem, optimization*

1. Introduction

Due to socio-economic changes taking place in Ukraine and under the influence of globalization, the logistics chains of supply of goods and raw materials at enterprises are changing. They become longer and more complex in structure. Influenced by information technology facilitating material and financial flows, the integration of individual supply chain links, which are independent business units, is intensifying. The geography of material flows is also expanding. It is manifested, in particular, in an increase in freight turnover in both international [1] and domestic [2] road transportation.

The effective operation of freight customs complexes (FCC) and terminals contributes to rolling stock optimization at transport enterprises engaged in freight transportation [3-5]. The technology of freight delivery with the use of an FCC as its intermediate temporary storage points in regular transportation will increase the number of MTE – motor transport enterprises` semitrailer trucks on routes and will allow their more efficient use [6].

In the international freight transportation on Ukraine-EU and EU-Ukraine route, the FCC located on the Ukrainian side of the border may serve as a transshipment point [2]. Ukraine`s western regions bordering on the EU member states, based on effective cross-border cooperation, allow capitalizing on the counties` favorable geopolitical potential. Long-term projects for the FCC use along the western border is one of the options for streamlining freight transportation, so the rational organization of MTE`s operation and cooperation with terminal and warehouse complexes is extremely important and relevant.

2. Logistics Approach to the Organization of Unbalanced Freight Transportation in Transport Networks

Let us describe the logistics approach, which solves the problem of staged freight transportation (multi-stage transportation problem–MTP) in its network representation. In this case, two alternatives are considered, either the total warehouse capacity of freight consumers and intermediate points is greater than or is equal to freight quantity offered for transportation by freight suppliers or it is less than freight quantity to be transported.

Suppose there are m homogeneous freight supply points (SP) $A_1, A_2, \dots A_m$, with freight quantity $a_1, a_2, \dots a_m$ respectively. There are n freight consumption points (CP) $B_1, B_2, \dots B_n$ with applications for its acceptance in volumes $b_1, b_2, \dots b_n$ accordingly. Moreover, the total volume of this freight delivery exceeds the total number of applications for it, namely:

$$\sum_{i=1}^{m} a_i > \sum_{j=1}^{n} b_j . \tag{1}$$

Suppose that there are also l intermediate warehousing points (WP) $C_1, C_2, \dots C_l$ for the temporary storage of excess freight, which can accommodate it in the quantity $c_1, c_2, \dots c_l$ respectively, and, in this connection, there are two possible

alternatives of the ratios $\sum_{i=1}^{m} a_i, \sum_{j=1}^{n} b_j \ i \sum_{k=1}^{l} c_k$ if the condition (1) is fulfilled:

alternative 1 $$\sum_{j=1}^{n} b_j + \sum_{k=1}^{l} c_k \geq \sum_{i=1}^{m} a_i; \qquad (2)$$

alternative 2 $$\sum_{j=1}^{n} b_j + \sum_{k=1}^{l} c_k < \sum_{i=1}^{m} a_i. \qquad (3)$$

Let us consider the second alternative (3) of freight delivery as the most interesting from the application perspective through a specific example, where the location diagram of freight supply and consumption points is presented in the form of a traffic network (TN). The TN indicates the main loading and unloading points; the average time of movement between them, namely: freight SPs are marked with black circles (Haisyn– A1, Odesa – A2), freight CPs are indicated with black squares (Cherkasy – B1, Kharkiv– B2, Zaporizhia– B3, Mykolaiv– B4) and WPs are coded with black triangles (Kropyvnytskyi– C1, Dnipro –C2, Kryvyi Rih– C3) (Fig. 1).

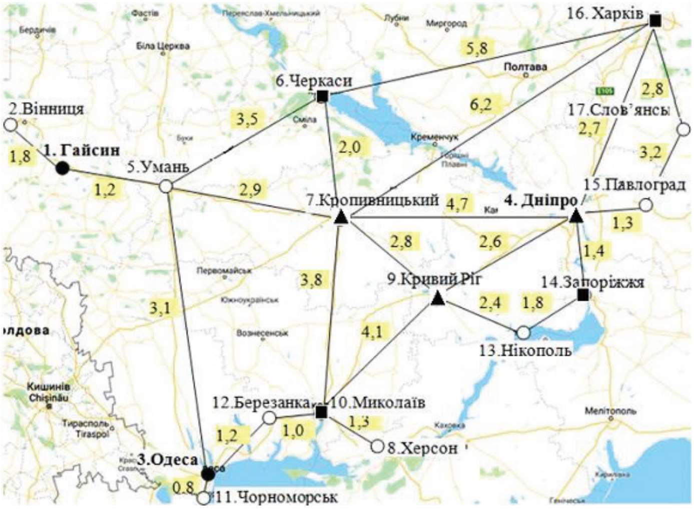


Fig. 1 Traffic network

In the TN, the number of freight SPs $m = 2$ (A_1, A_2), where $a_1 = 10$ freight units (FU), $a_2 = 10$ FUs, the number of freight CPs $n = 4$ (B_1, B_2, B_3, B_4), where $b_1 = 2$ FUs, $b_2 = 2$ FUs; $b_3 = 2$ FUs, $b_4 = 2$FUs, the number of intermediate WPs $l = 3$ ($C1$, $C2$, $C3$), and their capacity will be as follows: $c_1 = 1$ FUs, $c_2 = 1$ FUs, $c_3 = 1$FUs. There are also 8 intermediate transit points in the TN. A simplified TN diagram is shown in Fig. 2.

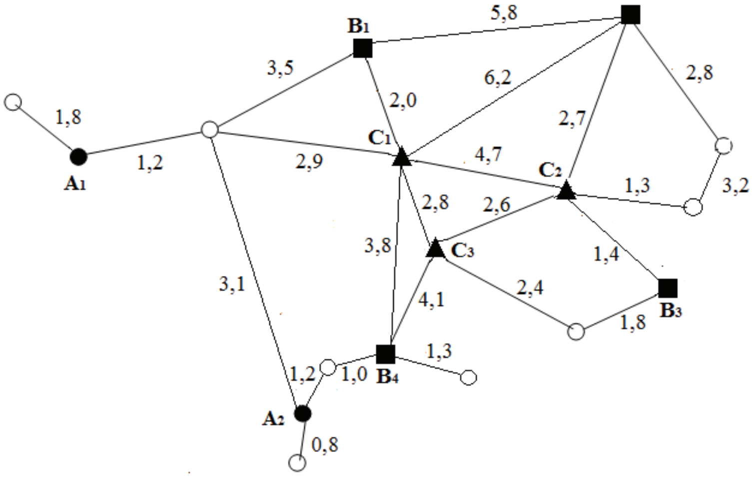


Fig. 2 Simplified traffic network diagram

In order to present this information in a form convenient for its further processing, it is necessary to summarize the network representation of the freight delivery scheme in a tabular form [7]. First, an array of distances between TN adjacent points is built, and this stage involves its manual assembly. Then automatically (using the appropriate program),

based on the array of distances, the origin-destination matrix between all TN points is built.

The shortest route method [8], using the origin-destination matrix data, evaluates the shortest distances in the TN from each freight SP and warehousing points (Table 1), from each warehouse point to each freight CP (Table 2). Routes corresponding to these distances are also created [7], which may include intermediate points on the freight transportation routes (for example, the routes from Haisyn SP to its four CPs):

Haisyn → *Uman* → *Cherkasy* = **4.7*;***
Haisyn → *Uman* → *Kropyvnytskyi* → *Kharkiv* = **10.3***;*
Haisyn → *Uman* → *Kropyvnytskyi* → *Dnipro* → *Zaporizhia* = **10.2*;***
Haisyn → *Uman* → *Odesa* → *Berezanka* → *Mykolaiv* = **6.5.**

Table 1

Distance of SPs to CPs and WP

SPs/CPs	Cherkasy	Kharkiv	Zaporizhia	Mykolaiv	SPs/CPs	Kropyvnytskyi	Dnipro	KryvyiRih
Haisyn	**4.7**	**10.3**	**10.2**	**6.5**	Haisyn	4.1	8.8	6.9
Odesa	6.6	11.6	10.3	2.2	Odesa	6	8.9	6.3

Table 2

Distance of WPs to CPs

SPs/WPs	Cherkasy	Kharkiv	Zaporizhia	Mykolaiv
Kropyvnytskyi	2	6.2	6.1	3.8
Dnipro	6.7	2.7	1.4	6.7
KryvyiRih	4.8	5.3	4	4.1

In order to solve the problem of planning and further provision of mass freight transportation service in the TN, a software application (SA) was developed using *Delphi*, the algorithmic programming language, and *Visual Basic for Application* macros to work with the Excel spreadsheet [9].

The SA execution process includes 4 steps illustrated in Fig. 3-6.

Fig. 3 presents a dialog box of the transportation structure task, i.e. the number of SPs, CPs, and WGs.

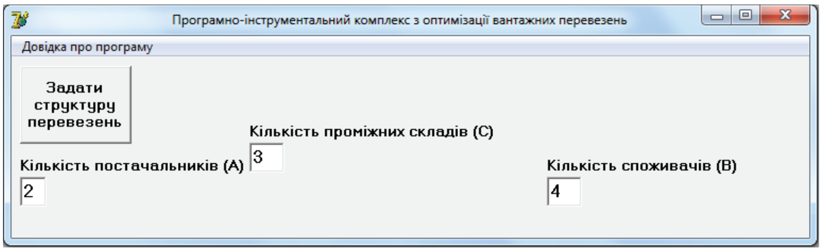


Fig. 3 Dialog box of the 1st step in SA execution

Fig. 4 illustrates a dialog box for entering the freight transportation volume.

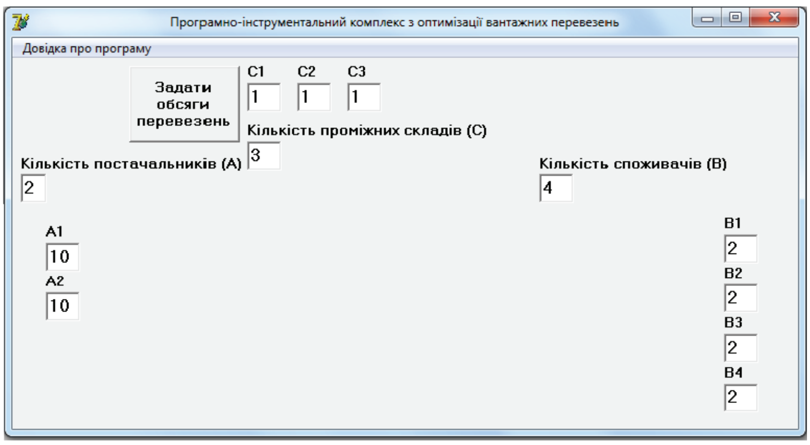


Fig. 4 Dialog box of the 2nd step in SA execution

Fig. 5 shows a dialog box for entering the matrix of TN transport communications, i.e. the shortest distances between SPs and CPs, SPs and WPs, WPs and CPs (see Tables 1-2).

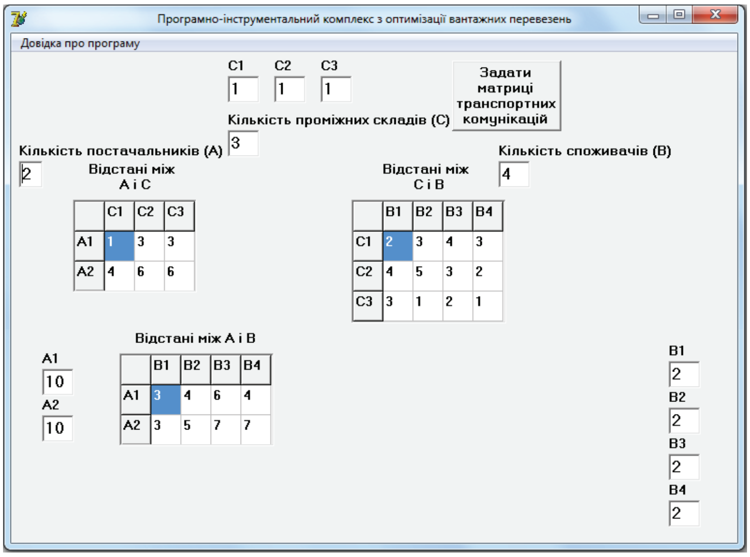


Fig. 5 Dialog box of the 3rd step in SA execution

Fig. 6 is a dialog box of the 4th step in SA running. It schematically presents the results of its execution, namely: the volume of freight transportation between SPs A_1, A_2 and CPs B_1, B_2, B_3, B_4 at the *first stage* of freight delivery (the cost of its implementation is 54.9 conventional monetary units – CMUs); freight transportation volumes between SPs A_1, A_2 and WGs C_1, C_2, C_3 at the first stage of freight delivery as well (the cost of its realization is 19.3 CMUs); freight transportation volumes between WPs C_1, C_2, C_3 and CPs B_1, B_4 at the second stage of freight delivery (the cost of its realization is 7.4 CMUs); freight transportation volumes between SPs A_1, A_2 and B_1, B_2, B_3, B_4 at the third stage of freight delivery (the cost of its realization is 55 CMUs); the total (current) cost of all the three freight delivery stages is 136.6 CMUs.

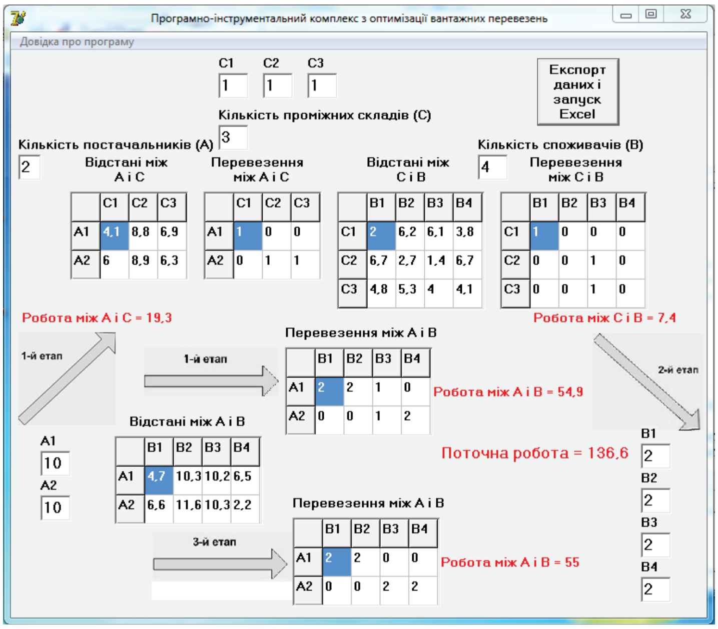
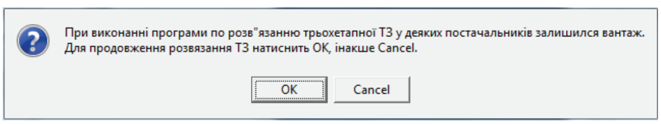


Fig. 6 Dialog box of the 4th step in SA execution

At the same time, an information message is displayed on the screen informing the user about the further calculations:



After pressing the OK key, the MTP solution continues and, as a result, Fig. 7 essentially presents a dialog box of freight delivery in the fourth stage. This figure (see Fig. 7) schematically illustrates the results of the last step in the SA execution, namely: the volume of freight transportation between an SP A_2 and a CP B_1 at a cost of 2.2 c.m.u. and the

ultimate (final) realization cost of all the four stages of freight delivery, which is 138.8 c.m.u.

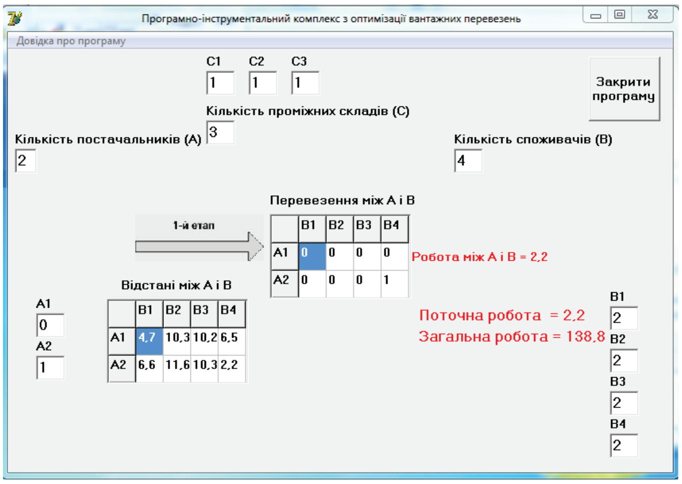


Fig. 7 Dialog box of the 4th stage of the MTP solution

3. Conclusions

The proposed logistics approach to the unbalanced freight transportation organization in transport networks was realized in the form of the software-instrumental complex (SIC), which combines the stage of the network representation of the freight delivery scheme in a tabular form and the stage of the planning and further provision of mass freight transportation service in the TN. It is proved to be efficient in optimizing freight traffic at the transport enterprises of the Association of International Road Transport Carriers of Ukraine.

This approach to the optimization of mass freight transportation in the TN, which is based on the use of modern information technology tools, demonstrates one of the solution methods, but has the following limitations:

1. At the 2nd, 3rd and subsequent stages, an assumption is made about the readiness of all its freighters to stow this freight in the quantity corresponding to the initial order.

2. For the successful application of the offered approach, it is necessary to transform a preliminary network representation model of the freight delivery into a tabular form.

3. The SIC can be used for small and medium transport networks due to the limited software environment for its implementation – Excel spreadsheets.

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Analysis of Access to Mobile LTE Services for Polish Rail Passengers on the Example of a Selected Section of the Railway Line

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Abstract

The article will present the current state of use of modern telecommunications systems LTE on Polish railways. Quick technological development and market requirements for modern communication systems caused that railway transport, having proved to be one of the basic carriers, must guarantee access to telecommunication services, both for passengers and the railway infrastructure itself. The rapid development of civilization, globalization, has resulted in the need for increasing access to wireless technologies. The introduction of technology based on the GSM-R standard on the railways has led to the integration in a single system of both voice and data services for traffic guidance and control. An unquestionable advantage of the GSM-R standard is also the possibility of cooperation in the field of voice services for passengers with GSM. While GSM-R provides an appropriate level of services for the safety and reliability of control systems, unfortunately, with the increase in requirements for data transmission services for passengers (e.g. Internet access, VoiP), it is not able to meet these requirements.

In addition, for GSM-R, when a train exceeds 250 kilometers per hour, users pass through many cells in a very short time. This results in a loss of signal transmission at 300 Hz. While this disappearance is hardly noticeable for calls, it causes a very high bandwidth loss during data transmission. Therefore, the article will include a study on the availability of mobile networks for services designed for passengers. The evaluation of the use of external wireless communication networks LTE in terms of mobile services, stability and signal availability will be made.

KEY WORDS: *Telematics, LTE, GSM-R*

1. Introduction

Currently, the research on the use of LTE system in railway tasks is carried out in an advanced way in Asian countries (China, India, Indonesia) and also on the European continent in Western European countries (Spain, Sweden) [6, 14, 27-30]. These considerations take into account the solutions proposed by telecommunications consortia Alcatel-Lucent, Nokia-Siemens and Huawei [3, 4, 15, 19].

Due to the specificity of access to the technology and frequency bands used, the solutions presented above are based on the analysis of electromagnetic compatibility of existing radio systems based on frequencies specific for given regions (900, 1800, 2100, 2600 MHz bands) [5, 6].

Extremely important for the analysis of LTE system operation, not only in railway solutions, are issues related to the use of modern antenna systems based on the technique of adaptive antennas, the use of SDMA (Space Division Multiple Access) systems or MIMO multi-antenna systems [7, 12, 31].

Theoretical bases for theoretical analysis and modelling of broadband systems, including LTE, for various areas of application have been presented in publications [13, 16, 17, 20, 24-26]. The methodology of research as well as results and analyses of computer simulations concerning mathematical modelling of the system and transmission communication channel have been indicated, paying attention to ensuring adequate capacity and reliability of the system and taking into account the problem of train movement [10, 11, 21, 22].

LTE system architecture and issues related to broadband signal transmission were standardized in [1, 2, 23].

Currently, no research is being conducted in Poland to use the LTE system on railways as a natural successor to the European railroad radio communication system based on the GSM-R standard, currently being introduced in our country. Within the framework of research works carried out at the Faculty of Transport of Electrical Engineering and Information Technology of the University of Technology and Humanities in Radom, an attempt was made to develop a method of safe data transmission between railway traffic control devices using fourth generation radio systems [7-9, 18].

2. LTE Signal Transmission Conditions for High Speed and High-Speed Trains

In the LTE system parameters described in the standardization documents, the range of functionality of this system in relation to mobile users defined as (EU) [2]. According to them, four levels of functionality were distinguished in relation to the speed of objects using the system:

- full functionality for users (EU) moving at speeds up to 15 [km/h];
- high performance for users (EU) travelling at 15 - 120 [km/h];
- functional support for users (EU) travelling at speeds up to 360 [km/h];

– no functionality has been defined for mobile users travelling at speeds between 350 - 500 [km/h].

Therefore, there is a need to define the requirements and define the transmission capacity of railway telegrams using LTE technology. The LTE system specification states that the theoretical signal delay is 10 [ms], and 10 - 100 [ms] in the control level.

2.1. Rail Research

In order to make measurements, a transmission measurement system for the open LTE system has been built, presented in Fig. 1. The system will be used for testing, similarly as in [7], in which the transmission takes place in the first stage of testing between the server and the virtual control-command and signaling device, located on the train path. Within the framework of measurements, systems that are not real time systems from Microsoft Windows and Apple Mac OS X operating systems family were used. For modeling we assume GSM-R transmission parameters with the assumption that meeting these conditions meets transmission safety conditions. The measurements were made in accordance with ETSI TS 102 250 standard.

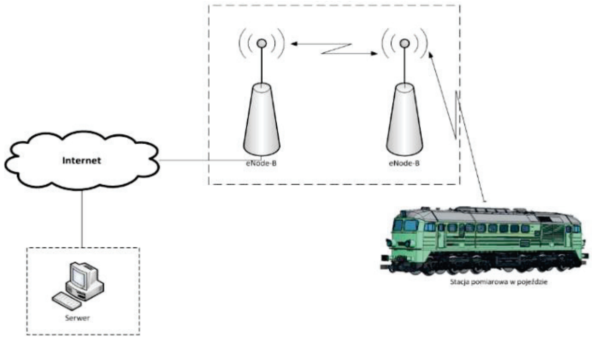

Fig. 1 Measurement diagram

The vehicle used a computer with Mac OS X 10.9.5 (Fig. 2) and a Huawei LTE modem with the following parameters:

– type of input/output: SIM card slot, microSD memory card reader, USB 2.0;
– supported standards: LTE, GSM, GPRS, EDGE, UMTS, HSPA+/HSPA;
– frequency of operation: 800/850/1800/1900 MHz;
– 3G/4G transmission bands: GSM - 850/900/1800/1900 MHz;
– UMTS - 900/2100 MHz;
– LTE - 800/900/1800/2100/2600 MHz;
– maximum wireless transmission speed: downlink up to 150 Mbps (LTE), uplink up to 50 Mbps.

Fig. 2 Mobile testing station

On the receiving side there was a Windows 10 server connected to the Internet via a broadband LTE network via the MOXA OnCell G3470A-LTE gateway (Figure 3) with the following parameters:

– supported standards: GSM/GPRS/EDGE/UMTS/HSPA/LTE;
– transmission bands: LTE 2100/1800/2600/900/800 MHz (B1/B3/B7/B8/B20), UMTS/HSPA 2100/1900/850/800/900 MHz;
– transmission speed: LTE - 20 MHz bandwidth: 100 Mbps DL, 50 Mbps UL;
– HSPA - 42 Mbps DL, 5.76 Mbps UL;
– EDGE - 237 kbps DL, 237 kbps UL;
– GPRS - 85.6 kbps DL; 42.8 kbps UL;
– 4 LAN interface ports RJ-45 10/100/1000Mbps;
– cellular network antenna connectors: 2, SMA (female);
– console port: RS-232 (RJ-45);

- network protocols: ICMP, DDNS, TCP/IP, UDP, DHCP, DNS, SNMP, HTTP, HTTPS, SMTP, SNTP, ARP;
- routing/firewall: NAT, forwarding port, IP/MAC/Port filtering;
- VPN: maximum number of tunnels - 5, IPSec (DES, 3DES, AES, MD5, SHA-1, DH2, DH5), PSK/X.509/RSA;
- configuration and management options: SNMP v1/v2c/v3, Web / Serial Console, SSH, Remote SMS Control;
- Number of SIM cards: 2.

The computer with the MOXA gateway was a server.

Fig. 3 Measuring station on the server side

Measurements were made on route Warszawa Centralna - Kraków Główny running on railway line no. 4 - Central Railway Bus (colour orange - Fig. 4) from 15.08 to 19.08.2019 between 5 a.m. and 10 p.m. taking into account train timetable, with train speed up to 160 km/h. Train speed was monitored by means of iPhone with Sygic software. For this purpose, a seat at the window was taken in the vehicle in order to better receive GPS signal.

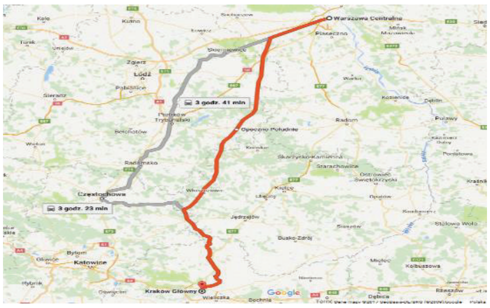

Fig. 4 The measurement route leave only the line for measurements

No mechanisms were used to block this mode of operation at the measuring terminals to ensure that domestic roaming networks can measure services.

The average results of measurements on the route under consideration are shown in Tables 1 and 2.

Table 1

Indicators for data transmission – download

		Orange	Play	Plus	T-Mobile
Mean Data Rate- upload	MDR [Mb/s]	3,43	2,78	5,02	3,21
HTTP IP-Service Setup Time	HIST [ms]	1 932,00	3 428,00	1 191,00	3 792,00
HTTP Session Failure Ratio	HSFR [%]	66,31	71,28	47,28	61,72

Table 2

Indicators for data transmission – upload

		Orange	Play	Plus	T-Mobile
Mean Data Rate- upload	MDR [Mb/s]	0,92	1,18	1,51	0,9
HTTP IP-Service Setup Time	HIST [ms]	1 741,00	1328,00	1 538,00	2632,00
HTTP Session Failure Ratio	HSFR [%]	38,36	42,23	28,95	42,34

Table 3

Loss and delay ratings for packages

		Orange	Play	Plus	T-Mobile
Round Trip Time	RTT [ms]	149,11	128,24	119,12	169,43
IP packet loss ratio	IPLR [%]	15,84	15,18	7,6	14,12
IP packet delay variation	IPDV [ms]	119,28	110,12	113,72	99,21

The studies described in Tables 1-3 give rise to the thesis that appropriate spatial planning of LTE systems allows for the resignation from dedicated development of a rail-specific system such as GSM-R. It is possible to use an open LTE system for railway purposes, both for controlling train movements and for passenger data transmission.
The results of radio signal level tests generated from terminals are shown in Fig. 5.

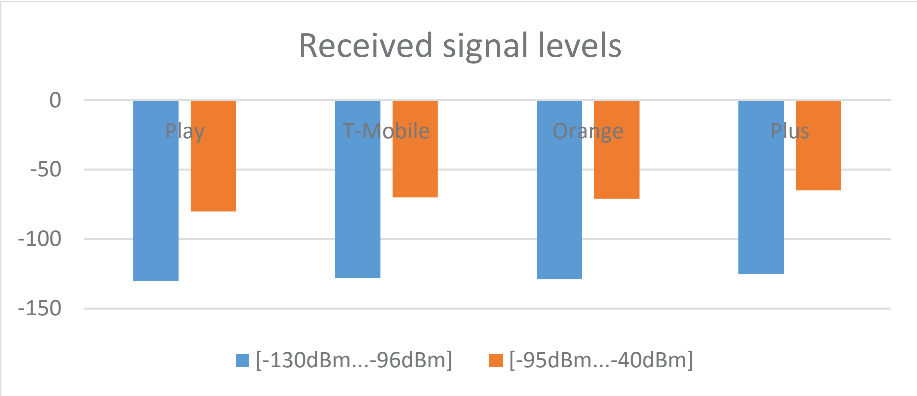

Fig. 5 Signal levels from terminals for 4G technology on the measure route

In some parts of the railway line, the signal level has disappeared, due to the fact that the communication infrastructure allows the signal to cover urban areas and roads. Rolling stock was not included. In case of network scaling and signal coverage of railway lines as well, there are huge savings. Dedicated communication infrastructure for railways is not needed then, because it can be replaced by open LTE network with appropriate coding of telegrams according to PN-EN 50159 standard.

3. Conclusions

The article presents the scope of conducted research on the availability of data transmission services in LTE standard on a selected railway line. The main objective of the conducted research was to assess the quality of mobile Internet available in rail transport for public users.

The information obtained during the research confirms the requirements of users for the QoS quality guaranteed by the operators allowing for trouble-free use of data transmission services in the LTE standard. Using the available tools, the quality of mobile LTE network on a selected railway line was tested. The tests consisted in making measurements of basic QoS parameters, as well as verification of operation of selected Internet services. The obtained average link speed and ping value in accordance with the minimum acceptable values recommended by UKE allow, in the opinion of the author of the article, to browse websites, use VoIP telephony and network games. The verification of other services showed that with the link parameters provided, it is also possible to use multimedia services, i.e. streaming HD movies and Internet TV. Minimum packet losses during transmission confirm the possibility of trouble-free use of e-mail services.

The conducted research allowed to verify the actual parameters of the LTE network in the scope of data transmission in rail transport, thus they may contribute to the evaluation of the offered data transmission services with the use of LTE technology in less urbanized areas.

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Analysis of International Trade in Transport Services in Selected EU Countries

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Abstract

Rapid changes in technology as well as the integration and specialization of economy reinforce trade motives and the consequences of integration into the world trade system. Trade in services includes trade in transport and travel services, telecommunication, computer and information services, manufacturing services on physical inputs owned by others, business services and other business services. Import and export belong to the basic international trade activities, allowing to obtain utility values from abroad or to supply them abroad. They reflect the advantages and disadvantages of individual economies reflect government policies and regulations. The aim of this paper is to point out the state and basic tendencies in trade of transport services in relation to total international trade in services. The survey focuses on the selected countries of the EU. In identifying the state and basic tendencies in trade of services and their components, we used OECD statistical data, about international trade in services, export and import and also the structure of the trade. The modification of Balassa RCA index is used for evaluation some comparative advantages. Trade in services and, in particular, transport services, is under constant pressure from various factors, such as those of associations, interest groups, environmental criteria, licenses, qualification of employees or other regulations.
KEY WORDS: *international trade, transport, travel, services*

1. Introduction

At present, changes are taking place in the field of the economy, which are most often characterized by terms such as globalization, integration, trans-nationalization. They correspond qualitatively to new relationships between national economies, societies, processes that cross national borders. The international economic system is no longer aggregated by nationally determined functions, but becomes autonomous as production and markets become truly global. Economic activities are fragmented, divided and re-integrated to create new interconnections between countries, economies or entities. The importance of the division of labor between individual states, national economies and groups is growing, and consequently the importance of foreign trade activities [1].

As the importance of services in the creation of GDP and added value in individual economies grows, so does their importance in international trade [4]. Import and export belong to the basic foreign trade activities, while they enable to obtain utility values from abroad (import) or to supply them abroad (export). At the same time, these activities reflect the advantages and disadvantages of individual economies, or rather reflect government policies [6, 14]. In the past, mercantilism has emphasized the importance of government measures to support exports and restrict imports. Smith and Ricardo pointed to the need for an unrestricted free market with an invisible hand of the market to ensure that countries and their economies differentiate themselves according to their ability to produce the goods efficiently. Heckscher-Ohlin's theory of international trade and comparative advantages points to the connection with various subsidies at the national level, which affect the efficiency of production, as well as with the intensive use of own resources in exports and obtaining what is rare in imports [10]. Porter's theory of national competitive advantage [25] points to the impact of the four attributes, namely subsidies on factors of production, domestic demand conditions, supporting industries and corporate strategies, structure and competition in the market. New theories of trade point to other characteristics in the economy or individual sectors, for example, the importance of the amount of economies of scale achieved [2, 15].

Most theories dealt with trade in goods, less with services. With the growing understanding and perception of the importance of knowledge in the transformation processes in sectors of the economy associated with the provision of services, new issues are evoked in relation to international trade in services and their individual components. Transport services are becoming an immediate part of foreign trade relations and with the development of integration there are changes in trade with them [7].

In the professional literature, the definition of the service category is not yet uniform and consistent [8, 27]. To define this term, a wide range of approaches is used, which take into account storability / non-storability, weight / weightlessness, different consumption patterns, etc. [9, 25]. As there are no separate categories of services according to their characteristics, it is more appropriate to consider the difference between them as gradual and related to the smooth transition between the tangible and intangible continuum [15]. Similarly, when defining e-services, the professional public refers specifically to the technology of service provision, i.e. the use of ICT in the process of service provision [16, 18].

2. Theoretical Background

When assessing and identifying trends in foreign trade in transport services, it is necessary to define two key areas, namely the definition of services, including their breakdown and the processes associated with foreign trade, including the possibility of evaluating and identifying trends.

Trade in services reflects the value of services exchanged between residents and non-residents of the economy, including services provided through foreign affiliates established abroad. Trade in services includes trade in transport and travel services, communication services (postal, telecommunications, computer and information services), construction services, insurance and financial services, computer and information services, royalties and manufacturing services on physical inputs owned by others, other business services (business, operational leasing, technical and professional services, etc.), cultural and recreational services and government services. Trade in services leads to the exchange of ideas, know-how and technology, although it is often constrained by obstacles such as national regulations. While transport services indicate the development of international trade and the demand for it comes from international trade, other business services indicate changes in the business environment, companies and challenges to improve their position in the international market. All services are based on specific knowledge, skills and abilities [5, 17, 18].

The assessment and identification of trends in international trade in services is based on three interrelated concepts - division of labor, opportunity costs and comparative advantages [20]. The identification of the state and basic trends in trade in services and their components can be based on OECD statistics 2018 [21, 22, 24], which contain data used to analyze trade, exports and imports. All OECD countries compile their data according to the 2008 System of National Accounts (SNA) [23].

Within the analysis of trade in transport services, the basic trend and the trend in terms of the structure of trade in transport services according to individual modes of transport can be identified by basic statistical tools. A modified Balassa RCA index is used to compare export trends. The Balassa index is defined as the share of a selected country's exports in a given commodity group in that country's total exports to the share of world exports in that commodity group in total world exports. It is therefore based exclusively on data on exports in a given commodity group, the country's total exports and world exports. It indicates the relationship between the specialization of the selected country and the specialization of another country, or a reference group of countries, in this case the world [13, 14]. Modification of the index is possible according to the relevant commodity group, total exports in the given group and exports of the given regional grouping.

The formulation of the result is, of course, dependent on the achieved value of the index. The existence of the country 's comparative advantages in exports in a given commodity group is indicated by the value of the RCA indicator greater than 1. If the index of a given commodity group is less than 1, this is a comparative disadvantage [26]. Indicates that the country exports less than the reference group average in a given commodity. For an even more detailed identification of the revealed comparative advantage, according to source [11] possible index values can be divided into four categories (a-d) determining its size and intensity:

a) $0 < RCA \leq 1$ no comparative advantage;
b) $1 < RCA \leq 2$ weak comparative advantage;
c) $2 < RCA \leq 4$ moderate comparative advantage;
d) $4 < RCA$ strong comparative advantage.

3. Aim and Methodology

The aim of this paper is to point out the state and basic tendencies in trade in transport services in relation to trade in services and trade in individual types of transport services based on international statistics. The survey focuses on the Visegrad countries (further V4 countries), e.g. Slovak Republic (SR), Czech Republic (CR), Hungary (H) and Poland (PL) as part of the European Union and the Eurozone. V4 countries have been a part of the European Union (EU28) since 2004. SR is also part of the Eurozone (EU19).

Table 1

Main performance indicators for V4 countries in 2013 and 2016 (OECD 2013-2016) [23]

Indicator		SR		CR		H		PL		EU28		EU19	
		2013	2016	2013	2016	2013	2016	2013	2016	2013	2016	2013	2016
Population	mil	5,6	5,4	11	10,5	10,4	9,9	39,7	38,6	507	511,5	338	341
GDP per capita	PPP$ 2015	27838	30520	31252	34454	24522	27335	24697	27362	37419	39435	39900	41755
GDP growth	%	-	8,99	-	16,35	-	18,51	-	12,33	-	10,07	-	8,89
GDP growth per capita	%	-	22,39	-	16,14	-	32,74	-	26,12	-	5,39	-	4,65
Increase in exports of trade in services	%	-	0,42	-	1,10	-	8,42	-	11,43	-	2,47	-	2,06
Increase in exports in trade in transport services	%	-	4,98	-	5,37	-	7,74	-	10,68	-	-8,98	-	-1,44
Export performance in transport services	%	28,13	29,32	22,59	23,54	24,16	24,01	27,34	27,15	19,00	16,88	17,28	16,64

From the point of view of the previous economic development of these countries until the year 1989, it is usually assumed that their foreign trade activities have a similar development and therefore form a regional grouping of V4. The performance indicators of evolution of GDP and export in services as well as the transport services for V4 countries in the 2013-2016 are shown in Table 1. Export performance in services expresses the volume of exports in transport services in total exports of services.

In identifying the state and basic tendencies in trade in transport services and their components, we used OECD 2018 statistical database [21, 22, 24], which contain data used to analyze trade, export and import. We focused on the evaluation of transport modes shares, regional distribution or main regional direction and structure of transport services trade.

4. Results

When comparing and evaluating the V4 countries in terms of their export and import of transport services in years 2013 and 2016, it can be stated (Table 2) that the shares in the export of transport services to the EU28 countries were equal to 69% in the year 2013 for Czech Republic and 82% in the year 2016 for Hungary. Similar results are in the import of transport services, while the share of imports from EU28 countries with the exception of the Czech Republic reaches a high level (Table 3). In terms of mutual trade ties of the V4 countries, relatively small shares were identified, with the exception of the export of transport services of the Czech Republic to Slovakia.

In terms of the increase in exports of trade in services in the period under review (Table 1), there are significant differences between the V4 countries. The lowest increase of 0.42% was in the Slovak Republic, the highest in Poland 11.43%, but all V4 countries recorded either a positive or negative significant difference compared to the EU28 and EU19. The V4 countries achieved positive growth in trade in transport services, but both the EU28 and the EU19 saw a decline in trade in transport services. Similarly, the V4 countries achieve significantly higher export performance in trade in transport services (ratio between exports of transport services and exports of services) compared to the EU28 and the EU19.

Table 2

Transport services exports in V4 countries in terms of their geographical direction in 2013 and 2016

Export in transport services	SR		CR		H		PL	
	2013	2016	2013	2016	2013	2016	2013	2016
	100%	100%	100%	100%	100%	100%	100%	100%
EU28	**71%**	**71%**	**69%**	**72%**	**79%**	**82%**	**79%**	**81%**
Euro area	**47%**	**49%**	**49%**	**52%**	**55%**	**53%**	**63%**	**63%**
Austria	11%	15%	3%	3%	**16%**	13%	4%	4%
Germany	16%	15%	**15%**	**15%**	14%	**14%**	**26%**	**26%**
SR			6%	7%	4%	4%	2%	1%
CR	15%	12%			1%	2%	3%	3%
H	4%	3%	3%	3%			1%	1%
PL	1%	1%	5%	5%	4%	5%		
V4	**20%**	**16%**	13%	15%	9%	11%	6%	6%
UK	1%	2%	7%	7%	8%	9%	4%	5%
USA	1%	0%	2%	2%	2%	2%	4%	3%

Table 3

Import of transport services in V4 countries in terms of their geographical direction in 2013 and 2016

Import in transport services	SR		CR		H		PL	
	2013	2016	2013	2016	2013	2016	2013	2016
	100%	100%	100%	100%	100%	100%	100%	100%
EU28	**85%**	**83%**	**47%**	**48%**	**79%**	**80%**	**73%**	**76%**
Euro area	**48%**	**48%**	**37%**	**37%**	**59%**	**60%**	**55%**	**54%**
Austria	16%	13%	2%	2%	10%	8%	3%	3%
Germany	18%	22%	10%	11%	20%	20%	24%	23%
SR			6%	6%	6%	6%	2%	2%
CR	20%	16%			3%	3%	4%	4%
H	7%	6%	2%	2%			1%	1%
PL	6%	7%	2%	2%	3%	4%		
V4	**33%**	**29%**	10%	10%	13%	13%	7%	7%
UK	1%	1%	3%	4%	5%	4%	4%	6%
USA	1%	1%	7%	7%	5%	4%	6%	5%

Tables 4 and 5 are stated the results with respect to foreign trade activities related to trade in transport services and passenger transport services within the V4 and EU28 countries as well as EU19 in the years 2013 and 2016. Percentages of trade in transport services show a positive difference between exports and imports in Slovakia, Hungary and Poland. They are also positive in Czech Republic in the year 2016. The only exception was the year 2013, when the

import volume of transport services in the Czech Republic was higher than exports. In the V4 countries as a whole, exports exceed significantly imports in trade in transport services, in contrast to both the EU28 and the EU19.

Table 4

Structure of trade in transport services by transport mode

Trade in transport services		SR		CR		H		PL		EU28		EU19		V4	
		2013	2016	2013	2016	2013	2016	2013	2016	2013	2016	2013	2016	2013	2016
Sea transport	export	1%	1%	1%	1%	1%	1%	4%	3%	**39%**	**32%**	23%	20%	3%	2%
	import	10%	9%	5%	6%	4%	4%	17%	16%	32%	29%	20%	17%	10%	10%
Air transport	export	3%	3%	21%	20%	33%	37%	12%	12%	28%	31%	19%	24%	17%	18%
	import	0%	0%	5%	9%	9%	8%	6%	5%	3%	3%	5%	4%	6%	6%
Rail transport	export	15%	12%	8%	7%	7%	5%	4%	3%	3%	2%	5%	4%	7%	5%
	import	0%	0%	5%	9%	9%	8%	6%	5%	3%	3%	5%	4%	6%	6%
Road transport	export	**41%**	**38%**	**59%**	**56%**	**47%**	**45%**	**61%**	**60%**	22%	23%	**39%**	**38%**	**56%**	**54%**
	import	55%	51%	48%	57%	38%	40%	50%	46%	26%	28%	40%	43%	47%	48%

When assessing the share of exports and imports of passenger transport services in the total trade in services of V4, EU28 and EU19 countries, it can be stated that, unlike in the EU28, in V4 countries exports exceed imports, with the highest percentage differences seen in Hungary. Road transport dominates in the structure of transport services export and import (Table 4) in the all V4 countries as well as in EU19. The share of personal travel services in travel services both in export and import is about 5% lower in the V4 countries compared to the EU28 and EU19 (Figs. 1-2).

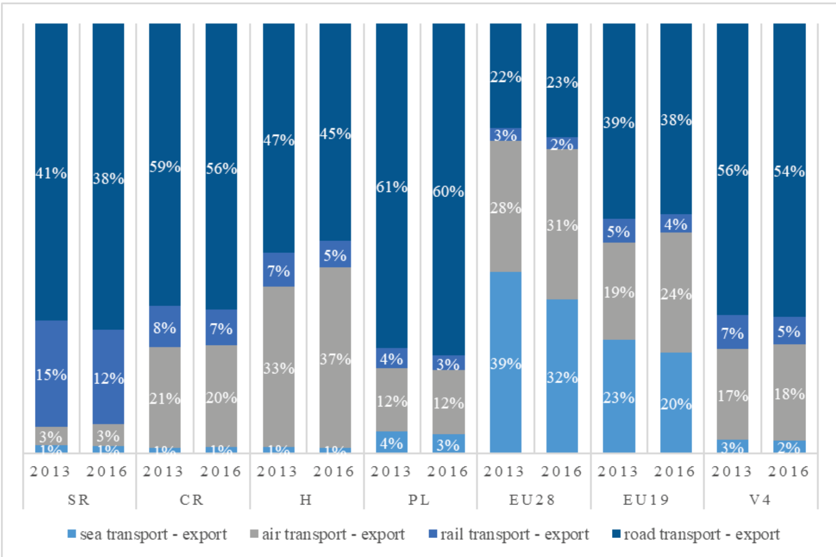

Fig. 1 Share of export in services of selected countries, EU28 and EU19 countries

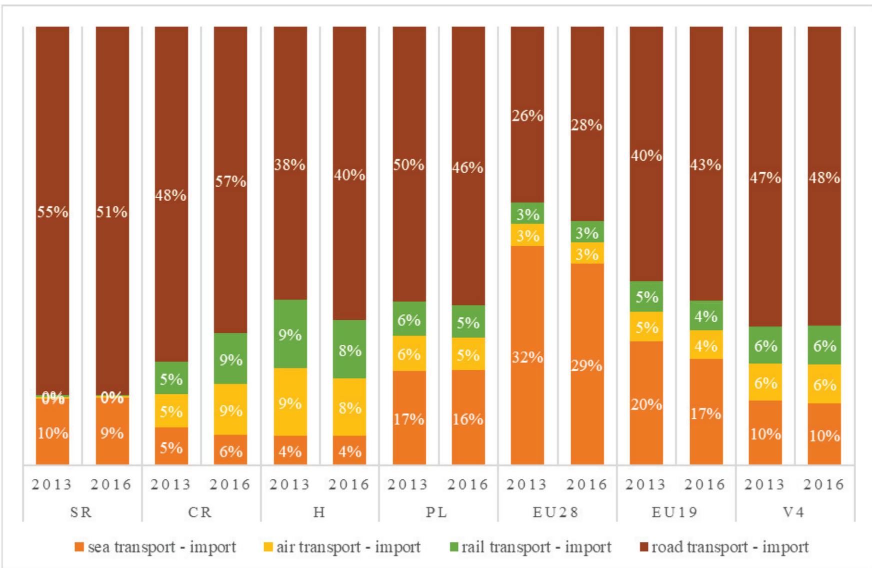

Fig. 2 Share of import in services of selected countries, EU28 and EU19 countries

Table 5

Structure of trade in travel services

Trade in travel services		SK		CZ		H		PL		EU28		EU19		V4	
		2013	2016	2013	2016	2013	2016	2013	2016	2013	2016	2013	2016	2013	2016
Business	export	15%	14%	27%	23%	12%	9%	19%	25%	15%	15%	14%	13%	19%	20%
	import	13%	14%	23%	18%	21%	17%	27%	22%	19%	18%	15%	15%	24%	19%
Personal	export	85%	86%	73%	77%	88%	91%	81%	75%	85%	85%	86%	87%	81%	80%
	import	87%	86%	77%	82%	79%	83%	73%	78%	81%	82%	85%	85%	76%	81%

In order to determine the tendencies and possible specialization of the V4 countries, we investigated the share of exports in transport services in the export of services. If we focus on assessing exports and the potential comparative advantage of the V4 countries in the transport services business through the Balassa RCA index [11, 14], it can also be stated (Table 6) that Slovakia and Poland have a weak comparative advantage in the transport services (Balassa RCA index is more than 1.00), which in the period under review in Slovak Republic increased. To compare the level of the Balassa index for transport services, we state (Table 6) that:

- Slovakia achieves a moderately strong comparative advantage in trade in telecommunications services (Balassa RCA index is more than 2.00), which increased even more in the period under review;
- in trade in postal and courier services (Balassa index higher than 2.00 in 2013, and higher than 1.00 in 2016) and transport services, a weak comparative advantage, which is, however, higher than in the Czech Republic and Poland;
- In other countries, only weak comparative advantages were recorded (Balassa RCA index between 1 and 2), namely in Hungary in trade in telecommunications, postal and courier services, in Poland in trade in transport services.

Table 6

RCA Balassa Index - export in V4 countries for transport services

Balassa Index RCA	SR		CR		H		PL	
	2013	2016	2013	2016	2013	2016	2013	2016
Transport services	**1,10**	**1,14**	0,88	0,91	0,95	0,93	**1,07**	**1,05**
Telecommunication services	**2,83**	**3,82**	0,43	0,33	**1,44**	**1,94**	0,66	0,43
Postal and courier services	**2,39**	**1,34**	0,75	0,74	**1,31**	**1,42**	0,68	0,86

5. Conclusions

International trade in services has been growing in recent years, and the share of services in GDP is also growing, especially in the developed countries of the world. Within the V4 countries in 2013-2016, overall trade in services increased on the export side by 7%, on the import side decreased by 0.85%, trade in transport services increased by 22.9% on the export side and remained at the same level on the import side. Trade in postal and courier services on the export side increased by 7.76% as well as the same percentage increase on the import side. In trade in telecommunications services, exports increased by 5.79% and imports decreased by 2.28%.

Trade in services and, in particular, transport services, despite the V4 membership in the EU28 and in the single market, is under constant pressure from various factors, such as those of associations, interest groups or other groups [3, 19]. Three of the V4 countries are not members of the euro area and the use of national currencies and their own monetary policy also affects international trade in the trade in services. However, new transport-related technical and technological solutions create new opportunities in the trade in services and need to be constantly addressed. Technological changes in different sectors and markets lead to changes in the trade in services, which are inevitably linked to international trade and the use of the comparative advantages of individual countries in the international environment [12]. However, barriers and emerging opportunities in trade in services need constant attention, as innovations in products, processes or business models based on digital technologies, data analytics, software, etc. are directly linked to cross-border data flows. Trade in services as the center or heart of innovation is currently gaining new meaning and dimension.

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Services of River Passenger Transport in Ukraine in the Trend of Behavioral Economy

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Abstract

The retrospective analysis and analysis of prospects for the use of river freight transport in Ukraine give reasons to expect river passenger transportation services as a complementary generation of the offer of business stakeholders. Formation and realization of the corresponding potential of river passenger transport will be possible in the conditions of restoration and stimulation of demand for such services. Conditions and mechanisms for creating demand for inland passenger traffic by the regular and tourist sectors have been investigated. The necessity to search for extracurricular success factors of river passenger transport of value direction is substantiated. The effectiveness of the implementation of which, in particular, depends on the rate of spread of the behavioral economy, the implementation of its principles in the predominantly rational behavior of potential passengers of river transport in terms of logistic service quality (facilities, time, convenience, compatibility, etc.).
KEY WORDS: *river passenger transport, demand for transport services, inland waterway transport, value factors*

1. Introduction

Globalization of the economy and regional integration as significant factors influencing the formation of a competitive supply of river transport has a significant impact on economic growth and sustainable development of individual regions and the country as a whole. Modernization of river transport, which should be considered not only as a component of modernization of the economy but also as an element of the transformation of public life, affects the improvement of market decision-making processes of consumers and mechanisms of public choice.

The history of river passenger transport in Ukraine both within the USSR and during its independence shows a decline in demand for river passenger transport over a long period time. For example, if in 1975 the number of transported passengers amounted to 27.9 million passengers, in 2000 – 2163.3 thousand passengers, then in 2018 – only 596.2 thousand passengers. However, the decline in demand for such transportation was accompanied by a decrease in the supply of services by businesses and other stakeholders, including the state, which showed low interest for the development of the sector and low efficiency of public administration. The unsatisfactory condition of the majority of river infrastructure and suprastructure and point investments by some private investors do not stimulate the development of river passenger transport in Ukraine.

The development of river freight transport will facilitate access to river infrastructure by the passenger transport business, first of all, by means of opening river waterways and the resumption of river ports.

In addition, since in foreign markets the tourist segment plays the leading role in maritime passenger traffic and is positioned as part of the cargo segment, passenger seaports can be part of port transport and logistics clusters which may later be joined by river ports with the participation of “river-sea" vessels. This also indicates the untapped potential of river ports as part of expanding the geography of passenger traffic.

Not less important consequential result of the growing demand for river transportations is the strengthening of the role of human values, improving the environment, economic socialization, sustainable development with its inherent features of a socially inclusive approach to generating economic growth, going beyond rationality and shaping inclusive behavior by economic agents and others, and collectively – the formation of an environment that becomes attractive for generating demand for passenger transportation in Ukraine. In addition, an increase in demand for cruises, the realization of tourism, recreational potential of the country etc. can be the point factors of growth.

The above-mentioned versatility of approaches to assessing the prospects of river passenger transport in view of the actualization of the impact of the behavioral economy on its development enriches the expected usefulness obtained by the participants of the passenger transportation market and determine the relevance of this study.

2. Methodology

The method of formulating the conclusions of the empirical study is an observation made by forming an information base of the studied object and identifying preferences among business entities in the process of verifying the hypothesis about the possibility of realizing the potential of river passenger transport in Ukraine under certain conditions. The development of river passenger transport in Ukraine is analysed with the help of a comparative analysis of the most developed sectors of river passenger transport of Germany, Poland, France. Marketing research techniques used in the study are the survey method with the help of self-developed questionnaires and desk research. The implementation of the performed empirical study was carried out in the following sequence.

3. Results

The review of the most developed segments of river passenger transport in such European countries as Germany, Poland, France has been performed in this work in order to derive the dominant trends in the development of river passenger transport, the results of comparison of which are given in Table 1.

Table 1

Comparative analysis of countries: the segment of passenger transportation by river transport, 2016 [1]

No	Indicator	Unit	Europe	Countries		
				Germany	Poland	France
1	Length of navigable river routes	km	28000	6708	3572	5034
2	Density of river roads	km/1000 km²	2.75	18.78	11.42	7.82
3	Number of enterprises in the sector	units	4000	437	248	308
4	Number of employees in the sector	person	18645	5787	545	2518
5	Absolute deviation of the number of employees in the passenger transportation service, 2016/2012	person	3948	1745	272	551
6	Profitability of the sector (the ratio of gross operating income to turnover)	%	-	29	29	7
7	River cruise fleet (vessels)	units	359	58	1	32
8	Number of small river cruise ships (10-39 beds)	units	67	3	-	24
9	Number of one-day cruise ships, including:	units	-	913	117	365
	- ships on rivers and canals	units	-	783	117	365
	- ships on the lakes	units	-	130	-	-
10	Number of passenger seats on rivers and canals	thousand seats	-	168.8	10.32	47.6
11	Number of passengers carried by rivers and canals	million person	-	34	-	10.6

The analysis of Table 1 showed that the highest density of river roads among the analysed countries is in Germany - 18.78 km/1000 km^2, it is characterised by the largest share of navigable river routes that are regularly used - 84.2%.

There are about 4,000 domestic passenger transport service companies in Europe. They employ 18,645 people. The share of enterprises in Germany, Poland, France and Italy is 49%. They employ 59.95% of employees. The largest increase in employees in 2012-2016 was in Germany - 1745 people, (30%), France (551 people, or 21.88%) and Italy (470 people, or 20.19%). While in Germany the increase in employment is related to the annual increase in business profitability, in French shipping there are high maintenance costs, which has a negative impact on profitability [1; p.11]. In Germany and Poland, the profitability of passenger traffic is higher compared to the profitability of freight traffic. However, in France, the profitability of passenger transport is lower than in the freight sector.

The European passenger market is divided into the following segments: river cruises; one-day trips by rivers, canals, including ferry traffic; one-day trips by lakes.

River cruises. In 2018, the number of passengers on river cruises in Europe increased by 14.6% compared to 2017 and amounted to 1.64 million tourists. The structure of this segment is distributed as follows: the share of tourists from the United States and Canada is about 38%; the share of tourists from Asia, Russia and Scandinavia was 41%; the share of tourists from Britain and Ireland - 31%. Since 2004, the growth of the river cruise fleet has been registered in Europe. In 2018, there were recorded 359 active cruise ships with 52078 berths [1; p. 31].

One-day trips by river. In the segment of day trips by river (passenger ships without cabins) in European passenger transport, the leading positions are occupied by Germany, France and Italy. In terms of the number of ships and passenger seats, the leading positions are occupied by Berlin, Hamburg and Paris. Demand for transportation tends to increase but depends on the phases of the economic cycle. For example, in a number of countries (Italy, France) there was a significant drop in demand during the economic crisis of 2011-2012. However, in 2016 the number of passengers carried by rivers and canals in Germany increased to 34 million people, France - 10.6 million people [1].

One-day trips to the lakes. The leader of the segment is Italy due to the presence of a significant number of lakes in the country, as well as Germany, which jointly lead in the number of tourist ships (191 and 130, respectively). As for the segment of one-day trips by river, the situation in this sector is significantly dependent on the phases of the economic cycle. In 2016, the number of passengers transported by lakes in Germany was 10.6 million people, in Italy - 11.4 million people.

All segments of passenger traffic are characterized by the following features [1]:

- significant seasonal fluctuations in demand for transportation despite the efforts of companies to extend the season in the winter;
- change in the age structure of travellers: an increase in the share of consumers aged 26-40 in more than four times (in 2018 to 8.3% against 2% in 2017);
- increase in the share of German travellers in the age group 41-55 from 11.8% to 18.3%;
- higher rates of development of the premium segment of passenger transportation relative to the segments of luxury and ultra-luxury. For example, in Germany, demand in the premium segment increased from 39.4% in 2017 to 45.6% in 2018, while the market share of the luxury and ultra-luxury segment (together) increased from 6.3% in 2017 to 14.3% in 2018;
- in terms of the ethnicity of travellers, the increase in demand in 2018 was the following: consumers from Asia, Russia, Scandinavia and Eastern Europe - an increase of 41%; Britain and Ireland - by 31%, America and Germany - 14.3% and 14.7% respectively.

The integration of Ukrainian passenger transport with existing international transport corridors into interstate transport passenger flows and the spread of global trends of globalization and inclusive development in the passenger transport sector shows lower involvement of Ukrainian citizens in international and domestic water passenger traffic compared to the use of not only freight transport in the country but in terms of passenger traffic in the country (Table 2).

Table 2

Analysis of the dynamics of the river passenger transportation segment in Ukraine, 2000-2018 [3]

No	Indicator	2000	2010	2015	2016	2017	2018	2018/ 2000, %
1	Number of passengers transported, thousand people	2163.3	985.2	550.8	448.5	562.9	596.2	27.56
2	Number of trips per person, trips	0.04	0.02	0.01	0.01	0.01	0.01	25
3	Passenger turnover, thousand passengers km, including:	26727.3	41603.8	8040.5	12554.1	19567.1	25511.7	95.45
	- international traffic	-	24053.0	2682.1	7813.2	12836.0	17354.4	-
	- internal traffic	26727.3	17550.8	5358.4	4740.9	6731.1	8157.3	30.52
4	The average distance of passenger transportation, km. including:	12	42	15	28	35	43	358.34
	- international traffic	-	2227	1788	1132	1146	1181	-
5	River vessels, units, including:	2025	2064	1321	1312	1401	-	-
	- passenger, units	-	-	151	151	166	-	-
6	Density of waterways, km of ways per 1 thousand km^2 of territory	4	4	3	3	3	3	75
7	Intensity of passenger traffic, million passengers km per 1 km of way length	0.01	0.02	0.01	0.01	0.01	0.01	100

According to the analysis, the number of passengers in 2018 amounted to 42153.2 thousand people or 27.56% from 2000. The number of trips per person per year during this period decreased by 4.

In the conditions of the same freight transport work of this transport for 2000 - 2018 (the rate of decline for this period was 4.55% in 2018 - 25511.7 thousand pass-km.), the average distance of passenger transportation increased from 12 to 43 km. Deterioration of passenger transport performance occurred in the context of declining infrastructure and suprastructure of logistics processes in the industry - reducing the number of river vessels, the length of public waterways, thousand km (17.39% for the period 2000 - 2018), the density of waterways, km of roads on 1 thousand km2 of territory (by 25% for the analysed period). The analysis indicates a stage of stagnation in the Ukrainian segment of passenger traffic, significant over-regulation by the state and, as a result, low interest of business and local authorities in its development.

Instead, the trends of globalization and informatization which have embraced the world economy on a large scale have led to significant social and economic transformations and initiated a phase of inclusive development of modern economic systems in these countries based on principles of behavioral economics.

If at the level of individual countries the state of economic development is measured by the index of development inclusiveness, IDI, which more thoroughly assesses the development of generally accepted ratings based on GDP per capita, levels of exports and imports, capital investment, etc., then for local areas (port-side regions, certain

cities, ports, etc.) the consequences of economic growth can be assessed, for example, with the indicators of social-economic development and quality (comfort) of life or doing business in certain areas.

In this context, the authors of the publication propose to consider river passenger transport taking into account economic efficiency, environmental rationality and social orientation of business in the segment of passenger transport and complementary development of adjacent to river freight and passenger transportations port regions (Fig. 1).

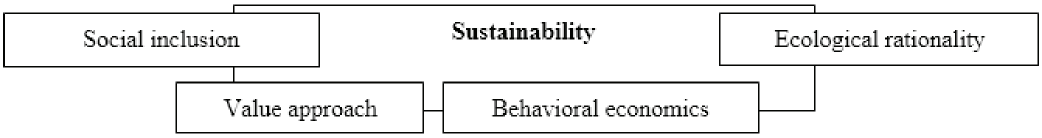

Fig. 1 Concepts of development of the territories adjacent to river transportations

As the author's estimate, Ukrainian river passenger transport, in the context of the study of complementary development of areas adjacent to passenger traffic in conditions that meet the resource and environmental characteristics of the regions, should be considered as:

- additional to freight transportations component of the city, suburban and intercity transport network. For example, a potential part of the city transport infrastructure of Zaporizhzhia, the river trams requires their adaptation to the city transport network and logistics system of the city and suburban areas (between Stryzhavka and Sabarov), development of river transport infrastructure, including the construction of a single property complex of the river station. The river suprastructure also needs to be developed. It is expedient to restore navigation on the river through the city, return of Zaporizhzhia river port to state ownership, which is facilitated by social-economic factors (availability of river passenger services, competitive level of river transport prices against road transport), ecological features of the city (the flow of the river throughout the city of Zaporizhzhia) and geopolitical factors (safety of the coastal area) [4]. As an example that has been successfully implemented, it is expedient to mention river passenger transportation by high-speed hydrofoils "Nibulon Express" by the rivers Dnipro and Southern Buh from 2017, the services of which were used in 2017-2019 by more than 75 thousand passengers [3];
- a component of the creation of tourist and recreational infrastructure of the region, the specifics of which will be functional diversity: medical (climatotherapy), health (route-walking, water sports, fishing, etc.); cultural-cognitive (cultural-historical, etc.); entertaining (theatrical-concert, active-recreational; gastronomic; shopping, entertaining, etc.); educational (training, conferences, briefings, etc.); combining types of recreation with the involvement of different modes of transport; cyclicality (limited by the navigation season) and will contribute to the reorientation of the economy of these regions towards the growth of value added in the service sector through the efficient use of resource potential;
- a factor of complementary development of other industries, the actual manifestations of which are the following in shipbuilding: production of low-tonnage watercraft for urban transport (for example, Zaporizhzhia, "Analogue" plant) and pleasure activities (Mykolayiv, "NIBULON" shipping company) [2], ship repair industry, the revival of water and motorsports (for example, "Maritime School" as part of the Society for the Promotion of the Army and Navy, Zaporizhzhia), catering, etc.), which stimulates structural changes, promote the use of new (innovative) technologies, employment growth, encourages the extension of the life cycle of these industries, etc., which will ultimately "unblock" economic activity at the regional level, increase the share of services in the gross regional product of riverine regions;
- factor of development of interregional cooperation (concerning the attraction of investments, development of interregional passenger routes, joint promotion of regional potential in foreign markets);
- the factor of promoting the unloading of other types of land transport, especially urban transport by attracting consumers to river passenger transport;
- the factor of solving ecological and economic problems of port regions by the use of electric traction engines on watercraft.

The marketing component of the effectiveness of ensuring the quality of the transportation process should relate to increasing the mobility of passengers, trips per year; reduction of the average daily interval of movement, hours; including peak hours, min.; increasing the speed of river transport, km/h; reduction of the average load on the free area of the interior of the river vehicle at peak hours, people/m^2, ensuring the regularity of river vessels on the routes, %.

In this context, the results of a marketing study of the factors generating demand for river passenger traffic, conducted in the Dnipro region, indicate a fairly optimistic assessment of the progress of river traffic in Ukraine. In particular, the purpose of the study was to identify the existing and future demand for passenger transportations by river transport, to clarify the criteria for choosing this type of transport.

The survey method was chosen as the method of marketing research, the self-developed questionnaire - as a research tool. The sample size included 68 respondents. This method involves obtaining information from the respondent on pre-formulated questions as a result of communication with the help of self-developed questionnaire Google Forms. The information obtained during the survey was processed using the computer program SPSS and Microsoft Excel.

According to the research, during long-distance trips throughout Ukraine (101 - 500 km) 81% of respondents use the road (bus transport) and 76% - railway. For 71% of respondents, the business was the main purpose of the trips. The main factors in choosing this type of transport are, first of all, travel time, fare and comfort.

But at the same time, the assessment of the properties of transport for long-distance trips shows the following. The reliability and safety of traffic are in the first place with the highest score (5 points - very important), travel time - in second place; environmental friendliness of transport - in the third. This confirms the hypothesis of conscious choice underlying the study as these conditions, sometimes with the exception of travel time, can be provided by river transport. The following results also confirm the feasibility of developing river passenger transport in Ukraine: given the opportunity to travel by river, almost 37% of consumers would make their choice in favour of river transport (Fig. 2).

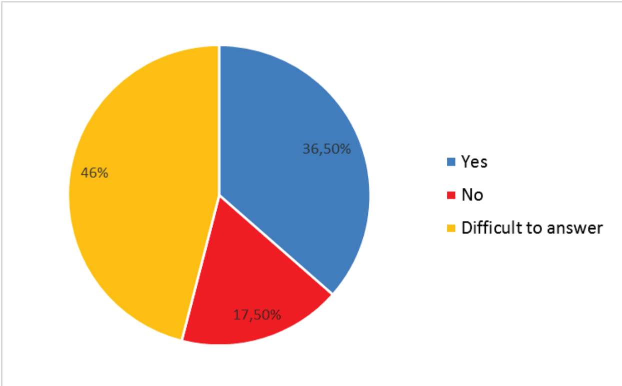

Fig. 2 Choice by consumers of river transport

The choice of potential consumers of river transport for travel is based on the following important principles: a trip by the river is an additional aesthetic pleasure, the consumer is "interested in trying something new", the possibility of combining a business trip with a tour, environmental friendliness and transport safety (Fig. 3).

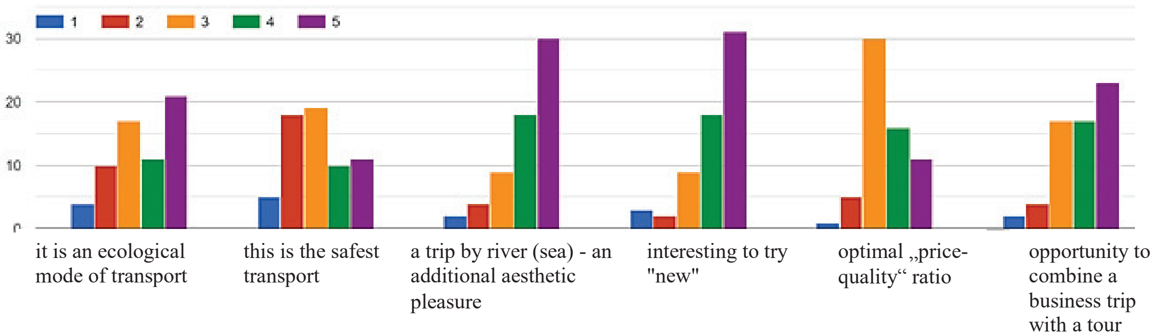

Fig. 3 Conditions for choosing a consumer of water transport

Another area of river transport development is tourism. According to the results of the study, it can be concluded that such a proposal is quite interesting for Ukrainians.

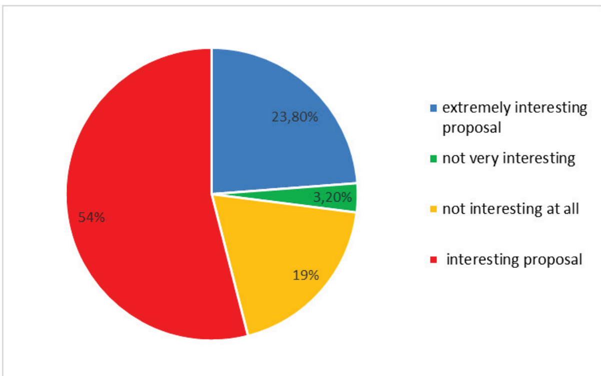

Fig. 4. Respondents' interest in the offer of river cruises

For 23.8% of respondents such a proposal is extremely interesting, for 54% - it is an interesting proposal (Fig. 4).

At the same time, it was found that 17% of Ukrainians travel around the country regularly, 81% - travel occasionally. This underlines the need to develop river transport not only to perform direct communication functions related to the movement of people but also to travelling. At the same time, the factors of choosing transport for travel become less rational with regard to the traditional ones - time and money. Such properties as an interesting route (60%), excursions while driving (54%) and the presence of a developed port infrastructure during stops (49%) come to the fore.

Along with the traditional tourist model "3xS", associated with the sun, sand and sea, a new model of recreation, called "3xE" - entertainment, excitement, education – is beginning to play a significant role. Here, physical activity, emotional experiences, adventures, entertainment are combined with cognitive and educational elements. The effect of this trend will be both the expansion of areas where tourism is developing and the creation of new tourist areas (attractions). Inland waterway transport, which is beginning to play an increasingly important role in tourism, is suitable for this tourist model.

4. Conclusions

According to the results of the study, the main factors of the development of the potential of river passenger transport are the current trends in the development of river tourism; a new concept of a holistic tourist offer, which considers inland navigation an important part of the tourist offer; fashion for active leisure, which promotes the development of river sports; climate change favourable for river tourism; participation of local authorities in the promotion of modern river tourism; involvement of local governments in the implementation of investments, which is an important component of tourism development and creates favourable conditions for the provision of a wide range of tourist services; development of such segment of transportation as yachting, chartered small ships for families or groups of people, other small ships and kayaks, the statistics of which are not taken into account in the statistical reports; favourable impact of river tourism development on the environment.

The current stage of decline of river passenger traffic requires urgent reforms, reorganization and search for effective ways of restoring passenger traffic, the efficient use of vehicles, investment in the construction of passenger ships and demand assessment on a marketing basis. In particular, the processes of transformation of river passenger transportation require the implementation of the following tools: construction of regional route systems for river passenger transport with the support of information and telecommunication technologies, development of models for coordination of all modes of transport in port-side regions, research of regularities of demand for river passenger transportation and defining the capacity of the Ukrainian market of passenger transportation, evaluation of its main segments; increasing the efficiency of monitoring passenger flows on river transport with the development of information and communication technologies.

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Calculation of Personnel Logistics Costs of Warehousing

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Abstract

Logistics and especially warehousing plays an important role in everyday work and is becoming one of the main factors of differentiation in the market. This is closely related to the calculation of logistics costs. The issue of personnel costs in logistics plays an important role at the present time. The aim of logistics cost management is to reduce personnel costs and increase the competitiveness of logistics service providers. Finding effective methods in the process of calculating business personnel logistics costs is very difficult today, but it is a topical issue in the field of management of the logistics costs. A significant part of the logistic tasks are carried out by logistics service providers, these businesses play a key role in operating selected logistics industries more efficiently. The aim of this article is to assemble the calculation of personnel logistics costs of warehousing in a logistics service provider with regard to management of logistics. The article is based on the research of the world literature, in-depth interviews with senior managers, an analysis of internal data of the logistics service provider and a snapshot of the day. The article shows as a case study how to better calculate the personnel logistics costs in a selected logistics service provider.
KEY WORDS: *personnel logistics cost calculation of warehousing, cost calculation, logistics service provider, warehousing, case study*

1. Introduction

Warehousing is one of the unforgettable activities within the logistic chain. It ensures the warehousing of products in various forms and in many positions within the logistic system. The role of warehousing stems from market needs and product shifting to the consumer. The basic types of stocks can be distinguished whether they are the supply stage or the distribution stage. Warehousing provides both space and time benefits, helping to ensure a high level of customer service. Currently, companies are trying to minimize logistics costs. Logistics also includes warehousing. Customer satisfaction must not be compromised, which results from the reliability of the supplies. The aim of this article is to assemble the calculation of personnel logistics costs of warehousing in a logistics service provider with regard to management of logistics.

2. Theoretical Background and Methodology

Logistics is critical to business success because it fulfils the promise given to the customer [1-2]. In today's life, logistics is an area that plays an irreplaceable role in every business and company. The chain of logistics activities ensures the smooth running of the production process and logistics costs are associated with each logistics activity. These costs are significant items that largely affect the company's overall profit or loss [3].

Every company and logistics service provider asks how to reduce costs and waste while maintaining profit growth in a free market environment. This question is partially answered by logistics, which also opens the way for a wide range of business optimization methods and tools [4]. The purpose of logistics is to reduce costs, especially transport costs. While the first remains the most significant logistics cost, the cost of transporting supplies is second. In addition, other goals are time savings and improved service reliability, including flexibility. Companies involved in the physical distribution of cargo strongly support strategies that enable them to reduce transportation costs in a competitive environment [5]. Logistics activities cover three main areas; these are incoming (inbound), internal and outgoing (outbound) logistics. Inbound logistics includes procurement and integration activities. Improved integration with suppliers can affect several dimensions of business performance, including cost, quality, technology, delivery, flexibility and profits [6-7]. Internal logistics can be seen as operations in the production, transfer and handling of materials, and inventory and warehouse management [8]. Internal logistics begins when raw materials enter the company until the product is ready for distribution. Internal logistics activities affect a variety of product aspects, including cost, quality and performance. As a result, they need to be constantly monitored and evaluated for continuous improvement [9]. Outbound logistics includes processes such as distribution, marketing, sales and service. It has been found that an information technology system improves such processes in a number of ways, including accurate order delivery information used to provide adequate capacity at the expert level for customer support. In addition, product tracking allows increased customization, meeting customer requirements and reducing long-term shipping costs. This leads to higher inventory turnover with a higher market share, due to the reliable and readily availability of those products or services that customers most demand [10].

Logistics is an important factor supporting globalization and international trade flows. Modern logistics systems savings are based on inventory reduction as the speed and reliability of supplies eliminates the need for warehousing. Consequently, the reduction of stock requirements is one of the advantages of logistics. However, this means that stocks have been transferred to some extent to the transport system, especially to roads but also to terminals. Stocks are in transit, further contributing to congestion and pollution. Environment and society, not logistics service provider, assume external costs [5]. Deconcentration of demand and supply, increasing customer requirements lead to increased logistics costs [11]. Companies and logistics service providers are increasingly paying attention to distribution costs, which can range from 30% to 40% of total product costs. Such data based on research carried out among Polish companies are given in the literature [12]. Total distribution logistics costs consist of transport 37%, inventory financing 22%, warehousing 21%, customer service and distribution 20% [13]. The issue of improving distribution logistics is particularly relevant for express courier services and logistics service providers [14]. Logistics costs are becoming increasingly blurred. Price is the focus of the company and the survival of the company. Many companies are paying more and more attention to this problem [15].

The new innovative approach in logistics can bring for warehousing the reduction of the logistics costs, mainly personnel costs for the logistics service provider. This is especially thanks to the implementation of warehouse management system and calculation of logistics costs [16]. Through an efficient management process, logistics costs, especially personnel costs can be effectively reduced, and conversely, efficiency and better resource allocation can be increased [17-18]. Express courier companies and logistics companies must strive to increase the level of customer service provided with the optimal pricing policies [19].

Transport is a major component of logistics costs, but it is not the only one. Others include warehousing, capital costs, insurance, obsolescence/loss, packaging and logistics management [20-21]. Logistics costs can be calculated using different methods and data sources, although the literature review shows that they can be divided into two main classes [22-25]:

- using available data from national accounts or other statistical sources such as national customs data or cif/fob ratios provided by the International Monetary Fund;
- is to obtain data on sector-specific logistics costs and wholesale industries or offers from carriers and logistics service providers.

Total logistics costs can be divided into the type of kidnapping tax [3, 26]:

- transport and handling costs related to the movement of goods come from internal and external freight, packaging and damage to goods during handling;
- packaging costs include all costs associated with packaging materials and packaging and labelling processes;
- inventory management costs are costs of maintaining good inventory levels;
- administrative costs include all costs associated with long-term planning and operational management of material flows;
- order costs can be attributed to order processing and production orders;
- capacity related costs are annual depreciation and maintenance costs;
- cost of shortages and delays;
- environmental costs.

Personnel and distribution logistics costs represent one of the highest shares of total logistics costs and their rationalization can bring great commercial and competitive advantages [27].

A case study has been selected as one of the qualitative research methods, as it is one of the most commonly used research methods aimed at implementing various managerial approaches into organizations' practice [28]. The case study is defined as an empirical overview of the current phenomenon in its natural environment using multiple sources of evidence. Study cases are selected based on predefined case conditions [29-30]. A real case study is a qualitative research method based on a study of one or a small number of situations to apply findings for similar cases [31].

3. The Case Study

Table provides an analysis of the time required for the occupation of warehouse space, according to which the personnel costs are determined. Hourly labour costs are determined according to the wage regulation of the selected logistics service provider. These costs include basic salary, afternoon and night shift supplements, variable salary, the share of the 13th salary, subsistence allowance, tax levies and other items. The table counts with three shift managers and a warehouse manager. No time analysis is performed for these positions. For other positions, i.e. forklift driver, administrator and production operator (worker), time analysis is performed (hourly wage costs are shown in green fields). 21 working days will be considered, which means a total of 63 shifts per month in 3 shift operations. The monthly time-lapse image revealed that the number of pallets in and out was 39,500 pieces per month, which, after dividing by 63 shifts, can obtain the number of pallets handled per shift, i.e. 627 pieces.

The time analysis was performed as follows:

- Detection of all activities to ensure operation;
- Designation of the worker performing the activity;
- Measure the time required to perform a given activity (per pallet);
- By multiplying this time by the number of pallets per shift, the duration of the activity per shift is obtained;

- The sum of these times is equal to the number of minutes needed to ensure shift operation;
- By dividing 60, the number of hours is determined.

This number divided by seven (the number of hours of active work of an employee) is the desired result, i.e. the number of employees required per shift (multiplying by three will result in the total number of employees in three shifts without management).

4. Calculation of Personnel Logistics Costs of Warehousing

Based on the number of employees, wage costs are determined as the product of hourly wage costs, the number of employees and the working time fund (21 working days and 8 hours working hours, i.e. 168 hours per month). Management costs are added to these costs (see Table).

Table

Analysis and calculation of time and personnel logistics costs of warehousing in CZK

	Income - Warehousing - Expedition	Shift Manager	Warehouse Manager				
	Management Costs	107,031	45,190		**39,500** pallets/month		
	Number of Working Days	**21**					
	Number of Shifts/Day	**3**			**627 pallets/shift**		
	Number of Shifts/Month	**63**			193.35	197.48	168.57
N.	Activities	Forklift Driver	Administrator	Worker	Forklift Driver	Administrator	Worker
1	Unloading of pallets	0.50	0.00	0.00	313.49206	0.00000	0.00000
2	Administrative activities related to unloading	0.00	0.10	0.00	0.00000	62.69841	0.00000
3	Goods receipt - quantity control	0.00	0.10	0.50	0.00000	62.69841	313.49206
4	Software entry of material into stock state	0.00	0.10	0.00	0.00000	62.69841	0.00000
5	Repackaging	0.00	0.00	0.00	0.00000	0.00000	0.00000
6	Pallets warehousing	0.70	0.00	0.00	438.88889	0.00000	0.00000
7	Order receipt - find material	0.00	0.10	0.50	0.00000	62.69841	313.49206
8	Picking at the dispensing point	1.00	0.00	0.00	626.98413	0.00000	0.00000
9	Delivery completion - dispatch control	0.00	0.50	0.50	0.00000	313.49206	313.49206
10	Depreciation from warehouse	0.00	0.30	0.00	0.00000	188.09524	0.00000
11	Issue of delivery note, packing note	0.00	0.30	0.50	0.00000	188.09524	313.49206
12	Loading of pallets	0.50	0.50	0.00	313.49206	313.49206	0.00000
13	Receiving empty packages - cargo control	0.00	0.00	0.00	0.00000	0.00000	0.00000
14	Warehousing of empty containers	0.00	0.00	0.00	0.00000	0.00000	0.00000
15	Removal of empty packaging	0.00	0.00	0.00	0.00000	0.00000	0.00000
16	Evidence of packaging	0.00	0.00	0.00	0.00000	0.00000	0.00000
	Minutes/pallet (In-Out)	0.00	0.00	0.00			
	Minutes/shift	2.70	2.00	2.00	1692.85714	1253.96825	1253.96825
	Hours/shift	0.05	0.03	0.03	28.21000	20.90000	20.90000
	Employees/shift	0.01	0.00	0.00	4.03000	2.99000	2.99000
	Employees/day	0.02	0.01	0.01	12.09000	8.96000	8.96000
	Total number of employees without management			30	12	9	9
					389,796	298,593	254,871
	Total personnel costs without management costs				**943,260 CZK**		
	Total number of employees including 3 shift managers and a warehouse manager				**34 Persons**		
	Total personnel costs including management costs				**1,095,481 CZK**		

The analysis shows that a total of 34 employees is required to ensure operation, representing the total of approximately CZK 1,095,500 (approximately 41,339 Euros) per month. The exchange rate Euro to CZK is: 1 Euro is 26.5 CZK.

5. Conclusion

The continuous development of technologies, the expansion of companies and the increasing growth of competition force companies to improve the quality of provided services. For the company to focus on its core business and to achieve quality results, it is preferable to outsource activities to companies specializing in the field. Such organized cooperation requires a close relationship between companies; continuous communication, exchange of information, solving common problems, etc. Integrating branches of outsourcing companies directly into customer premises becomes very advantageous. The case study from this article showed the calculation of personnel costs of warehousing in selected logistics service providers. This analysis showed that the total of 34 employees

are needed to ensure operation, which is approximately CZK 1,095,500 (approximately 41,339 Euros) per month.

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Evolution of High-Quality Express Passenger Train Services in Poland in 1989-2019

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Abstract

Intensive development of express passenger train services in Poland was observed in the second half of the 1980s. The number of trains grew fast and several limited-stop services were introduced at that time. In 1988 the first two train pairs, utilising the Central Trunk Line, started to operate at the maximum speed of 160 km/h. In 1992 two new categories of high quality express trains were implemented: EuroCity on international routes and InterCity serving the most important domestic connections. The largest number of express trains (belonging to various categories) operated in the late 1990s. In the following years, due to degradation of railway infrastructure on several sections, journey times were generally increased and some express trains were reclassified as ordinary fast trains.
The railway infrastructure modernisation projects, combined with rehabilitation (revitalisation), small-scale investments and with extensive maintenance works, allowed for significant journey times reductions on numerous routes, particularly from 2014/2015 timetable. Simultaneously, the new generation of rolling stock were introduced, including ED250 Pendolino high-speed EMUs, new coaches for loco-hauled long-distance trains and two types of long-distance EMUs for 160 km/h. Thanks to this coordination of infrastructure and rolling stock investment, it was possible to increase the number of high quality express train connections. On numerous routes, particularly those linking Warsaw with the capitals of voivodships, the fastest-ever journey was achieved.
On the basis of historic timetable data, the evolution of express train offer of the Polish railways in the 1989-2019 period has been analysed, either in terms of quantity of trains or their quality (journey time, on-board services). The research results have been presented in the series of maps illustrating changes in the shape of the network and the number of services. Moreover, several synthetic indicators have been developed. In the discussion, the development of express train services in Poland has been compared to the evolution of similar services in other Central-Eastern European countries.
KEY WORDS: *infrastructure, express train, operation, network*

1. Introduction

At the times of the socialist, centrally-planned Polish People's Republic, the domestic railway passenger transport offer consisted of three categories of trains: passenger (slow) trains, fast trains and express trains. It was noteworthy that passenger (*Osobowy*) trains operated not only on short- and medium-distance routes, but in some cases served also as long-distance connections, for example, Cracow–Szczecin, Kielce-Szczecin and Cracow-Gdynia routes (all mentioned connections exceed 600 km). However, the most frequently used train category for long-distance journeys were fast (*Pospieszny*) trains. In 1970s and in early 1980s the express train offer was composed of 11 train pairs.

Intensive development of express passenger train services in Poland was observed in the second half of the 1980s. The number of trains grew fast and several limited-stop services were introduced at that time. In 1988 the first two train pairs, utilising the Central Trunk Line (CMK), started to operate at the maximum speed of 160 km/h. Since 1986 the domestic express network was supplemented with a few Interexpress trains, establishing the connections between the capitals of the Comecon (Council for Mutual Economic Assistance) countries.

The transformation of the political system, as well as the social and economic transformation initiated the huge changes in railway transport. This transformation had huge impact on its competitive position, in particular in relation to the road transport (in case of freight and passenger transport) and to the air transport (mainly in case of passenger transport). The difficult situation of integrated railway companies (like PKP in Poland) in early 1990s was characterised by Engelhardt [5-6]. The author pointed out the very low cost coverage in passenger transport (usually only 20-30%) and insufficient public subsidies. Therefore, the development of express train services, sufficiently fast to compete with passenger car and simultaneously covering its costs from the revenues, was treated as one of the most important means of improvement of competitiveness of railways in the long-distance market segment.

The essential features of express trains are usually the highest possible commercial speed and the service quality, superior in comparison with ordinary passenger and fast trains. It was also the case of express train services in former socialist countries, like Poland, the German Democratic Republic (GDR), Czechoslovakia, Hungary, Bulgaria and Romania. In the late 1980s and early 1990s they had only limited number of stops on intermediate stations and the shortened journey times. They were composed of the best available rolling stock, including (as a rule) the restaurant or

bar car. To guarantee the comfort of passengers, the seat reservation was usually compulsory (extra charge). Moreover, the express supplement was charged in addition to the price of the fast train ticket (Bulgaria, Czechoslovakia). In Poland the dedicated express train tariff was in force (200% of the passenger train price).

In 1992 two new categories of high quality express trains were implemented on PKP network: EuroCity on international routes and InterCity serving the most important domestic connections. Enhanced comfort of the new trains included 6 seats in the second class compartments (instead of 8 in all other trains) and complimentary meal (beverages and sweets). To make the full use of the infrastructure capabilities, the InterCity and EuroCity trains usually operated with EP05, EP08 and EP09 locomotives, achieving 140-160 km/h and painted in orange instead of the usual green.

To make the evolution of high quality train services in Poland fully understandable, it is necessary to characterise the most important changes in the train categories at that time. In 2009, due to legal problems related to the reduced fares for dedicated groups of passengers, the new train category Express InterCity (EIC) was implemented in place of the two previous categories: EuroCity (EC) and InterCity (IC). Some Express (Ex) trains, however, were operated until 2014. In December 2014, the high-speed ED250 electric motor units started scheduled operation. The new category Express InterCity Premium (EIP) was introduced for these train services. The InterCity train category was implemented again, however, not in the express train segment, but as a brand of the high-quality fast trains, operated in the framework of PSC contract [21]. The remaining basic standard fast trains belong to TLK (Twoje Linie Kolejowe) category. The limited fast train services are also operated by Przewozy Regionalne (PolRegio) under the name of InterRegio.

During 30 years, between 1989 and 2019, the express train offer was gradually modified. The highest number of express trains operated in the late 1990s. In the following years, the number of such connections started to decrease. The significant progress has been achieved recently (starting from 2014), thanks to the modernisation of infrastructure and the implementation of the new rolling stock. The aim of the present paper is to research the transformation of the express train segment in Poland in the years 1989-2019.

2. Existing Works

Contemporary works related to the fast railway services are mainly focused on technical aspects of the design and construction of the high-speed railways, e.g. Brunello [4]. However, there are also works addressing the operation of such railways. For example, Massel characterised the transport offer on newly-built Berlin – Munich route, including train relations, their numbers, stopping patterns, journey times and connectivity aspects [12]. It is clear that investment in high-speed railways enhances temporal and spatial accessibility of the largest cities.

In 2004, the International Union of Railways (UIC) ordered a study devoted to the possibilities of developing of high-speed rail in Central and Eastern Europe (PECO Study) [9]. In this study prospects for construction of high-speed railway lines in 11 countries of the region have been analysed [11]. All the aspects related to the development of high-speed railways in Poland have been discussed in the comprehensive monograph edited by Zurkowski, including infrastructure, rolling stock, transport and environmental problems [22]. The analysis of impact of the proposed high – speed rail network in Poland on the spatial accessibility has been presented by Sleszynski [16]. It is noteworthy that transport accessibility in various context and scale has been researched in case of numerous countries and regions in Central-Eastern Europe. The methodology for assessment of accessibility has been presented in the works by Sleszynski [15] and Rosik [13].

The changes in the network of express train connections in Poland between 1975 and 1999 and their influence on the accessibility of 23 largest cities in the country have been researched by Kossowski [8]. It should be noted that the accessibility of the long-distance train connections in 1999 has proved superior in comparison with the year 1975. Bochenski [3] researched the changes in the rail accessibility of the Polish cities with more than 10 thousand inhabitants in the years 1950-2015. The technical (infrastructure) and organisational (transport services) accessibility have been analysed. According to this research, in the year 2016 almost 100 cities had no passenger rail connection. In the case of 62 cities, only freight railway access was available. Retrospective analysis of the transport offer and tariff changes in the long-distance market segment of the Polish railways in the years 1989-2007 have been presented by Wolanski [20].

Commercial speed is a crucial factor, characterising attractiveness of particular means of transport. This factor is extremely important in the case of long-distance railway services. The analysis of commercial speeds in Poland in the year 2010, focused mainly on the connections between Warsaw and the capitals of voivodships, has been published by Massel [10]. Inter-agglomeration transport modelling was the scope of comprehensive paper by Żurkowski [23].

The separate problem constitutes the railway cross-border transport. Gamon and Gomez elaborated a technical and operational analysis of the border crossings between Poland, the Czech Republic and Germany, taking into account differences in the power supply systems, signalling systems, operational rules, as well as difficulties resulting from language barriers [7]. The changes in passenger offer in international traffic in the years 1990-2015 have been studied by Beim and Soczowka [2]. They pointed out the development of passenger services on the Polish-German and the Polish-Czech borders and a significant decrease of cross-border traffic on the Eastern border.

Railway transport, and particularly rapid passenger transport in Poland, an formed important subject of extensive research. The investigations were focused mainly on problems related to accessibility and took into account the influence of the future high-speed network. However, there was no large scale comprehensive research concerning long-term changes in the express passenger services and taking into account all their essential aspects.

3. Research Methodology

In this chapter, the Authors explain how the infrastructural, economic, legal and organisational factors in the railway sector and in its environment determined the development of rail express train services in Poland. Basing on the comprehensive data, including historical railway timetables and transport statistics, the evolution of the express train offer of the Polish railways in the years 1989-2019 has been analysed, both in terms of quantity (number of trains), and its quality (journey times, services on board).

The most time-consuming activity has proved to be the extraction of the data from the timetables, necessary to fill in the data base on express services. It should be noted that until the year 2011/2012, the national railway timetables were published annually in a paper form (in the years 1993-1994 the separate timetables for summer and for winter period were printed). Starting from 2012/2013 timetable, only pdf files, generated by the infrastructure manager (PKP PLK), have been available. The data base has been constructed on basis of the railway timetables and the Railway Atlas of Poland [14]. It contains the numbers of trains on particular sections of the network, numbers of train kilometres, journey times and numbers of direct train connections between the capitals of all voivodships (according to the present administrative division). It should be noted that in case of the voivodships with two capitals, i.e. Kujawsko-Pomorskie and Lubuskie, in which the government (the Provincial Office) and self-government (the Marshall Office) authorities are located in different cities, the larger city was included in the analysis (Bydgoszcz and Zielona Gora respectively).

The outcome of the research has been presented in a series of maps illustrating the changes in the express train network and in the numbers of trains, including not only year-round services, but also seasonal trains. Due to changing practice in the definition of periods of operation, only trains operating at least 5 times a week and 6 months a year have been counted as all year round trains. This reflects the changes in tourist traffic, especially in mountain regions, when some trains did not run in spring and in autumn period.

It should be noted that the adopted methodology has not been limited to the typical parameters used in the statistics of the Central Statistical Office (GUS) and the Office of Railway Transport (UTK). An additional problem is that some railway statistics from the 1980s and 1990s were not published annually. Therefore based on their database, the Authors proposed a few new synthetic indicators.

4. Research Results

A synthetic representation of the express train network and its transformation in 1989-2019 period has been shown in Fig. 1 in a form of maps, supplemented with the table summarising the number of trains and their categories in particular years (presented in 5 year intervals). A characteristic feature of this network is the radial system of trains connecting the regional administrative centres with Warsaw. It is noteworthy that only a limited number of connections serving the cities other than Warsaw were operated. There are two essential factors of this phenomenon: the settlement network (distribution of the population) and the technical characteristics of the railway network, in particular the maximum speeds on main lines. The best maximum speeds have been offered mainly on the railways concentrating in the capital. On the remaining routes, including those covered by AGC agreement and/or forming the part of TEN-T network, the maximum train speeds have been usually lower. This determined the possibilities of the introduction of an express train, taking into account the criterion of the commercial speed, which should not be lower than 80 km/h [24].

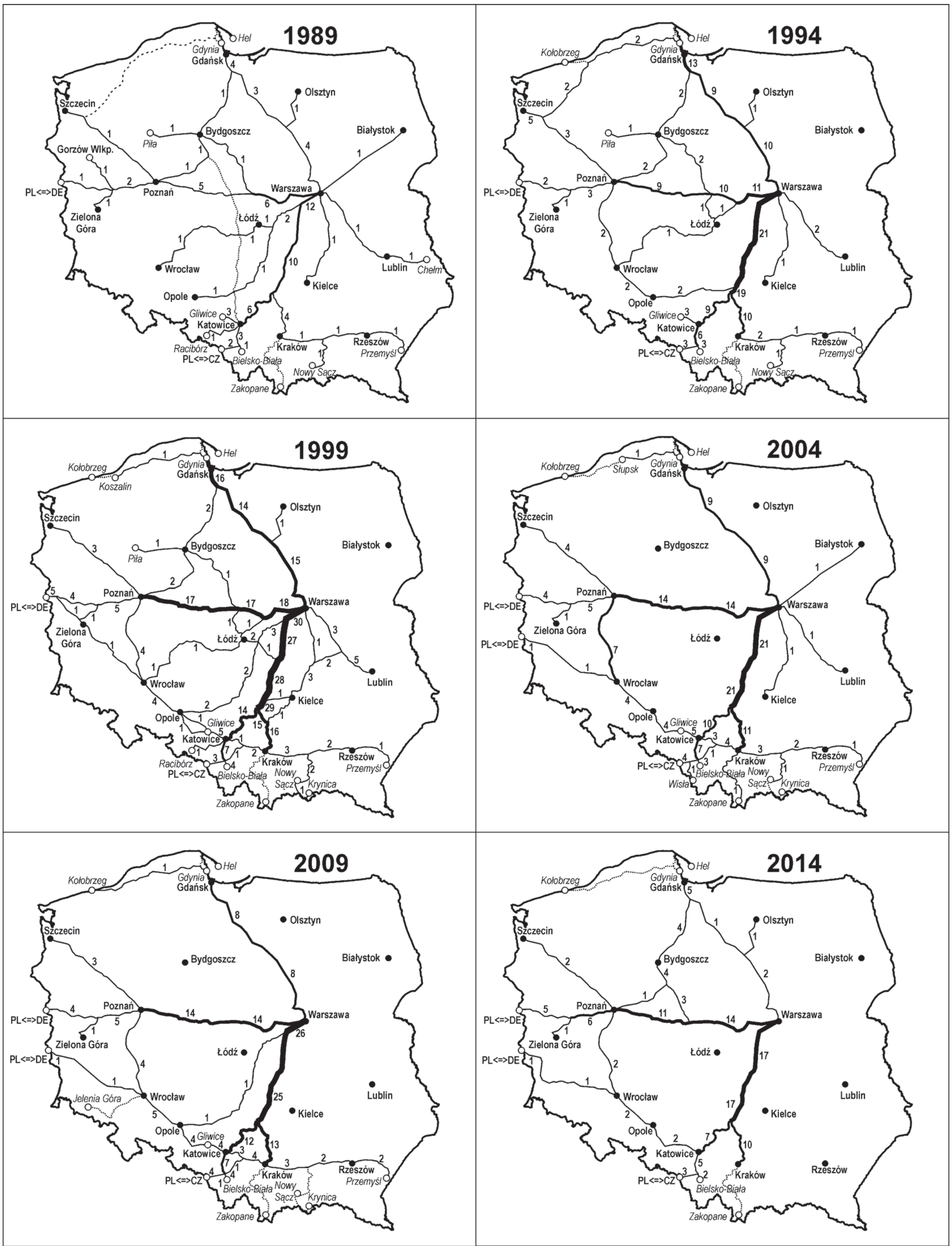
The development of the network in the early 1990s was possible thanks to the utilisation of the railway lines with the maximum speed at the level of 120-160 km/h. On several routes, traditional fast trains were replaced with the express trains (or InterCity trains), in particular in the most attractive times of the day. Moreover, several improvements were introduced to the passenger offer, including implementation of the fixed-interval timetable, with the express trains operating every two hours, or even (especially in the peak times) every hour. It should be remembered that a rapid decrease in the total number of passengers carried by PKP occurred in the 1990s. There were significant cuts in the regional transport offer at that time. Howevers the share of express trains in the total rail passenger transport increased significantly (see Table 1 and Table 2).

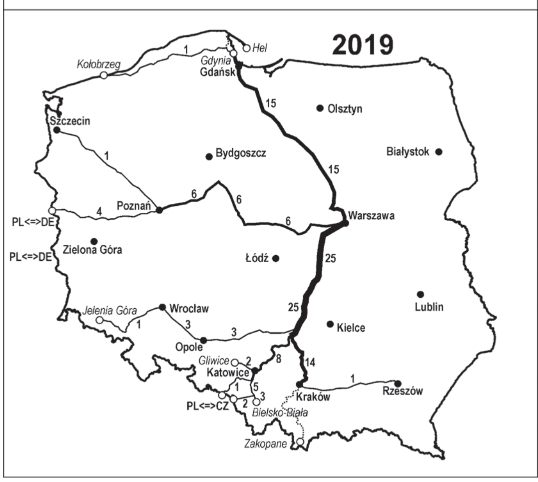
Table 2 shows the structure of operational work in passenger traffic made on the railway network. It should be noted, that only the trains operated at least 5 days a week and at least 6 months a year have been included in the calculations.

Table 1

The rail passenger transport in Poland 1985-2018

Type of train	1985	1990	1994	1999	2004	2009	2014	2018
Number of passengers [mln]								
Passenger	959,9	721,5	445,2	337,4	219,2	228,4	242,6	262,8
Fast	36,2	59,5	41,1	47,8	44,2	47,2	20,8	38,7
Express (incl. IC, EC)	5,8	6,4	7,4	9,9	6,3	5,5	3,4	6,4
Total	1 000,8	787,5	493,7	395,2	272,1	282,6	268,2	309,7
Share [%]								
Fast	3,6	7,6	8,3	12,1	16,3	16,7	7,8	12,5
Express (incl. IC, EC)	0,6	0,8	1,5	2,5	2,3	1,9	1,3	2,1





Year	Daily or working days trains	Seasonal and additional trains	Comments
1989	4 IEx, 23 Ex	4 Ex	– – – – – – –
1994	5 EC, 11 IC, 27 Ex	2 Ex	– – – – – – –
1999	1 EN, 8 EC, 17 IC, 30 Ex	1 Ex	1 Ex only one-way
2004	2 EN, 8 EC, 17 IC, 21 Ex	8 Ex	1 Ex only one-way
2009	2 EN, 8 EC, 20 IC, 15 Ex	2 IC, 11 Ex	2 additional Ex only one-way
2014	35 EIC	4 EIC	3 EIC only one-way
2019	22 EIP, 15 EIC	6 EIC	4 EIC only one-way

Ex – Express, IEx – InterExpress, IC – InterCity, EC – EuroCity, EIC – Express InterCity, EIP - Express InterCity Premium, EN - EuroNight

only seasonal and additional   after announcement

Fig. 1 The evolution of the express train network in Poland in 1989-2019

Table 2

Structure of trainkilometres in passenger traffic on the Polish railway network 1989-2019

[%]	1984	1989	1994	1999	2004	2009	2014	2019
Passenger	86,5	77,2	68,2	64,1	65,8	65,2	69,2	67,0
Fast	11,8	19,9	24,3	24,8	23,8	25,1	24,2	25,9
Express (incl. IC, EC)	11,7	2,9	7,5	11,1	10,4	9,7	6,6	7,1

Around the year 2000, the growth of the express train offer in Poland stopped. The main reason proved to be the deterioration of railway infrastructure. An insufficient level of renewals and maintenance in the years 1990-2010, resulting from the dramatic shortage of funding, led to the gradual reduction of maximum speeds on several railway lines and to the imposing of permanent speed restrictions on numerous sections, including main lines. As a consequence, the journey times on numerous sections had to be increased. In numerous cases the longer journey times, in combination with relatively high express train fares, made these trains unattractive for passengers. Consequently, several express trains were downgraded and started to be operated as ordinary fast trains.

The breaking point, as far as the condition of infrastructure is concerned, was achieved after the year 2010. Thanks to the combination of huge modernisation projects with EU funded revitalisation projects and with track renewals financed from the state budget and from the Railway Fund, it was possible to reverse the negative trends. Starting from 2011, the speed balance on PKP PLK network has been positive, which reflects a gradual improvement of railway infrastructure conditions. As a result of increased maximum speeds, the journey times were shortened in a scale of the entire network. Particularly large acceleration of train services could be observed in the 2014/2015 and 2015/2016 timetables.

These positive changes can be attributed to the effect of the synergy of infrastructure improvements with the implementation of the new generation of the rolling stock, including ED250 Pendolino high-speed electric motor units, operated as Express InterCity Premium. Increasing the maximum speed on the Central Trunk Line to 200 km/h, together with the modernisation of remaining sections on Warsaw – Cracow, Warsaw – Katowice, Warsaw – Gdansk and Warsaw – Wroclaw lines, made Pendolino trains competitive to domestic air transport.

It should be noted, that in the 1990s all passenger trains in Poland were operated by the integrated railway undertaking, i.e. Polish State Railways (PKP), which was also responsible for the management of infrastructure. In the framework of PKP restructuring, the new companies, responsible for particular market segments were established. To operate express passenger services, the PKP Intercity company was established in 2001. Its goal was to develop high quality long-distance connections linking the largest agglomerations on a commercial basis. The process of changes in the railway transport market and its liberalisation was characterised in detail by Taylor and Ciechanski [17-19].

In December 2008, the remaining long-distance services (fast trains) were transferred from PKP Przewozy Regionalne to PKP Intercity. This change has proved to be very controversial. Initially, especially in 2009 and 2010, it resulted in huge tensions in the entire railway sector. Several problems for passengers occurred as a result of the disintegration of the offer in interregional (inter-Voivodship) and regional market segments.

Contradictory to the railway freight market, there was no decision to liberalise the railway passenger transport market. There is a diversity of passenger operators in Poland. All of them, however, are in the ownership of the state or regional authorities (voivodships). The only exception is Arriva, DB Group company, which (after a competitive tender) has been contracted to operate the regional services on non-electrified routes in the Kujawsko-Pomorskie voivodship.

The attractiveness of express passenger services is determined mainly by the quality of service and by the level of fares. However, the situation in the road sector is equally important. Rapid development of the road infrastructure in Poland, and simultaneously, a growing number of private cars are key factors. Newly built sections of motorways and expressways were utilised in 2011 by Souter Holdings Poland to implement an extensive network of domestic and international bus services, aggressively competing with railways. On some routes, 10, 15 or 20 services per day were operated and two or even three double-deckers were used to cope with growing demand in peak hours. The main factors of the commercial success of Polski Bus were: attractive ticket prices and the journey times comparable to those offered by rail [1]. A significant acceleration of long-distance trains of PKP Intercity from December 2014 and from December 2015 reversed the trend and the bus competitor was forced to cut its services on several routes. In 2017, Polski Bus was taken over by Flixbus. Now only a limited number of connections of the previous network is still operated.

The key factors defining the competitiveness of the railway offer on particular routes are the journey time and the commercial speed. Four parameters have been proposed to assess the evolution of journey times and commercial speeds in Poland in 1989-2019 period:

1) The average journey time between all capitals of voivodships in both directions (in total 240 traffic relations);
2) The average journey time between Warsaw and the capitals of voivodships (15 traffic relations);
3) The average commercial speed between all capitals of voivodships in both directions (in total 240 traffic relations);
4) The average commercial speed for relations connecting Warsaw and the capitals of voivodships (15 traffic relations).

The average journey times in the years 1989-2019 and the average commercial speeds for inter-capital connections have been presented in Fig. 2. The average journey times for the connections between Warsaw and the

capitals of the voivodships are generally better in comparison with the average journey times for all analysed connections. For example, in the year 1989, the respective values of the average journey time were 3 hours 30 minutes and 5 hours 46 minutes. It can be explained with the parameters of railway infrastructure and its condition, which were the best in the case of lines radiating from Warsaw.

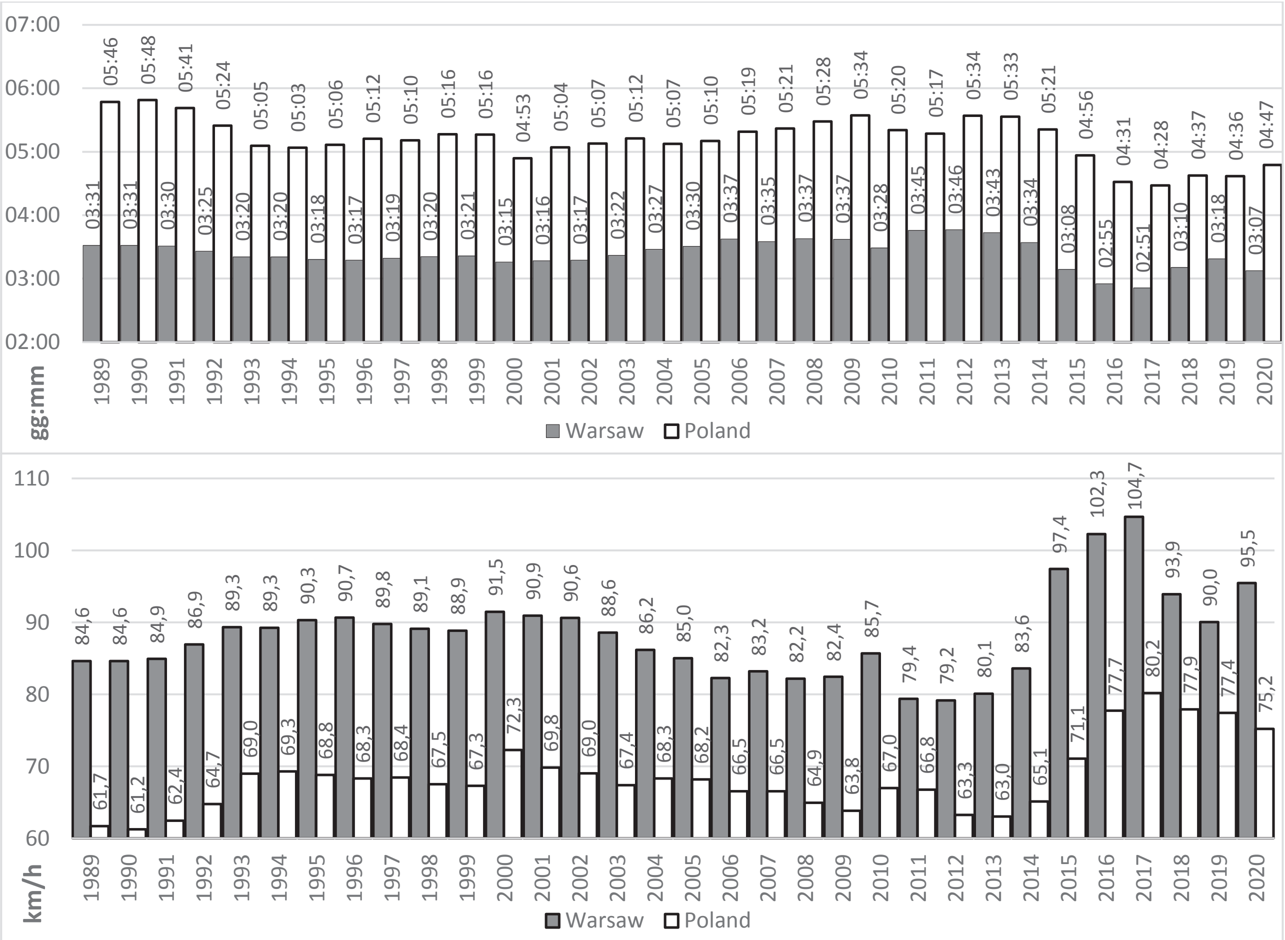


Fig. 2 Average journey times and commercial speeds for the connections between the capitals of Voivodships

The journey times and the commercial speeds of trains on the Polish railway network improved significantly from the year 1989 till 1994. This enhanced level was maintained until the year 2000, culminating with extraordinary journey time reductions implemented in the 2000/2001 timetable. At that moment, however, the infrastructure condition deteriorated rapidly, mainly to dramatically reduced expenses for maintenance and renewals (in 1999 only 132 kilometres of track were renewed). As a result the scheduled journey times on several routes could not be maintained, causing huge delays, especially in case of Cracow – Wroclaw – Poznan - Szczecin route (delays up to 1 hour). In the years 2001-2013, a general downward trend was observed, with average speeds dropping almost to the level of the year 1989 (in case of connections between Warsaw and the capitals of the voivodships even worse).

As a result, of modernisation of infrastructure in main corridors and the implementation of the new rolling stock the average commercial speed for all connections between the Voivodships improved significantly and exceeded 83 km/h in 2016/2017 timetable, while the average commercial speed for the connections radiating from Warsaw achieved the level of 105 km/h. It is notable that in the case of Warsaw – Katowice and Warsaw – Cracow routes the commercial speeds of Pendolino trains exceeded 130 km/h.

5. Express Train Services in Central-Eastern European Countries

In the 1970s and 1980s the close cooperation of national railways in Central-Eastern Europe (for example in the framework of OSZhD) resulted in an exchange of experience and, consequently, in several similarities in various aspects of railway technology (for example through the adoption of uniform OSZhD system of signal aspects) and operation. In all countries, the railway passenger transport offer evolved into the three-tier structure with the following train categories: passenger (slow) trains, fast trains and express trains, i.e. the same as on PKP network. In 1989, the express train services were operated in all European Comecon countries. The special case was the CFR offer structure in Romania, with the top train category branded as "Rapid". On the other hand, Hungary was the first Central-Eastern European country, in which EuroCity trains were introduced (1988). Brief characteristics of the express train services have been presented in Table 3 (international express trains, composed of sleeping cars only are not included).

It should be noted, that there was no uniform approach in categorisation of international trains in particular countries. For example, in 1989, the “Pannonia” train from Berlin to Sofia was operated as a fast train (*Schnellzug*) in GDR, express train (*Expresni vlak*) in Czechoslovakia, fast train (*Gyorsvonat*) in Hungary, rapid train in Romania and fast train (*Brzi vlak*) in Bulgaria. As a result, some express trains changed their category at the national border.

Table 3

Express train services in Central-Eastern European countries in 1989

Country	No of domestic Ex train pairs	No of international Ex train pairs	Max. speed [km/h]	Highest commercial speed [km/h]	Route with the highest commercial speed
Bulgaria	9	0	130	81	Sofia – Plovdiv
Czechoslovakia	8	20	140	81	Praha - Bratislava
GDR	11	4	120	88	Berlin – Schwerin
Hungary	17+1	2 (EC)	120	91	Budapest – Debrecen
Poland	23+4	4	160	111	Katowice – Warszawa
Romania	6+2 (Rapid)	5	120	79	Bucureşti - Constanta

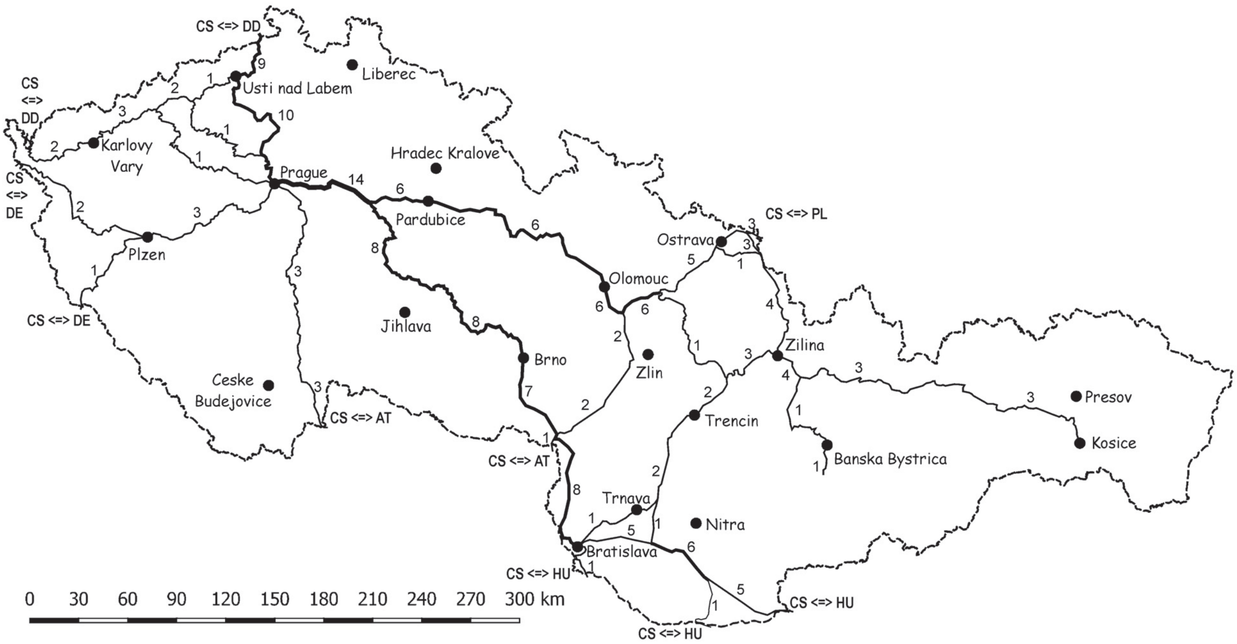


Fig. 3 The express train network in Czechoslovakia in 1989

In the following years, significant changes took place in the train offer structure. New, higher quality domestic trains were introduced by several national railways:

- Express trains in Romania, superior to still existing Rapid services (1992);
- Intercity trains in the former GDR (1990), Hungary, the Czech Republic (1993), Slovakia (1993), Romania (1995).

Moreover, Intercity trains were implemented in 1994 in Bulgaria, however, not as the top-quality express service, but rather as a better category of the fast train.

In the following years, additional new categories were introduced by some railway companies: InterCityRapid (ICR) in Hungary (2004) and InterCityExpress (ICE) in Romania (1998-2002).

Recently the quantity of train categories in several countries has been significantly reduced. Therefore, all long-distance train services in Bulgaria are operated as fast trains (*Brzi vlak*). Similarly, full transport offer in this segment in Romania is branded as IR (*Interregio*).

6. Conclusions

To conclude it is necessary to state that two phases of the rapid development of express train services in Poland can be distinguished: the first starting from the late 1980s till the year 2000, and the second from the year 2014 till now. These periods of growth were separated with a long time of stagnation and recession, from the beginning of the century till 2014. The factors facilitating the development of the express train offer in the first phase were mainly organisational, and can be treated as ‘quick win’ measures, focused on the best possible utilisation of existing assets (infrastructure, rolling stock, lack of “on-rail” competition) to retain the share of rail in the long-distance market

segment. Contradictory to this, the new offer in the intercity sector, implemented in 2014-2015, was the result of massive infrastructure and rolling stock investments.

The experience of a few European countries, also, from Central-Eastern Europe, shows that the overall effect of infrastructure investment could be enhanced. However, it is necessary to take into account the administrative and legal factors, which not necessarily were favourable for the development of rail transport in general, and express train services in particular. Also the competition of road transport, utilising the newly built motorways and expressways seriously affected activities of railway operators, mainly PKP Intercity.

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The Procedure of Operational Risks Management in Railway Companies

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Abstract

The operation of railways is inevitably linked with the possibility of occurrence of a wide variety of hazards, some of which have high potential to cause accidents with very serious consequences. It is acknowledged that the elimination of all hazards and risks connected with them is virtually impossible. However, this well-known fact does not mean that the technical operation of railways there should be only reactive attitudes towards safety as a whole and risks in particular. The potential hazards and associated with them risks must be reduced to a practically acceptable level. Solving this problem is associated with a very important element of safety management, namely risk management. The paper contains a definition and clarification of the theoretical framework and some practical principles for the operational risks managing in the railway company activities.
KEY WORDS*:* *risk management, operational risks, railway company, decision making, risk acceptance*

1. Introduction

The successful safety management of transport companies requires two basic things - firstly, reliable information about events and phenomena occurring within the operation process, and secondly, proper analytical tools for their analysis and assessment. In a more specific sense, where decision-making on issues of operational safety is necessary, the availability of information regarding the hazards and risks for the transport process is a basic requirement. Historically, railway managers have always relied on "sufficient expertise and information" for this type of industry, especially when it is necessary to evaluate the risks associated with the operation of technical equipment and its usage by the operating personnel. In other words, thanks to its long history and specific characteristics, railway transport has always had great success in maintaining a significant amount of "fundamental knowledge" on safety. However, recent decades have been marking a significant growth of the new technical and technological solutions used within the rail industry. The lack of adequate and typical for their specifics knowledge about their safe behaviour leads to the need for the development of new analytical and forecasting techniques, the majority of them based on the concept of risk and the principles of its management.

Therefore, the proper understanding of the nature of risk, its elements and principles of management, and also the peculiarities of the process of decision-making in this area are essential for achieving an acceptable level of system safety in railway companies. The paper presents the essence of risk and related concepts, approaches and applicable decision-making methodologies and contains a definition and clarification of the theoretical framework and a practical approach for managing the operational risks in the railway systems.

2. Practical Guidelines for Decision-making in System Safety

From a practical point of view, within the safety management system of a rail undertaking (infrastructure manager or carrier), there are three major issues whose proper understanding and relevant actions are fundamental for successful decision-making in system safety management. They could be expressed by the next three questions: What the terms hazard and risk mean? How the hazards could be identified and the concomitant risks ranked? How to make a successful decisions most appropriately to reduce the highest risks on a practicably reasonable level?

2.1. Hazard and Risk Essence

It could be said that there is no broadly accepted definition of risk. The literature review in the field of operational safety shows that the concept of risk is used in many fields and areas of human activity, but in a number of cases quite descriptively [1-4]. For the practical issues of rail safety, the most appropriate understanding of risk is as referred to as triplet (s_i, p_i, c_i), whose elements are: s_i - i-th accident (incident) scenario, p_i – the probability of scenario i occurrence, c_i - consequences (effect) after scenario i [4].

Risk is an inevitable attribute of every hazard. The latter is an ongoing (but unwanted) state of a technical or technological system and is usually the initial stage of an accident scenario.

The probability of hazard existence depends on system design and its attributes and maybe just 1 (hazard exist in the system) or 0 (hazard does not exist in the system). Every hazard has three major components and the comprehensive knowledge about them makes the hazard recognizable.

Hazard major components are:

- *Source of hazard* (Hazardous system element). This is the major hazard element creating the impetus for its occurrence, such as a mechanism whose specific failure may be hazardous regarding system functioning.
- *Actuating mechanism*. This is a unique sequence of events (initiating and successive) transforming a hazard from dormant (principally existing) state to an active accident state.
- *Target*. It could be a person or an object that is vulnerable to injury and/or damage, and it describes the severity of the accident happening after hazard actuation.

Railway accident (incident) happens when all components of the actuating mechanism of a hazard (generally randomly oriented with respect to the corresponding process having specific relation with the entire transport process) are "arranged" in a logical order. This order is known as an accident scenario [5]. The accident scenario contains an initiating (trigger) event and one or (usually) more intermediate events leading to the final mishap state. The concepts of hazard actuating mechanism and accident scenario [6] are illustrated in Fig. 1.

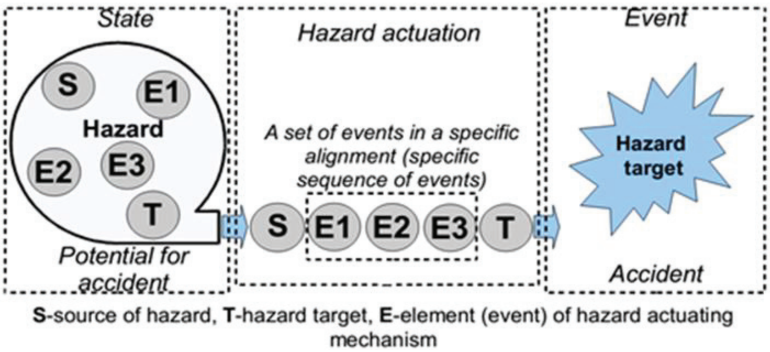

Fig. 1 Hazard – accident actuation

2.2. Hazard and Nature of the Risk

This is one of the most important stages of the overall process of risk analysis. This is an analytical and sometimes complex to implement the process of "visualization" and "knowledge acquisition" concerning a hazard based on certain statistical information on incidents (accidents) and knowledge about the studied technical or technological system (subsystem, individual element) [7-8]. In addition, the correct identification of hazards requires extensive knowledge on both the general methodological issues of risk management and the existing analytical approaches (and also methods) for the description of hazards elements [9].

There are several practical approaches to identify hazards within the scope of the technical operation in a railway undertaking, the most common of them are based on:

- available information on adverse events and gained operational experience;
- known or prior facts regarding the causal chain "source-target" that is typical for a hazard;
- analysis of good practice existing in the risk management in other organizations;
- concentration on potential and conceivable adverse events within the corresponding studied process;
- verification and analysis of common or partial safety criteria, norms, regulations, provisions, rules, principles and objectives, etc.

The identification of a particular hazard should contain a description of all three components. The description should be clear and concise, yet comprehensive enough to be used as a basis for further risk analysis. Unidentified hazards or misstatement descriptions may lead to extremely undesirable consequences, such as expenditure of time and resources for activities (mitigation measures) associated with low-risk hazards and skip the implementation of adequate measures in respect of other high-risk hazards.

In that sense, one of the most essential elements of the safety management system of a railway undertaking is the so called hazard record. It should describe most completely all possible hazards that may occur within the implementation of the transport process. Hazard record plays the role of a knowledge foundation based on which the decision-making for safety improvement is made.

Therefore, the correct description of hazards is an important element not only of the theory but of the practice of risk management [10]. There are quite a few methods of hazard identification and analysis. The analyst must carefully choose the appropriate analytical tools to achieve the objectives of performed analysis.

Another essential practical problem that is to be solved and is situated between the procedures of hazard identification and decision-making for defining mitigation measures for safety improvement is hazard gradation (ranking) with respect to the level of their risks. In any railway subjects or companies, there are usually a great number of conceivable hazards and the concomitant risks have to be ranked. This is necessary because some of them (those having the highest level of risk) will demand immediate actions and allocation of resources.

A very powerful tool used to rank and prioritize risks is the Pareto Analysis. This analysis is based on the Pareto principle, well-known in the field of quality management [11]. That principle applies very widely to many types of activity and can be stated as: “Most of the effects are due to a few of the causes.” The Pareto principle is also known as

the 80/20 rule because it is based on the idea that 80 percent of a situation's problems can be traced to 20 percent of the causes.

In the operational safety management of given railway systems, the Pareto analysis could be implemented through the next steps:

1. Preparation of a list of hazard (risk) sources according to the specific activities of the studied railway company, e.g. activities as sources of risk e.g. from A1 to A10.
2. Assessment of the magnitude of every activity's risk (Table 1). This stage could be fulfilled by the usage of some methods. The simplest one is by the utilization of rank matrices - providing the capability to evaluate as the ranks of individual elements of risk and also the total risk rank (score).
3. Ranking of the sources of hazard in descending order of risk score (Table 2, Column 2).
4. Calculation of the cumulative scores - starting from the top of the risk score (Table 2, Column 3).
5. Analysis of which sources have contributed to 80% of the total risk. In the example, in Table 1 almost 80% of the total risks have been contributed by just four (sources of a hazard: A3, A1, A7, A4) of the total ten sources of hazards. That means: 80% has been contributed by 40 % of the sources.
6. Emphasis on those activities (sources of hazard) which contribute most to the total operational risk (safety) in a specific railway company.

Table 1
Risk rank table

Activity (Source of hazard)	**Risk Rank** (Score)
A1	20
A2	1
A3	67
A4	10
A5	8
A6	3
A7	15
A8	4
A9	4
A10	3

Table 2
Cumulative ranks in [%]

Activity (Source of hazard)	**Risk Rank** (score) *descending order*	**Cumulative Risk Rank** (score)
A3	67	49.630
A1	20	64.444
A7	15	75.556
A4	10	82.963
A5	8	88.889
A8	4	91.852
A9	4	94.815
A6	3	97.037
A10	3	99.259
A2	1	100.000

The Pareto Analysis is a starting point for a more detailed analysis (if applicable and necessity). Of course, the initial intention has to be emphasized on undertaking activities (sources of hazard) with the highest risk (those contributing to 80% of the total operating risk). Further actions should be focused on activities with calculated low total risk but having high potential for great severity of consequences. Additional analysis of their probability of occurrence has to be performed, and if it turns out high or there is great uncertainty concerning its magnitude some appropriate measures should be put in place.

3. Decision-making on Risk Acceptance

It must be recognized that the evaluation procedure regarding the acceptability of risk as a whole and in particular the choice of approaches and criteria to implement that evaluation is the most controversial elements of the entire process of risk management. Works [12-13]. summarizes the complexity of these elements. The assessment of risk acceptance has two main elements: approach (principle) of acceptance and criterion of acceptance.

The criterion of risk acceptance is a pre-accepted benchmark $R_{benchmark}$ against which the risk under assessment $R = f\,(s_i,\, p_i,\, c_i)$ is to be compared. Generally, the criterion can be of any kind: the value of a parameter, characteristics of a technical or technological system, rules for risk management, etc.

In most standards for risk analysis, assessment and evaluation, the criterion of risk tolerability are defined in advance as an essential element (touchstone) of the entire safety management procedure. The principle of acceptability determines how the criterion for risk evaluation is interpreted. In this sense, one of the main approaches is ALARP principle [14-15].

The ALARP principle is the most suitable for practical application, easy to understand and providing capability for comparatively accurate results within the safety management system of a railway undertaking. ALARP is an acronym for "as low as reasonably practicable" and says that the risks associated with the functioning of a system should be reduced to a level that is as low as reasonably practicable. That means, if the risk reduction achieved by implementing certain safety measures is insignificant compared to the costs of these measures, it would not be reasonably practicable to implement them. ALARP principle is the most suitable for practical application, easy to understand and providing capability for comparatively accurate results within the safety management system of a railway undertaking. ALARP is an acronym for "as low as reasonably practicable" and says that the risks associated with the functioning of a system should be reduced to a level that is as low as reasonably practicable. That means, if the risk reduction achieved by

implementing certain safety measures is insignificant compared to the costs of these measures, it would not be reasonably practicable to implement them. In other words, a risk reduction action is not reasonable (it does not lead to a reasonably low level of the risk) if there is a gross imbalance between the risk reduction and the related costs allocated to this reduction action. The ALARP principle defines 3 risk levels which can be illustrated by Fig. 2.

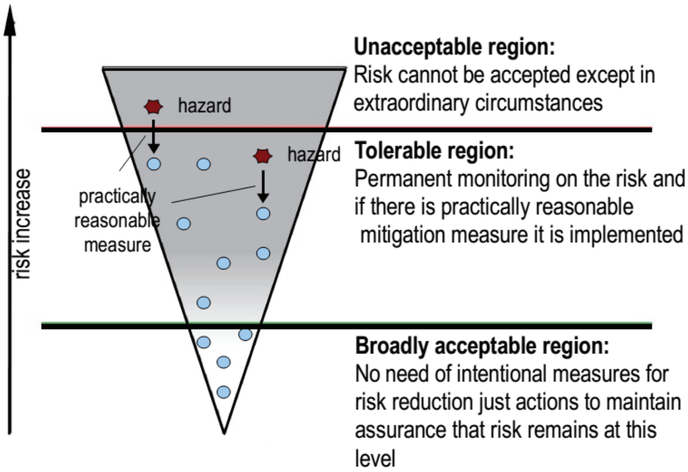

Fig. 2 ALARP regions

In most cases, the risk is situated on a certain level in the field of tolerable ALARP region (for the upper and lower limits of which there are quite a few proposals, e.g. [16-17]). As mentioned above, this fact implies the need for continuous monitoring, analysis and evaluation of the risk to justify the need to define and implement measures for its reduction. This need is sometimes obvious, but in many cases, further, analysis is required, and for this purpose, many engineering and economic approaches and methods are applicable [18-19]. The structure of the procedure for applying the ALARP principle for justifying risk reduction activities in railway companies can be summarized in Fig. 3:

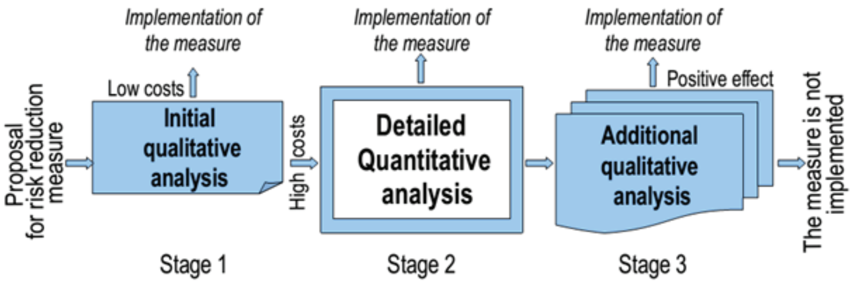

Fig. 3 Procedure of ALARP principle application

Stage 1: Performance of a qualitative analysis of the benefits and problems of application of a certain measure for risk reduction. If the cost of the measure is not considered to be significant - the measure is implemented. It is deemed that there is no significant disproportion between the costs and benefits of the measure.

Stage 2: If in the previous stage the costs have been defined as significant, additional economic analysis should be performed. Depending on the criterion (indicator) there are several possible approaches for further analysis, the most used of which are [1]:

- Cost Per Unit Risk Reduction – E_{CPURR}:

$$E_{CPURR} = \frac{NPV}{M_{equivalent}} = \frac{\sum_{t=0}^{n}\left[\left(B_t - C_t\right)\left(1+r\right)^{-t}\right]}{M + S/10 + L/200}, \tag{1}$$

where NPV is Net Present Value of implementing a risk control measure. This value is computed based on B_t – it is total costs in period t, C_t is total benefits in period t (without the economic benefit of the reduced number of fatalities), t is the time horizon for the assessment of studied risk reduction measure (0 - first year and n - last year of the assessment period), r is the discount rate. Value $M_{equivalent}$ is equivalent to mortality. This value is computed through: M is the number of *Fatalities*, S is the number of *Major injuries*, L is the number of Minor injuries [1]. Obtained for different risk reduction measures is used for decision making in the process of safety management and most specifically whether the implementation of respective mitigation action (measure) is economically expedient.

- Implied Cost of Averting a Fatality – E_{ICAF}:

$$E_{ICAF} = \frac{E_{annual}}{M_{reduction}}, \tag{2}$$

where E_{annual} is the annual cost of the mitigation action and $M_{reduction}$ is the reduction in annual fatality number.

The practical application of this approach requires a criterion by which to determine the effectiveness of the studied mitigation action. In specialized literature, there are some proposals for such a criterion. Work [16] proposes that a certain risk reduction measure could be deemed as cost-effective and because of that implemented to reduce the risk from one ALARP level to another.

Stage 3: Performance of additional qualitative analysis if the approach and criterion of the second stage did not show conclusive results on the effectiveness of studied risk reduction action. At this stage, lots of analytical techniques could be in the help of analyst and decision-maker, for example: What-if analysis, Check List Analysis, … In any case, it is necessary to address as many aspects of measure effectiveness as possible, for instance: 1. connection of the measure with the best available technical and/or technological solutions; 2. practical applicability of the measure to improve quality of undertaking's safety management system; 3. presence of potential for "residual" problems after the implementation of the measure and especially within the operational safety; 4. presence of potential conflicts between different conditions of the technical exploitation after measures implementation [20]. If the additional qualitative analysis shows the possibility (or presence) of the positive trends in result of mitigation action (measure) implementation, the action is adopted as effective, i.e. there is no significant disproportion between the costs and benefits of measure [16].

4. Conclusions

The process of risk management is vital for safety management in a given transport undertaking. It allows us to obtain a comprehensive picture of risks to the operational process caused by the behaviour of technical equipment and human-operator working together to meet the major purpose - safe transportation process. Moreover, risk management allows comparing the levels of a type of risk before and after the occurrence of specific events and/or conditions. This is particularly important for safety management because it allows assessment of the effectiveness of risk reduction measures. The latter is of great importance regarding the overall functioning of railway undertaking, simply because safety improvement is a controversial matter - always required but at the same time connected with costs (sometimes very large). The operating experience shows that in many cases safety experts meet serious difficulties to justify the need to define and implement safety measures. The main reason for that is the presence of uncertainty regarding many of risk evaluation aspects. The present paper discusses the approaches and stages of the practical implementation of a procedure for decision-making regarding risk and safety improvement in rail company activities.

Acknowledgments

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Investigation of Liquefied Natural Gas Ageing and Boil-off Gas Management at Klaipeda LNG Reloading Station

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Abstract

Today the world energy market is in great transition and the demand for clean energy such as liquefied natural gas (LNG) is increasing rapidly. LNG is the main transfer form of long-range for water transportation and short range for land transportation. For socioeconomic aspects, using LNG for road transport could reduce oil demand, contribute energy security in nations with scarce energy resources and could change the quality of life for people because LNG-powered transport produces a low amount of noise and air pollutants. For the environmental aspects, LNG supplies as fuel for marine vessels or road trucks, toxic engine emissions are lower than traditional fuels: up to 80% for carbon monoxide, 70% for nitrogen oxides and 45% for non-methane volatile organic compounds, because of reduction of sulphur oxides and particulate matter are larger than 97%.
The main objective of this research work was to evaluate the impact of technological operations and composition of LNG on LNG ageing and management of boil-off gas during its storage in Klaipeda LNG Reloading Station. This terminal is used as intermediate storage of LNG before loading LNG trucks, LNG bunkering ships and operation of process heat production plant. When LNG is stored for a long time, the volatile components (nitrogen and methane) start evaporating and this causes changes in composition and quality, which is called ageing process. This investigation could be useful in case of LNG market oversupply or with existing demand to storage LNG as a reserve.
It was found that the nitrogen and methane concentrations of LNG remained practically unchanged during the analysis of the loading in the Klaipeda LNG Reloading Station cycles, and the corresponding calorific values only fluctuated within the error range. So, the LNG does not chemically age concerning to its market value. However, there is technical ageing that affects the management of the distribution system. The LNG as well as the percentage of vaporized gas in the storage tanks were mainly influenced by technical parameters such as the time of complete unloading from the storage tank into the LNG trucks, a number of LNG loading to the LNG trucks and the transfers between storage tanks. The transfers between the tanks are in turn influenced by the heat exchange in the processing pipeline with the environment, which leads to an increase in LNG temperature. The analysis also showed that discharging a tank over a longer period of time causes rapid heating of the LNG. This leads to an increase in the BOG. It is recommended to avoid these transfers between tanks until the planned technical improvements have been implemented.
KEY WORDS: *LNG, LNG ageing, boil-off gas, LNG terminal, alternative fuel*

1. Introduction

Liquefied natural gas (LNG) has been increasingly used in the maritime transport sector in recent years due to almost no sulphur and particulate matter during the combustion process and it can emit about 90 percent less nitrogen oxides. According to DNV GL, ships powered by LNG can reduce CO_2 emissions by 15 to 20% [1].

Liquefaction of natural gas is carried out at a temperature up to –162°C. In this state, the LNG holds about 1:600 volumes of natural gas, and its conversion into liquid allows us to transport larger volumes of product cargo to any place in the world [2]. It is believed that LNG should become the fuel of the next decade and even the future. The most important driver of these changes is the new requirements that have led to the development of LNG in the transport sector and the development of infrastructure in the ports, including Klaipeda Seaport [3-5].

Through heat input into the storage tank, LNG begins to change over time, named as ageing or weathering. This not only affects the composition, but also the thermodynamic parameters [6, 7]. A change in composition would also result in a change in calorific value [8].

The amount of evaporated BOG at LNG terminals could be affected by various factors. In the absence of discharge, BOG mainly appears due to constant heat leakage into cryogenic tanks and associated recirculation pipelines used for LNG insulation [9]. During circulation, heat is absorbed through the pipelines and enters the tanks with LNG that leads to an increase of BOG release. Tanker truck loading together with LNG component composition also affects the amount of released BOG.

The main objective of this research work was to evaluate the impact of technological operations and composition of LNG on LNG ageing and management of boil-off gas during its storage in Klaipeda LNG Reloading Station.

2. Methodology

2.1. Object of This Work

The object of this work was the LNG distribution station JSC “Klaipėdos nafta” (Fig. 1).

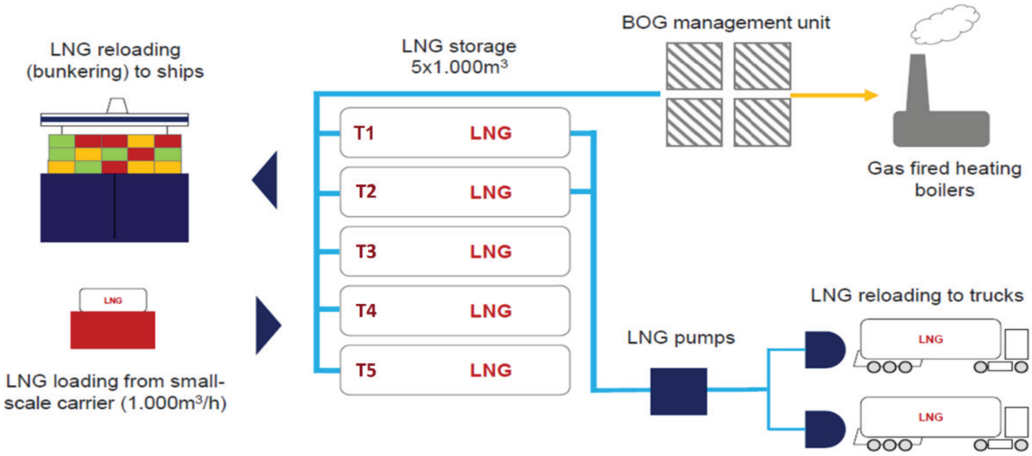


Fig. 1 Simplified scheme of the LNG distribution station of the JSC “Klaipėdos nafta”

LNG distribution station is intended for receiving, temporarily storing and reloading liquefied natural gas to tanker trucks or bunkering vessels or LNG powered vessels. LNG is purchased from Klaipeda FSRU „Independence“ or from other terminals in the Baltic or North Sea to LNG distribution station.

LNG small scale terminal infrastructure consists of five bullet type tanks (T1-5) with a volume of 1000 m^3 and with possibility to have a pressure up to 7 bars inside. Each of them could be filled up to of 90 % its capacity. The daily volume release of BOG could reach 0.05-0.15 vol. % from volume stored.

Meanwhile, the first storage tank T1 is intended to supply BOG to the boiler house of JSC „Klaipėdos Nafta“. The LNG from T1 is pumped to the LNG regasification unit consisting of four Ambient Air Vaporizers, an electric heater and other equipment needed to control the flow and temperature of the gas supplied to the boiler room. The maximum regasification rate is 7000 N m^3 h^{-1}. The LNG distribution station infrastructure also consists of a tanker truck loading platform, which can carry out two tanker loading operations from the second storage tank T2 at the same time, with a maximum loading speed up to 100 m^3 h^{-1}. Remaining three T3, T4 and T5 storages are used for storage of LNG which is pumped into tanks 1 and 2 as required. BOG that forms in the T 2-4 during operation remains trapped in the tanks and is not discharged to the boiling plant.

2.2. Basic Process Performance

For this work, measurements of LNG temperature, mass flow were determined with Coriolis flow meters and composition were recorded using a gas chromatograph over a period of four ship deliveries of LNG to the distribution terminal. During this period 150 tanker trucks were dispatched from these LNG stocks. After a preliminary analysis of the selected data, one loading cycle was selected for further detailed analysis, during which 35 tanker truck filling operations took place. This loading cycle consisted of two loading periods: period (a) – loading from the bunkering vessel into second storage tank (T2) and from it to the tanker truck. Period (b) consists of the same load being transferred from one storage tank to another (T2) and loading into tanker truck.

Calorific value and density were determined by JSC “Klaipėdos Nafta”. The filling level of the tanks was derived from the mass flows between the tanks and the loading station to the trucks.

3. Results and Discussions

Fig. 2 shows three LNG temperature measurement series during the loading of 35 tanker trucks. The curves for tanker trucks 17, 18 and 19 have a bend which is caused by the subsequent pumping of LNG from tanks 3-5 into Tank 2.

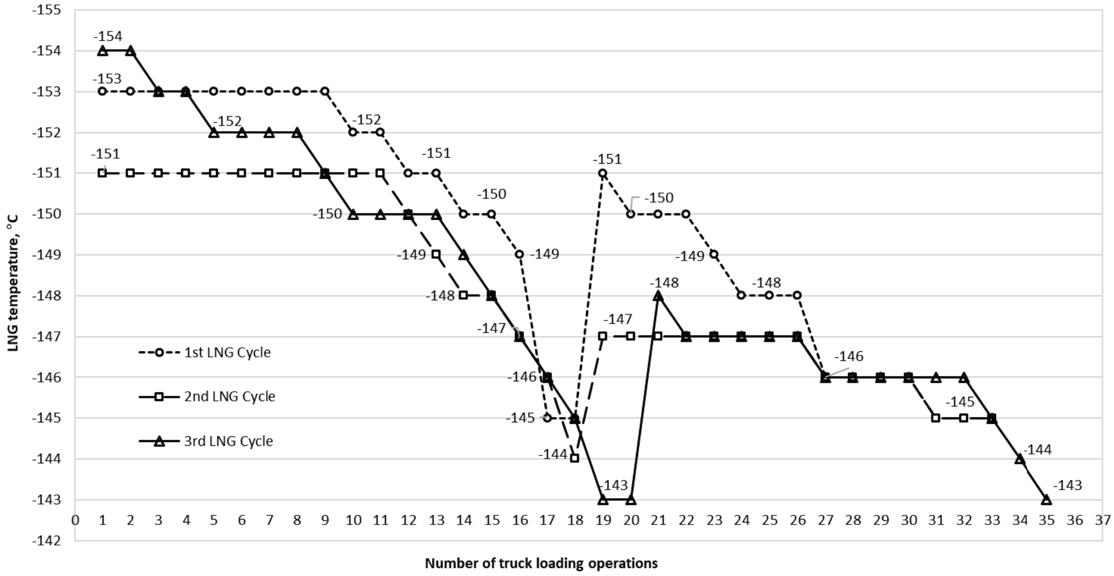
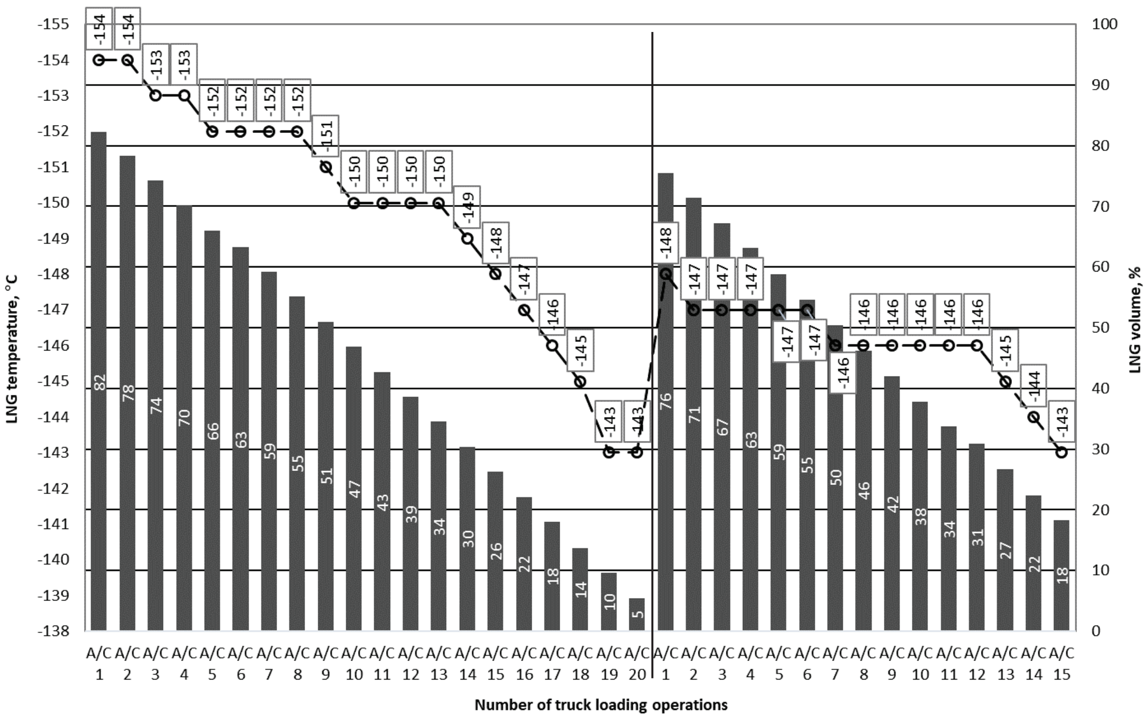


Fig. 2 LNG temperature variation dependence on the number of truck loading operations in three ship-to-shore operations

Fig. 3 shows changes of product temperature and level in storage tank after loading of a tanker truck. The temperature curve corresponds to the curve with solid line in Fig. 2.



a b

Fig. 3 Trends of temperature and product level in the tank while loading into tanker trucks: a - after loading from T2 to tanker truck (A/C number); b - after loading from T4 to T2 and loading tanker truck (A/C number)

Tank T2 was filled to the 82% level by a bunkering vessel. The tank was then successively emptied in two periods in tank trucks:

a) 20 tanker trucks participated in this cargo period and the maximum filling level of the tank decreased from 82 vol.-% to practically the lowest level permitted of 5 vol.-%. The initial temperature of the cargo of –154°C increased to –143°C. Data in Fig. 3 shows that after discharging liquefied natural gas to a third tanker truck, when the level of the cargo tank decreased by 8%, from 82 to 74 vol.-%, first temperature warm up observed from –154°C to –153°C. Overall, the temperature increases very unevenly during the following tank truck loads.

During the LNG unloading process into a tanker truck, a vacuum is created at the top of the tank, resulting in faster LNG evaporation to compensate for this pressure loss [10].

b) Reloading of LNG from the fourth storage tank T4 to a second storage tank T2 and afterwards to a tanker truck.

It is important to highlight that after mixing second storage tank T2 LNG warmed up residue of –143°C with the fourth storage tank T4 reloaded product, total cargo temperature reached only –148°C instead of the approximately –151°C corresponding to the first period. On its completion of 15 tanker truck loading operations LNG level in the tank reached 18 vol.-% and product warmed by 5°C up to –143°C.

This can probably be explained by heat ingress in the cargo loading line, possibly because of the different pipeline lengths between tanks and the transfer rate of the loading pump.

The analysis of the loading data in period (b) shows that the temperature change of the LNG is slower, and the loss reaches 5°C during the entire back loading period.

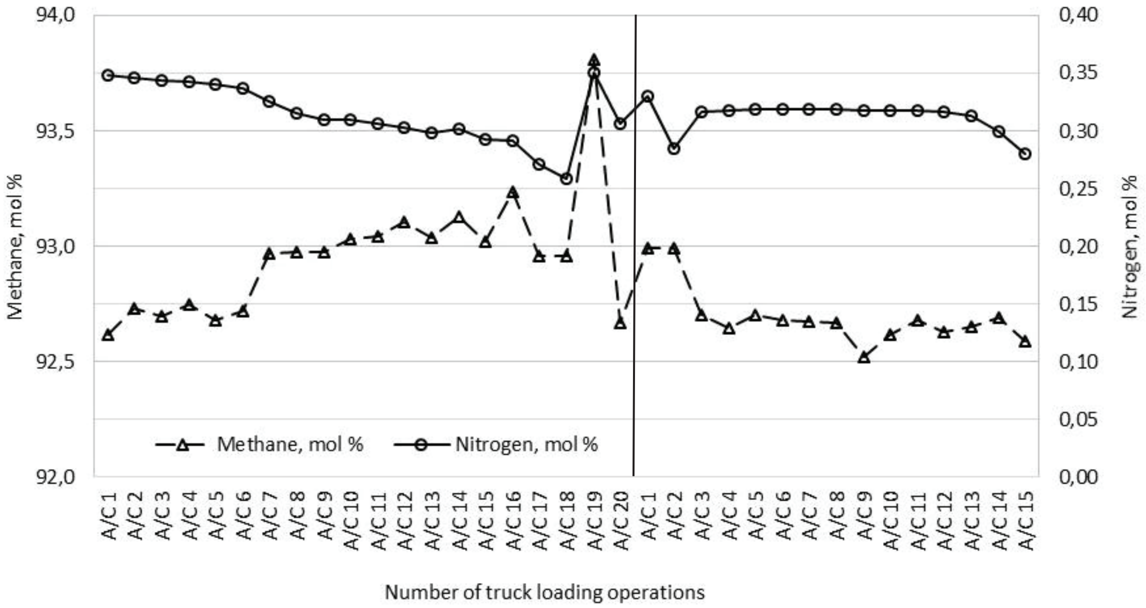


Fig. 4 Trend of methane and nitrogen content in mol-% while loading into tanker trucks: a - after loading from T2 to tanker truck (A/C number); b - after loading from T4 to T2 and loading tanker truck (A/C number)

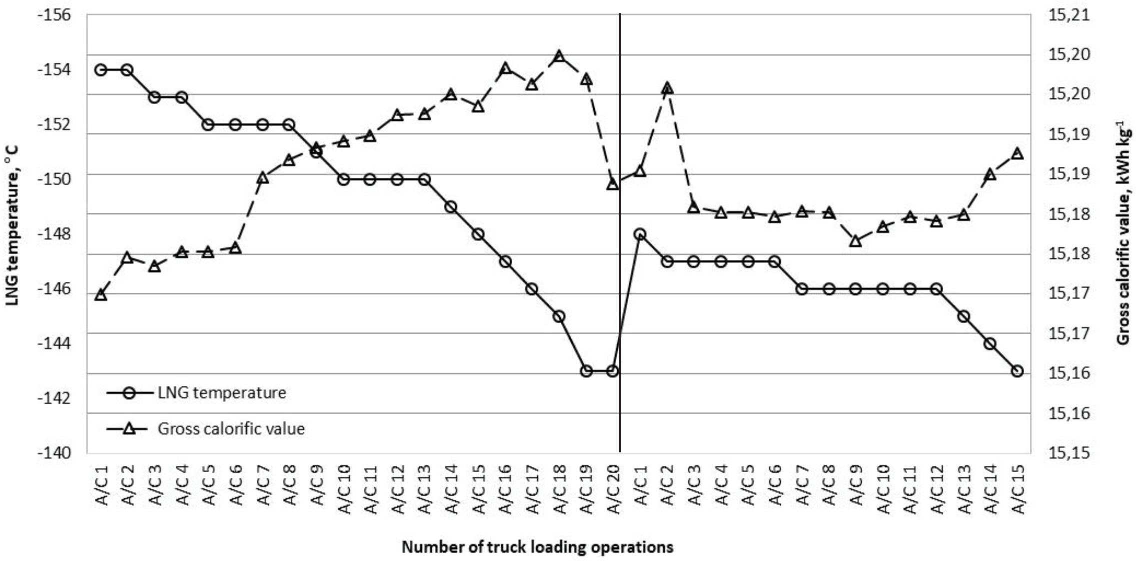


Fig. 5 Trend of LNG temperature and gross calorific value while LNG loading in tanker trucks

It can be seen from the data presented in Fig. 4 that during the analysed cargoes the concentration of methane in LNG varied from 92.61 to 92.59 mol-%, and nitrogen from 0.35 to 0.28 mol-%.

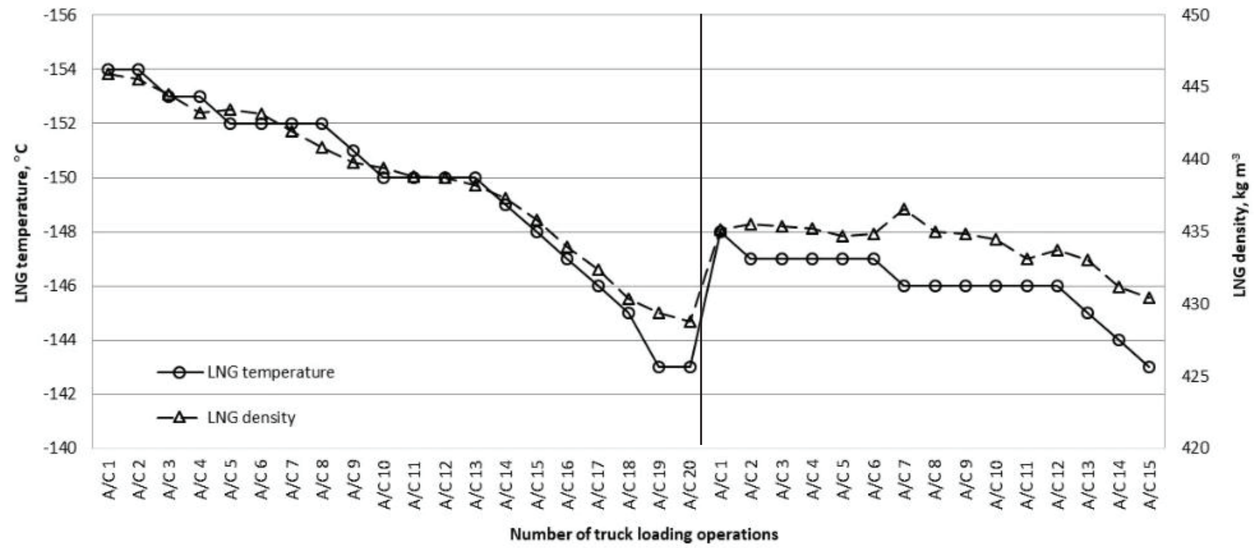
It was found that gas nitrogen and methane concentrations were practically unchanged during loading of LNG from storage tanks to tanker trucks. This is probably due to the evaporation and auto cooling processes of the product that take place during the loading of LNG into the tanker truck. At this point vacuum is formed at the top of the tank,

which promotes the release of BOG and during release, the tank charge cools down, inhibiting the change in component composition.

Fig. 5 shows the trends of LNG temperature and higher calorific value changes during loading onto tanker truck. It was found that during storage of LNG, temperature changed from –154 to –143°C. Meanwhile, refuelling from another storage tank using the same LNG cargo resulted in a 5°C drop in temperature from –143° C to –148°C.

It was determined that after the 1st loading into the tanker truck, the higher calorific value of LNG reached 15.170 kWh kg^{-1}. Meanwhile, after loading the 20th tank, it increased by 0.014 kWh kg^{-1} to 15.184 kWh kg^{-1}. After reloading liquefied natural gas cargo with the same composition from one storage tank to another and reaching the 15th tanker truck loading operation, the calorific value increased by 0.002 kWh kg^{-1} – from 15.186 kWh kg^{-1} to 15.188 kWh kg^{-1}.

Summarizing the tendencies of temperature and higher calorific value changes of LNG loading cases during the process of tanker truck loading operations, it can be stated that with temperature increase in the storage tank from –154°C to –143°C, the gross LNG calorific value varied within the standard deviation from 15.298 ± 0.05 kWh kg^{-1} (a period) to 15.304 ± 0.03 kWh kg^{-1} (b period).



a b

Fig. 6 The trend of the temperature and density of LNG in the case of tank truck loading

Fig. 6 shows the change in temperature and density of LNG after each loading operation to a tanker truck. It was found that during the loading cycle of cargo during period (a) the highest decrease of density was observed (17.17 kg m^{-3}, or 3.9%), when the temperature of LNG warmed up to 11°C. Compared to period (b), when the temperature change was 5°C and remained more stable, the density decreased by 4.72 kg m^{-3}, or 1.9%.

The decrease in density can be explained as follows: As a result of heat entering through the walls of the storage tank, the temperature of the LNG increases, and as the temperature of the LNG increases, the volume increases, and the density decreases accordingly.

Due to the ageing process (the lighter components start to evaporate), the heat entering the upper part of the storage tank through its walls accelerates the formation of BOG from the free surface area of liquefied natural gas. As a result of heat ingress, the temperature of the liquid increases, LNG warms up, and as the temperature of the LNG increases, the volume increases, and the density decreases accordingly.

4. Conclusions

1. It has been determined that at the LNG distribution station the ageing process of the stored LNG and the management of the evaporated gas are influenced by the initial composition of the cargo, the time it was unloaded from the storage tank to the tanker trucks and reloading operations from one storage tank to another which due to different pipe length in technological line leads to a different amount of heat ingress and influences LNG temperature.

2. It was found that the concentration of nitrogen and methane in the LNG was practically unchanged during the analysed period, while the higher calorific value varied within the standard deviation. So there is no chemical aging. However, there is technical ageing, which affects the management of the distribution system. The analysis of the data shows that when the storage tank is unloaded over a longer period of time and the LNG level in the tank decreases around 50 %, the rapid heating of LNG occurs:

– During loading of the liquefied natural gas, when the cargo was loaded from the ship to the storage tank within 18 days, after 20 loading operations, the LNG warmed up the most, even at 11°C, which caused the largest decrease of the LNG density in the tank – 3.9%.

– Meanwhile, after reloading between storages, LNG has warmed up to 5°C within 12 days. The density of LNG decreased by 1.9% over the whole period.

3. It was found that reloading of LNG from T4 to T2 caused heat loss and warmed up by 6°C - from –154°C to –148°C, therefore it is recommended to avoid product reloading operations between storage tanks as this would ensure minimum temperature loss during its storage.

After the completion of this work, the plant was modernized. It is now possible that tank trucks can be loaded from any tank. It is also possible to fill all tanks from a ship. If it will be necessary to do tank to ship bunkering probably it will be possible to do it from all tanks. However, tanks 1 and 2 will be closed for that operation, because of the boiling plant and to have big enough pressure for the transportation gas via pipeline to the tank. It is possible to send BOG to a boiler plant from all tanks.

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FEM Analysis of a Variant Solution of a Quick Clamping Device of Attachments for a Skid-Steer Loader

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Abstract

The article introduces the solution of the issue of implementation of a problem of the own engineering design of a quick clamping device of attachments for a skid-steer loader Locust L1203, which is produced by the WAY Industries, Inc. company. There are presented a structure, a drive-train and a control system of the loader as well as the current unsuitable state of the quick clamping device. Therefore, it is necessary to modify and optimize it. There are listed important input data, which effect the engineering design of the optimised structure. Moreover, numerical analyses of the own engineering design of the quick clamping device are performed in order to ensure its safe operation. Computations and simulations will serve as a base for the production of a real prototype of a device and testing. After successful results, serial production of the device will be introduced.
KEY WORDS: *a skid-steer loader, an engineering design, a steel structure, numerical analyses, a quick clamping device*

1. Introduction

Improving productivity and safety of the production process is the primary task of transport and handling machines. Mechanisation and automatisation of the production process contribute significantly to improvement of productivity. Mechanisation and automatisation are necessary for such areas, in which a person is not able to work sufficiently in terms of performance and precision. For this reason, the subject of this research is a small compact skid-steer loader Locust L1203 form the Slovak producer WAY Industries, Inc., which by its operability makes easier the work of a man in a wide range, as evidenced by peripherals manufactured for this universal loader [1, 2, 15].

There are many attachments for skid-steer loaders. Every from them is intended to be used for different purpose ad they are used in various branches, such as agriculture, forestry, construction, etc. The solved quick clamping device is determined to carry more types of attachments, e. g. an angle broom, a breaker, a backhoe, a concrete mixer, a root grapple, pallet forks and others.

2. A Skid-Steer Loader Locust L1203

There are more producers of building and handling machines, such as Bobcat, JCB, John Deere, Caterpillar, Volvo and others. Some produce their machines in every weight and dimensional categories; others are more focused on a certain assortment of machines. The WAY Industries manufacturer is one of them. It produces a small and compact skid-steer loader (Fig. 1).

Fig. 1 A skid-steer loader Locust L1203

The loader has four wheels, which are driven by hydromotors, controlled independently. The loader is equipped by a hydraulic system, which handles various attachments [14, 16, 18].

Recently, the producer manufactures three basic models of skid-steer loaders. Figure 2 shows the basic geometrical dimensions of the biggest model, which is marked as Locust L1203. This one can handle the maximal weight of the load. The technical parameters of this skid-steer loader are listed in Table.

Table

Technical parameters of the Locust L1203 loader

Hight	2,180 mm
Length with a buckets	3,745 mm
Width with a buckets	2,100 mm
Operational weight	4,300 kg
Tipping load	1,200 kg
Maximal design speed	12 km·h^{-1}
Volume of a buckets	0.66 m^3
Stroke force	30 kN
Drawing force	41 kN
Lifting power	28 kN
Engine	YANMAR 4TNV 98 ZNSA 2
Engine power	62.5 kW/85 HP
Type of driving system	Hydrostatic
Hydraulic pump of an attachment	Regulation – LS/LUDV
Distributor of an attachment	With closed system
Balancing of a buckets	Hydraulic
Noise level	101 dB
Tyres	12.5 - 18

The hydraulic system of the loader serves for driving, steering and controlling of attachments and it consists of three hydraulic circuits, i. e. a control circuit, a working attachments circuit and a driving circuit. The hydraulic circuit of the driving system includes two regulation pumps, two hydromotors and accessories of the distribution. The hydraulic circuit ensures transmission of torque from an engine to side gearboxes using regulations pumps and hydromotors, reversing of operation of the loader, steering of the loader. Steering system work on the principle of different rotational speeds of wheels on the left and right side, which allows use to drive toward, turn left and right, reverse and even to turn about vertical axis [4, 6, 13].

Pair of aggregates, i. e. the regulation pump and the hydromotor are interconnected using high-pressure flexible tubes. Filling gear-pumps are built-in in the regulation pumps and suck working liquid from a tank through a filter. The filter includes a vacuum-meter, on which degree of pollution of a filter element is indicated. The maximal allowed value of the underpressure is 24.5 kPa at the hydraulic oil temperature of 50^{o}C. The working liquid is pulled from the filling pump through reversing valves, which are built-in the regulation pump body, to a low-pressure leg of the enclosed hydrostatic circuit.

The controlling circuit of the distributer and the driving system of the loader consists of a pump, which is built-in pair of a servo valve and an appropriate distributor. The pump sucks working liquid from a tank and presses it to input sections of cross valves. They regulate working liquid either to working sections of the distributor, i. e. working attachments are controlled or to servo cylinders of regulation pumps, i. e. the driving system is controlled. The direction of working liquid is determined by the position of servo-valves levers.

3. The Variant Solution of Quick Clamping Device Optimisation

The current state of the quick clamping device is shown in Fig. 2a. It is mounted to the boom end and it serves for connection of attachments with the loader. This component allows us to change attachments during couple of minutes and there is not necessary to mount them slow to the boom. Its main parts are two side beams. In the upper part are metal bushes.

a

b

Fig. 2 a - The current state of the quick clamping device; b - the boom with the quick clamping device

The main disadvantage of the current state of the boom is the fact, that the device is handled manually. The operator has to enter a loader cabin, to approach an attachment and to hang it on the quick clamping device. After that, he has to get out of the cabin and manually lock the attachment using a levers system. For operation, the operator has to enter the cabin again and then he can use the loader (Fig. 2, b).

Therefore, the main demand is to eliminate this time-consuming process, i. e. to ensure comfortable handling with the quick clamping device form the loader cabin.

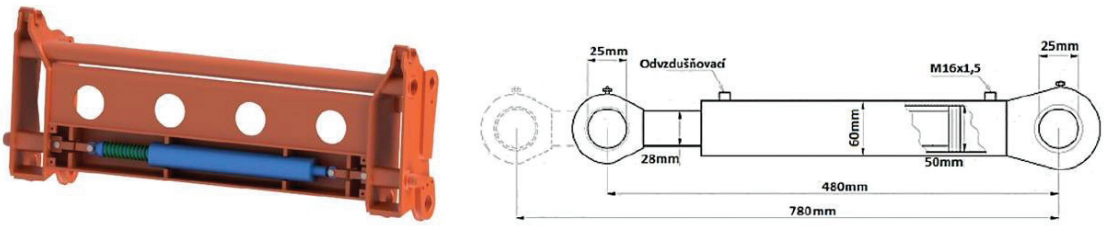
Another demand is that the basic dimensions of the current state of the quick clamping device will be kept also for the newly designed technical solution. Only the cross beam dimensions can be modified.

3.1. Engineering Design with a Single-Acting Hydraulic Cylinder

The first engineering design of the modified quick clamping device is the design with one single-acting hydraulic cylinder with a pull-back spring, which is shown in Fig. 3, a. For the proper choice of the hydraulic cylinder, external dimensions of the cylinder have been the most important parameters. The single-acting hydraulic cylinder is mounted between two consoles, which are fixed using a securing pin. The distance of holes in consoles, in which hydraulic cylinder's eyes are mounted, is of $b = 630.8$ mm. The length of end parts of securing pins for attachments locking in the oversailing state is of $l = 1{,}082.8$ mm and in the plug-in state is this length of $l' = 1{,}026$ mm. Hence, we can determine the value of the piston stroke as follows:

$$z = l - l' = 1{,}082.2 - 1{,}026 = 56.2 \text{ mm}. \tag{1}$$

After market analysis, the hydraulic cylinder marked CJF 50/28/300 U25 has been chosen. A scheme of this cylinder is shown in Fig. 3, b.



a b

Fig. 3 a - The engineering design with a single-acting hydraulic cylinder; b - a scheme of the single-acting hydraulic cylinder

This cylinder is connected with a hydraulic system of the loader using a quick-acting coupling FFI 34 GA M. Since it is the single-acting cylinder, one valve is a release valve. Subsequently, the maximal axis forces of the hydraulic cylinder at the maximal working pressure $p_{max} = 18.5$ MPa were calculated using the following formulation:

$$F_{max1} = \frac{p_{max} \cdot \pi \cdot D_1^2}{4} \cdot \eta, \tag{2}$$

where D_1 is the internal diameter of the cylinder, $D_1 = 50$ mm and η is the total mechanical efficiency of the cylinder, whereby the value of $\eta = 95\%$ is given by the cylinder producer. When we substitute values to the formulation (2), the wanted value of the force F_{max1} is of $F_1 = 34{,}508.43$ N. The formulation (3) expresses the calculation of maximal force F_{max2} during retracting of the hydraulic cylinder:

$$F_{max2} = \frac{p_{max} \cdot \pi \cdot \left(D_1^2 - d_1^2\right)}{4} \cdot \eta, \tag{3}$$

where d_1 is the external diameter of the piston rod and the value is of $d_1 = 28$ mm.

Then, by substituting of corresponding values to the formulation (3), we get the value of the force F_{max2} during retracting of the hydraulic cylinder $F_{max2} = 23{,}686.59$ N. The working pressure p is regulated using a valve to the value of $p = 3$ MPa. Acting forces at this value of pressure are determined by the same formulations (2) and (3) for the pressure value of $p = 3$ MPa. Then, the force value for extension is of $F_{v1} = 5{,}595.98$ N and for retracting the force value is of $F_{z1} = 3{,}841.04$ N.

As it is noticed above, this engineering design includes a pull-back spring. It is a compression spring with following parameters: the spring wire diameter is of $d = 4$ mm, the internal diameter of the spring is of $D_3 = 38$ mm, the length of the unloaded spring is of $l_4 = 120$ mm, the number of coils is of $z = 12$, the spring stiffness is of $k = 5.52$ N·mm^{-1} and the maximal compression of the spring is of $l_{max} = 64$ mm. These parameters allow us to calculate the maximal force, which the spring can absorb without plastic deformation. The formulation for the maximal force calculation is:

$$F_{max} = k \cdot l_{max}. \tag{4}$$

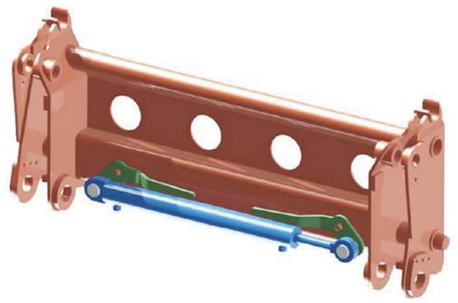
Substituting spring parameters described above to the formulation (4) we get the maximal force in the spring of $F_{max} = 353.44$ N. From this follow, that the hydraulic cylinder can produce even at the pressure of $p = 3$ MPa sufficient force for spring compression. This compression suffices for pulling down of securing pins.

The advantage of this engineering design is the need for only one hydraulic flexible tube. Another advantage is removing several elements from the original system, which reduces the cost price of the quick clamping device.

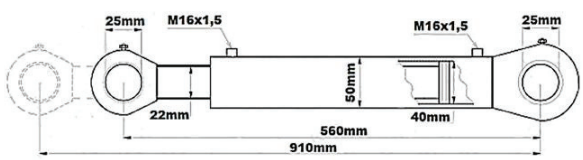
The disadvantage is a more complicated structure of the securing mechanism, which leads to the needed modification of the cross beam and to increase of production time. The most serious deficiency of this design is related to practical operation and it is the fact that in the case of failure, it has not any additional mechanical actuation, which would serve as the emergency operation. For that reason, other engineering design has been created.

3.2. Engineering Design with a Single-Acting Hydraulic Cylinder

The second engineering design of the quick clamping device (Fig. 4, a) consists of using a double-acting hydraulic cylinder (Fig. 4, b). The double-acting cylinder is mounted to the quick clamping device using pins. These bolts transmit the compressive force from the hydraulic cylinder to two levers. Levers are fulcrumed and either extension or retract pins ensuring the mounting of the attachment.



a



b

Fig. 4 a - The engineering design with a double-acting hydraulic cylinder; b - a scheme of the double-acting hydraulic cylinder

Analogous to the previous engineering design, the basic dimensions have been the main criterion for the proper choice of the hydraulic cylinder. The spacing of holes for pins is of $a = 656.24$ mm. The length of end parts of pins for ensuring attachments in the oversailing state is of $l = 1{,}082.2$ mm and in the plug-in state is of $l' = 1{,}026$ mm. It means, the piston stroke is the same as in the first design, and it is of $z = 56.8$ mm. Based on the obtained data, we have chosen the hydraulic cylinder CJ2F 40/22/350 U25. In this case, two hydraulic flexible tubes with quick-acting couplings FFI 34 GA M are used. Flexible tubes serve for the hydraulic liquid inlet to a hydromotor on attachments. The maximal force of the hydraulic cylinder is calculated from cylinder dimensions and maximal working pressure. Formulation (2) expresses the calculation of the maximal force for extension of the hydraulic cylinder F_{max3}, whereby the internal diameter of the hydraulic cylinder is of $D_2 = 40$ mm and the total mechanical efficiency of the cylinder is given by the producer and it is of $\eta = 95\%$. Then, after substituting of corresponding values to the formulation (2) we get the value of $F_{max3} = 22{,}085.4$ N. The maximal force for retracting F_{max4} we get from the formulation (3), where $d_1 = 22$ mm is the external diameter of the piston rod and the value of the force F_{max4} is of $F_{max4} = 15{,}404.56$ N. Also in this engineering design the hydraulic liquid pressure is regulated to the maximal value of $p = 3$ MPa. When we substitute all needed parameters to formulations (2) and (3), we get the value of the force for pushing forward of $F_{v2} = 3{,}581.4$ N and for retracting of $F_{z2} = 2{,}498.025$ N. These forces are sufficient for working of securing pins as well as for minimizing of damage of quick clamping device structure and attachments.

The main advantage of the second engineering design is the simple modification of the original clamping device. It is necessary only to change newly designed rotating levers and to assembly new components to the system. Such a solution is a budged price and it reduces the time needed for modification of the quick clamping device. In case of a hydraulic cylinder failure, this cylinder can be simply removed and a latching system can be handled manually, as it is used in the current state. Therefore, the second engineering design is accepted for production.

4. Finite Element Analysis of the Chosen Engineering Design

The second engineering design of the quick clamping has been submitted to finite element analysis. For these analyses, Ansys software package has been used [5, 9, 10, 17]. The main objective has been to found out the distribution of stresses and deformation in the device structure. All useless elements, which have any influence on numerical results, have been removed from the FE model. Therefore, the model consists of basic supporting parts of the quick clamping device, on which the load acts. The quick clamping device is mounted to the boom using four securing pins, which are placed side holes in side beams. For that reason, axes of these holes are set as boundary conditions of attachment and the quick clamping device is fixed in them. A detail of a model of the lever-type gear is shown in Fig. 5.

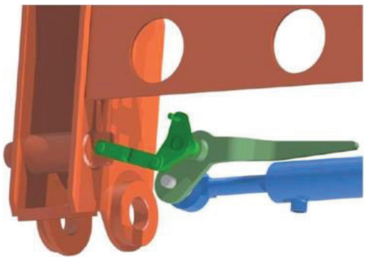
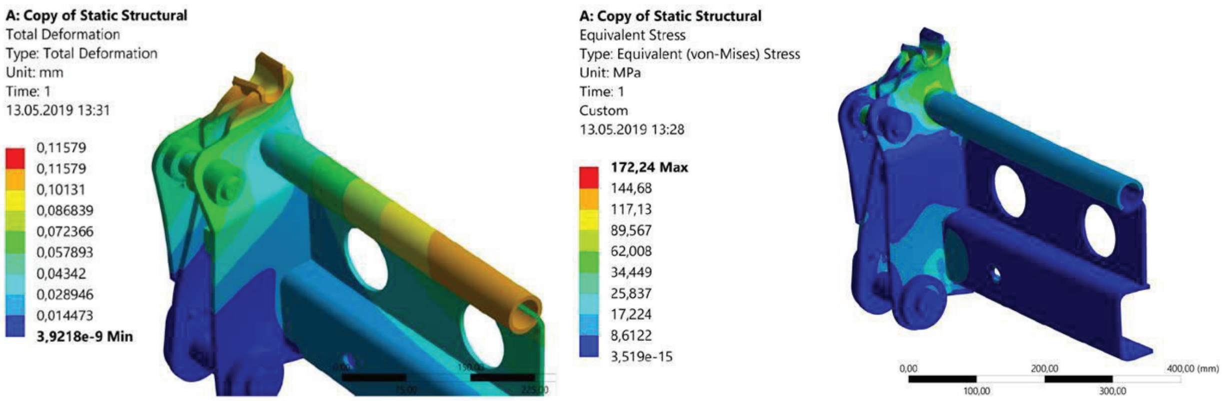


Fig. 5 A 3D view on the detail of the designed structure of the lever-type gear of the quick clamping device

The acting force is another boundary condition. This force simulates the load, which is generated by the fully loaded buckets and it is located in the middle of the buckets. From Tab. 1, it is possible to find the tipping load of m_N = 1,200 kg, whereby the calculation has to include also the weight of the bucket of m_L = 153 kg. The value of the acting force F_m is given by the following formulation:

$$F_m = \left(m_N \cdot m_L\right) \cdot g, \tag{5}$$

where g is the gravitational acceleration of $g = 9.81\ \text{m}\cdot\text{s}^{-2}$. Applying corresponding values to the formulation (5) we get the force value, which is applied as the boundary condition of the load of the quick clamping device, namely F_m = 12,272.93 N. Using the model symmetry, the half of this force has been input to the model, which leads to shorter computing time. After defining boundary conditions, the calculation was performed.



a b

Fig. 6 a - Distribution of maximal deflections in the quick clamping device body under maximal static load; b - distribution of the von Misses stresses in the quick clamping device body under its maximal permissible static load

Fig. 6, a shows simulated deflections, which are generated under a given static load. It can be seen, that the greatest deformations are detected in the bushes locations and the lateral beam of the quick clamping device. The highest calculated value of the deflection is 0.12 mm. It is an acceptable value of the deflection for such a rugged structure and it does not lead to the significant influence of the functionality and safety operation of the device.

The distribution of stresses in the quick clamping device is shown in Fig. 6, b. From these results, we can identify, that the maximal values of stresses are generated again in the bushes locations, in which the buckets are mounted and their value is over 170 MPa. On the contrary, in the middle parts of the structure are stresses, which values are only about 30 MPa. When they are compared with the yield of the strength of the used material, i e. with the value of R_{e235} = 235 MPa, generated stresses can be neglected. Bushes are made of the steel with the yield of the strength of R_{e355} = 355 MPa. Therefore, the structure of bushes is dimensioned properly in terms of the static load.

The selected engineering design was analysed in terms of strength and deformation of the structure. Based on simulation computations there were justified, that the structure of the quick clamping device meets all requirements. For detailed analysing of the structure, a dynamic analysis of the device should be performed. In future research, a multibody model will be created and all necessary output parameters will be evaluated [3, 7, 8, 11, 12].

5. Conclusion

The described work includes a summarization of knowledge about the quick clamping device, which is intended to be mounted on the boom of the skid-steer loader. The main reason for modification of the current state of the device

structure is the improvement of handling of the device directly from a loader cabin.

Therefore, the engineering design of the quick clamping device has been created regarding all requirements imposed on the device by the producer in terms of manufacturing, technology processes, ergonomics and safety. The main demand has been to design such a system, which will be able to ensure attachments that an operator of the loader does not need to get off the loader cabin. Two engineering designs have been proposed. The first one has not met all safety demands in case of emergency operation of the device. The second engineering device includes different hydraulic systems. This design combines advantages of simplicity of structure, safety operation in case of hydraulic system failure, fairly good price and minimal needs to modify the original structure.

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Study of Criteria for Evaluating the Development of Intermodal Services of the Type "Car on the Train" by Applying SWOT Analysis and Best-Worst Method

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Abstract

This paper aims to propose a methodology for assessing the criteria for the effectiveness of transportation of intermodal services "car on the train" named also motorail trains. The motorail trains offer service at which passengers can take their car along with them on their journey. The passengers are carried in the train, while the cars are loaded separately in specialized wagons of the same train. This study proposes a methodology based on the combination of Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis and multi-criteria Best-Worst method (BWM) to evaluate different criteria for assessment the motorail transportation. The methodology of the research includes two steps. The first step includes the SWOT analysis to identify strengths, weaknesses, opportunities, and threats related to passenger railway transport. The sub-criteria for each SWOT group has been defined. A total of 31 sub-criteria are included in this study. The second step includes the determination of the weights of the main criteria and sub-criteria. The Best Worst Method (BWM) which is based on a linear programming method has been applied. It was found that the main importance for SWOT group has the strengths group criteria. The methodology could be applied to evaluate different alternatives of development of passenger railway transport based on defined criteria, sub-criteria and their weights.
KEY WORDS: *SWOT analysis, BWM, multi-criteria analysis, passenger, car, train, motorail, railway transport*

1. Introduction

The intermodal services of the type "car on the train" are also called a car shuttle train, car-carrying train or auto trains. This technology allows passengers to transport from door to door their car. This service is common in many countries. The motorail services are available for both domestic and international transport in many European countries. Some regular day and night trains include car-carrier wagons.

It is important to evaluate the effectiveness of the introduction of this technology by analyzing predefined criteria. The intermodal service of the type "car on the train" offers a number of advantages for users such as: passenger comfort, opportunity to use free time, safety and security, environmental protection.

This paper aims to propose and assess the criteria for evaluating the service "car on the train".

The SWOT analysis as a strategic planning technique to identify strengths, weaknesses, opportunities, and threats related to the investigated system. The strengths and weaknesses are internal parameters, while the opportunities and threats focus on the external environment. The SWOT analysis is an appropriate means to study the sub-criteria related to the four parameters.

The SWOT analysis has been used by authors to make research on different purposes. The SWOT analysis has been applied to select a logistic strategy [1], public transport [2], and other research fields and decision-making activities [3-5]. The scenario for rail freight development, based on a detailed SWOT has been studied in [6]. SWOT analysis is used to analyse inner and external factors of intercity mass transit, [7]. Thirteen sub-criteria have been defined in SWOT groups and assessed by using AHP method. In [8] the Bus Rapid Transit transport has been analysed based on SWOT analysis. The questionnaires have been applied and the results have been modelled based on SWOT technique.

It should be noted that some authors only define the criteria in SWOT groups, while other authors additionally determine the weights of the criteria using multicriteria analysis methods.

The novel contribution of this paper is the elaboration of a methodology for assessing the effectiveness of the development of motorail service. The methodology consists of two steps. In the first step, the criteria in each SWOT group have been defined. In the second step, the weights of criteria have been assessed based on Best – Worst Method.

2. Methodology

This paper proposes a new integrated approach based on the combination of SWOT analysis and Best-Worst method for multicriteria analysis.

The methodology includes the following steps:

- Step 1: Defining the criteria for decision making. This step of methodology uses SWOT analysis as a strategic planning technique to identify strengths, weaknesses, opportunities, and threats related to the investigated system. This study proposes the following sub-criteria for each SWOT group:
    - Internal strengths (IS): IS1 - Opportunity to use a restaurant; IS2 -Availability of free Time; IS3-Ability

to use the Toilet; IS4 - Ability to use travel time for other activities; IS5 - Opportunity to sleep and rest; IS6 - Ability to move during the trip; IS7- Security and safety of travel; IS8-Eco-friendly transport.

- Internal weaknesses (IW): IW1- Availability of loading and unloading operations; IW2 - Option for theft; IW3 -Lack of specialized wagons; IW4 - Poor customer reputation; IW5 - Increase in total transport time due to additional handling operations; IW6 - Extra fees; IW7 - Low frequency of the trains; IW8 - Transportation only in certain months.
- External opportunities (EO): EO1- Priority development of rail transport in the European Union; EO2 - Make rail transport a national priority; EO3 - Increasing competitiveness of rail transport generated by the technological development of the sector; EO4 - Development of intercity train services; EO5 - Increasing the speed of trains after the reconstruction of the railway infrastructure; EO6- High toll road taxis.
- External threats (ET): ET1 - Increased motorway speed (shorter journey); ET2 - Improving the condition of the road infrastructure; ET3 - Increasing the share of bus and coach transport; ET4 -Permanent decline in fuel prices; ET5 - Poor condition of the railway infrastructure and delays in the implementation of infrastructure projects; ET6 - Existing rail infrastructure does not allow the development of speeds that make the service offered competitively; ET7 - High rental rates for specialized cars; ET8 – The reduced financial opportunity to purchase specialized wagons; ET9 - Insufficient interest in customer service.

- Step 2: Determination of the weights of criteria.

This study applied the BWM method to calculate the weights of criteria. This approach uses a pairwise comparison of the criteria. The decision maker identifies the most important criterion called best, and the criterion with the opposite role called worst. The method uses linear programming to define the criteria weights. The methodology of BWM consist of the following steps, [9, 10]:

- Determination of the best and worst criteria.
- Determination of the preference of the best criterion over all the other criteria.
- Determination of the preference of each of the other criteria over the worst criterion.
- Determination of the weights.

The experts give their preferences by using a linguistic scale for pairwise comparison for BWM. The scale includes numbers between 1 and 9. Score 1 shows that the compared criteria have the same importance. The value 9 presents extreme importance. Table 1 presents the linguistic scale.

Table 1

Linguistic scale for pairwise comparison for BWM

Scale	Score	Scale	Score
Equally important	1	Strongly more important	5
Equal to moderately more important	2	Strongly to very strongly important	6
Moderately more important	3	Very strongly more important	7
Moderately to strongly important	4	Very strongly to extremely more important	8
		Extremely more important	9

The results Best-to-Others vector is as follow:

$$A_B = (a_{B1}, a_{B2}, ..., a_{Bn}), \tag{1}$$

where a_{Bj} – preference of the best criterion B over criterion j. In this case, a_{BB}=1.

The results Others-to-Worst vector is as follow:

$$A_W = (a_{1W}, a_{2W}, ..., a_{nW})^T, \tag{2}$$

where a_{jW} – preference of the criterion j over the worst criterion W. In this case, a_{WW} =1.

The following minimax model is formulated to determine the weights of criteria:

$$min\max_j \left\{ \left| w_B - a_{Bj}.w_j \right|, \left| w_j - a_{jW}.w_W \right| \right\}; \tag{3}$$

$$\sum_{j=1}^{n} w_j = 1; \tag{4}$$

$$w_j \geq 0, \text{ for all } j = 1,..., n, \tag{5}$$

where w_j – weights of criteria, j = 1,...,n.

The model given by formulas (3) – (5) is solved by transferring to linear optimization model as follow:

$$\min \xi^L; \tag{6}$$

$$\left| w_B - a_{Bj}.w_j \right| \le \xi^L \text{, for all } j; \tag{7}$$

$$\left| w_j - a_{jW}.w_W \right| \le \xi^L \text{, for all } j; \tag{8}$$

$$\sum_{j=1}^{n} w_j = 1; \tag{9}$$

$$w_j \ge 0 \text{, for all } j = 1,\dots,n. \tag{10}$$

The model given by formulas (6) – (10) is linear and has a unique solution. The optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$ and optimal value ξ^* are obtained. The value ξ^* is defined as the consistency ratio of the system. A value closer to zero is desired for consistency.

3. Results and Discussion

The BWM method has been applied to determine the weights of SWOT criteria and sub-criteria. Six experts, two specialists from academia and four specialists from BDZ Passengers service LTD, have been made group assessment of criteria using scale 1-9, (Tab.1)

The assessment starts with the main SWOT criteria. The criterion Internal strengths (IS) have been selected by the experts as the best criterion. The criterion External opportunities (EO) has been determined as the worst criterion. Table 2 and Table 3 present the pairwise comparison for the best and the worst criterion.

Table 2

Pairwise comparison vector for the best criterion for main criteria

Best to Others	Internal strengths (IS)	Internal weaknesses (IW)	External opportunities (EO)	External threats (ET)
Internal strengths (IS)	1	2	3	3

Table 3

Pairwise comparison vector for the worst criterion for main criteria

Others to the Worst	External opportunities (EO)
Internal strengths (IS)	3
Internal weaknesses (IW)	2
External opportunities (EO)	1
External threats (ET)	2

For the main group Internal strengths (IS), the sub-criterion Security and safety of travel (IS7) has been determined as the best; the sub-criterion Opportunity to use a restaurant (IS1) has been determined as the worst. Table 4 and Table 5 presents the pairwise comparison.

Table 4

Pairwise comparison vector for the best criterion for Internal strengths (IS)

Criteria Best to Others	IS1	IS2	IS3	IS4	IS5	IS6	IS7	IS8
IS7-Security and safety of travel	3	3	4	2	2	2	1	2

Table 5

Pairwise comparison vector for the worst criterion for Internal strengths (IS)

Criteria Others to the Worst	IS1- Opportunity to use a restaurant
IS1- Opportunity to use a restaurant	1
IS2 - Availability of free Time	4
IS3 - Ability to use the Toilet	1
IS4 -Ability to use travel time for other activities	4
IS5 - Opportunity to sleep and rest	4
IS6 - Ability to move during the trip	3
IS7- Security and safety of travel	4
IS8 - Eco-friendly transport	3

For the main group Internal weaknesses (IW), the sub-criterion Lack of specialized wagons (IW3) has been determined as the best; the sub-criterion Extra fees (IW6) has been determined as the worst. Table 6 and Table 7

presents the pairwise comparison. For the main group External opportunities (EO), the sub-criterion Increasing the speed of trains after the reconstruction of the railway infrastructure (EO5) has been determined as the best; the sub-criterion High toll road taxis (EO6) has been determined as the worst. Table 8 and Table 9 presents the pairwise comparison. For the main group External threats (ET), the sub-criterion Increased motorway speed (ET1) has been determined as the best; the sub-criterion Increasing the share of bus and coach transport (ET3) has been determined as the worst. Table 10 and Table 11 presents the pairwise comparison.

Table 6

Pairwise comparison vector for the best criterion for Internal weaknesses (IW)

Criteria Best to Others	IW1	IW2	IW3	IW4	IW5	IW6	IW7	IW8
IW3 - Lack of specialized wagons	3	4	1	3	3	3	2	2

Table 7

Pairwise comparison vector for the worst criterion for Internal weaknesses (IW)

Criteria: Others to the Worst	IW6 - Extra fees
IW1- Availability of loading and unloading operations	1
IW2 - Option for Theft	1
IW3 - Lack of specialized wagons	3
IW4 - Poor customer reputation	2
IW5 - Increase in total transport time due to additional handling operations	3
IW6 - Extra fees	1
IW7 - Low frequency of the trains	4
IW8 - Transportation only in certain months	2

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Table 8

Pairwise comparison vector for the best criterion for External opportunities (EO)

Criteria Best to Others	EO1	EO2	EO3	EO4	EO5	EO6
EO5 - Increasing the speed of trains after the reconstruction of the railway infrastructure	1	1	3	1	1	3

Table 9

Pairwise comparison vector for the best criterion for External opportunities (EO)

Criteria Others to the Worst	EO6 - High toll road taxis
EO1 - Priority development of rail transport in the European Union	3
EO2 - Make rail transport a national priority	3
EO3 - Increasing competitiveness of rail transport generated by technological development of the sector	2
EO4 - Development of intercity train services	3
EO5 - Increasing the speed of trains after the reconstruction of the railway infrastructure	4
EO6 - High toll road taxis	1

Table 10

Pairwise comparison vector for the best criterion for External threats (ET)

Criteria Best to Others	ET1	ET2	ET3	ET4	ET5	ET6	ET7	ET8	ET9
ET1 - Increased motorway speed (shorter journey)	1	1	2	3	2	2	3	3	3

Table 11

Pairwise comparison vector for the best criterion for External threats (ET)

Others to the Worst	ET3 - Increasing the share of bus and coach transport
ET1 - Increased motorway speed (shorter journey)	3
ET2 - Improving the condition of the road infrastructure	3
ET3 - Increasing the share of bus and coach transport	4
ET4 - Permanent decline in fuel prices	1
ET5 - Poor condition of the railway infrastructure and delays in the implementation of infrastructure projects	4
ET6 - Existing rail infrastructure does not allow the development of speeds that make the service offered competitive	4
ET7 - High rental rates for specialized cars	3
ET8 - Reduced financial opportunity to purchase specialized wagons	3
ET9 - Insufficient interest in customer service	3

The values of Consistency ξ^* for the main criteria and sub-criteria are shown in Table 12. It can be seen that these values are closer to zero, which shows a high degree of consistency.

Table 12

Values of Consistency for main criteria and sub-criteria

Table	Main criteria	IS	IW	EO	ET
ξ^*	0.07	0.08	0.07	0.03	0.05

The weights of the main criteria and sub-criteria are determined according to linear optimization model (formulas 1-10) by using Solver in Excel. Table 13 shows the weights of the main SWOT group criteria, local weights for each group and the global weights of sub-criteria. The global weights present the priority of all sub-criteria taking into account the weights of the main criteria.

Table 13

Local and global weights of main criteria and sub-criteria

Main criteria	Weight	Sub-criteria	Local weight	Global weight	Main criteria	Weight	Sub-criteria	Local weight	Global weight
Internal strengths (IS)	0.444	IS1	0.044	0.019	External opportunities (EO)	0.123	EO1	0.207	0.026
		IS2	0.096	0.043			EO2	0.207	0.026
		IS3	0.072	0.032			EO3	0.080	0.010
		IS4	0.144	0.064			EO4	0.207	0.026
		IS5	0.144	0.064			EO5	0.241	0.030
		IS6	0.144	0.064			EO6	0.057	0.007
		IS7	0.210	0.093			-	-	-
		IS8	0.144	0.064			-	-	-
Internal weaknesses (IW)	0.259	IW1	0.057	0.015	External threats (ET)	0.173	ET1	0.183	0.032
		IW2	0.078	0.020			ET2	0.183	0.032
		IW3	0.241	0.063			ET3	0.118	0.020
		IW4	0.104	0.027			ET4	0.043	0.007
		IW5	0.104	0.027			ET5	0.118	0.020
		IW6	0.104	0.027			ET6	0.118	0.020
		IW7	0.156	0.040			ET7	0.079	0.014
		IW8	0.156	0.040			ET8	0.079	0.014
		-	-	-			ET9	0.079	0.014

Fig. 1 illustrates the weights of the main SWOT group criteria. It can be seen that the main importance of SWOT group has IS - Internal strengths, (0.444).

Fig. 2 presents the global weights of all sub-criteria. It can be seen that the main importance have the criteria: IS7 - Security and safety of travel (0.093), IW3 - Lack of specialized wagons (0.063); IS4 - Ability to use travel time for other activities (0.064), IS5 - Opportunity to sleep and rest (0.064); IS6 - Ability to move during the trip (0.064); IS8 - Eco-friendly transport (0.064).

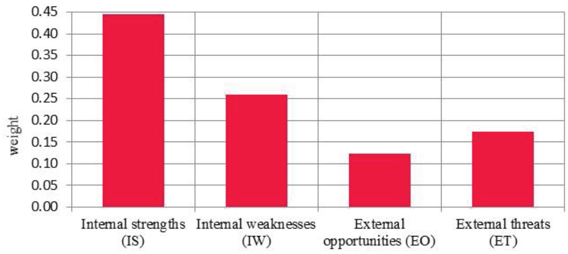

Fig. 1 Weights of main SWOT criteria

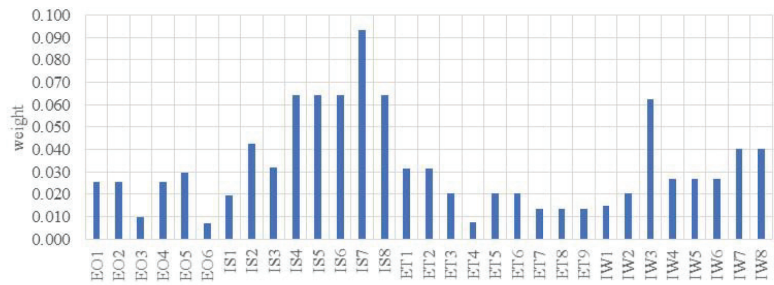

Fig. 2 Weights of the sub-criteria

3. Conclusions

In this research has been developed a methodology for evaluating the development of intermodal services of the type “car on the train” by applying SWOT analysis and Best-Worst method. The sub-criteria related to the strengths, weaknesses, opportunities and threats have been defined. Thirty-one sub-criteria have been defined in SWOT groups. It was found that the main importance of SWOT group has the IS - Internal strengths, (0.444). The main importance has the sub-criteria: IS7- Security and safety of travel (0.093), IW3 - Lack of specialized wagons (0.063); IS4 - Ability to use travel time for other activities (0.064), IS5 - Opportunity to sleep and rest (0.064); IS6 - Ability to move during the trip (0.064); IS8 - Eco-friendly transport (0.064). The received results for the weights of criteria could be used to rank the alternatives of transportation by motorail trains. In this case, an application of other multi-criteria methods is needed.

Acknowledgments

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Modeling and Simulation in the Research of Automatic Wagon Shunting Control Systems

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Abstract

In the gravity shunting process, many factors influence the moving wagons. They change the rolling speed. External influences come from the environment. Internal ones depend on the construction of single wagons, the structure of the groups of wagons and also the sort of transported cargo. These influences are variable as a function of distance and time.

Automatic shunting control systems should provide the fast, accurate and safe wagons movement to the appropriate directional tracks. The basic tasks of these systems include the automatic operation of switches and automatic speed control. There is required an ability to forecast changes in the movement of groups of wagons and appropriate impact in individual areas of marshalling yard.

The cost of testing new automated control systems is high. During the tests there is a danger for the safety of people, rolling stock and station infrastructure elements. Therefore, an important role in the research process plays the models of the gravity shunting process and the ability to simulate the movement of wagons.

The article discusses the use of a simulator of the wagon shunting process during research carried out by the author.

KEY WORDS: *marshalling yards, wagon shunting control systems, railway transport safety*

1. Introduction

Sorting of trains at automated marshalling yards should ensure the safe movement of individual wagons to the appropriate marshalling tracks. At stations equipped with a hump, wagons move as a result of the conversion of potential energy into kinetic energy. The basic element of the shunting process is acceleration and retardation of the wagons. Accelerated from the hump wagons are moving independently [1]. Therefore, it is necessary to use braking devices (rail brakes) that reduce their kinetic energy and allow speed regulation.

The initial kinetic energy of the shunting wagons (exceeding the top of the hump) is proportional to the speed that the locomotive pushes the train. During the movement of the wagons from the top of the hump to the destination point in the marshalling track, the potential energy gradually decreases due to the track inclination.

During rolling down, the kinetic energy of the wagons is being gradually reduced due to various factors. External - coming from the environment and internal - depending on the technical parameters of the wagons. Among others, these includes: resistance (depending on the structure of the wagons, their technical condition, weight, weather conditions), aerodynamic resistance (depending on the shape and size of the front and side surfaces of the wagons, wind strength and direction), the technical condition of the tracks, type of load transported, interactions (collisions) between the set of shunting wagons.

The wagon shunting process should enable the displacement of each set of wagons to the correct marshalling track, reach the appropriate place in the track (target point), and arrive at standing wagons with safe speed.

If several sets of wagons are moving on the selected marshalling track at the same time, the location of the target point changes dynamically. The speed control system must enable forecasting the location of the target point, e.g. by estimating the results of measuring the movement parameters an individual set of wagons.

2. Automatic Speed Regulation in Marshalling Control Systems

In Poland, two braking positions are used at automated marshalling yards. On the way of rolling down wagons, there are built: brakes of 1st position (in the track lead of the station) and brakes of 2nd position (in marshalling tracks). These are electrohydraulically controlled clasp brakes (Fig. 1).

On the way of rolling down the wagons, there are various restrictions on the speed limit. These limitations are a result of the variable geometry of individual tracks, their technical condition, as well as the technical parameters of built-in infrastructure elements.

Restrictions concerns:

- speed of pushing the train on the marshalling hump;
- speed of wagons entry onto brakes of 1st and 2nd position;
- traffic speed at switches;
- speed of traffic on track curves;
- speed of the reach to the point of destination (wagons standing on marshalling tracks).

Fig. 1 Clasp brake type ETH on 1st braking position

The time-limited restrictions are also introduced by the current traffic situation in the rolling area of the wagons. For safety reasons and to enable operation of switches, it is necessary to maintain the required speed differences between a successive set of wagons in the track lead of the station, as well as in marshalling tracks. It is also important to maintain appropriate spacing between successive wagons in the track brake zone.

One of the tasks of the automatic control system is to assess the traffic situation at the marshalling yard (including control of the switches and marshalling tracks occupation, shunting speed monitoring), forecasting the displacement of wagons in zones Sp1 and Sp2 (Fig. 2) and appropriate adjustment of their speed according to the needs and restrictions.

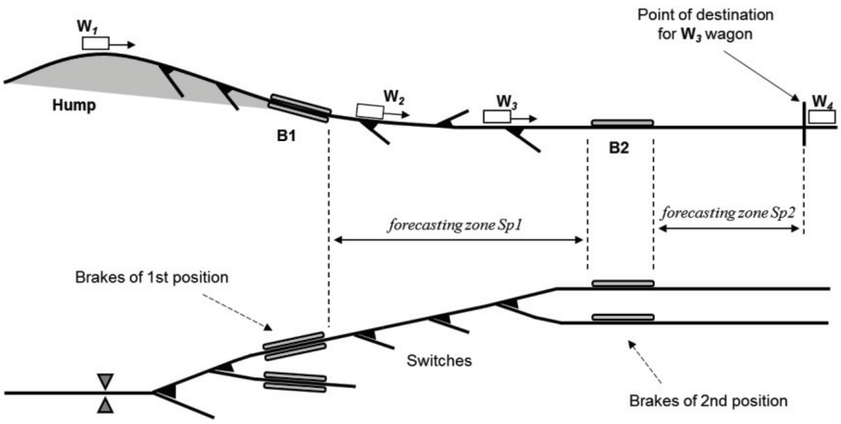

Fig. 2 Arrangement of brakes (B) and switches on the way of rolling down the set of wagons (W) and the zones of forecasting the movement of the Sp1 and Sp2

The intensity of external and internal interactions that cause the reducement of the kinetic energy of the wagons is changing dynamically, also as a function of time and also as a distance. Therefore, forecasting the value of the movement parameters of the wagons at individual points of the way is usually wrong [2]. Safe achievement of the target point requires monitoring the position of individual wagons and their speed changes. Also important is the ability of effective counteraction of the effects of existing impacts.

3. Simulation in the Research of Automatic Shunting Control Systems

The correct functioning of the automatic shunting control system (ASC) affects not only the efficiency of the marshalling, but also the safety of this process. Errors in the functioning of the automatic control system can lead to the occurrence of dangerous events. Cause a threat to the health or life of employees, damage to of rolling stock or cargo as well as infrastructure elements of the marshalling yard.

Therefore, before the start of the functional tests of the ASC system at a real marshalling yard, laboratory experiments are carried out using simulators. Their goal is to assess the correct functioning of the ASC system in various, often atypical, conditions of wagons movement. In particular, the simulator allows you to evaluate and optimize the rail brake control algorithm in the wagons speed control process.

The algorithm of controlling the system's executive elements must be adapted to the topology of the marshalling

yard for which the ASC system is intended. Therefore, the simulator maps the station's track system (Fig. 3), the location of switches and the arrangement of individual system components (rail brakes, speed meters, track sensors, etc.).

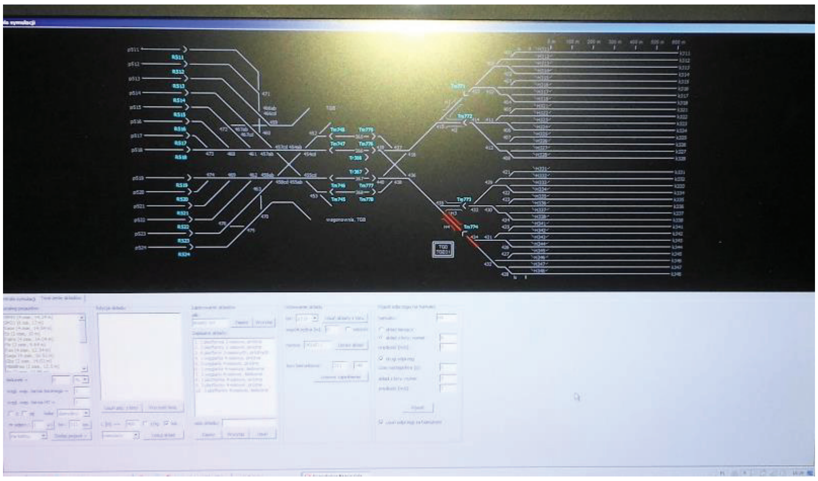

Fig. 3 Diagram of the station track system on the screen of the shunting process simulator

The built mathematical model enables prediction of changes in kinetic energy of the wagons during free rolling from the hump and changes in their speed under the influence of rail brakes.

In the used model, it is possible to define, inter alia, the number of wagons that are shunted, their mass, resistance to movement and the frequency of rolling down from the hump [4].

Visualization of the marshalling process, on the simulator screen (Fig. 4), allows you to observe the course of individual experiments and assess the correctness of the control algorithm.

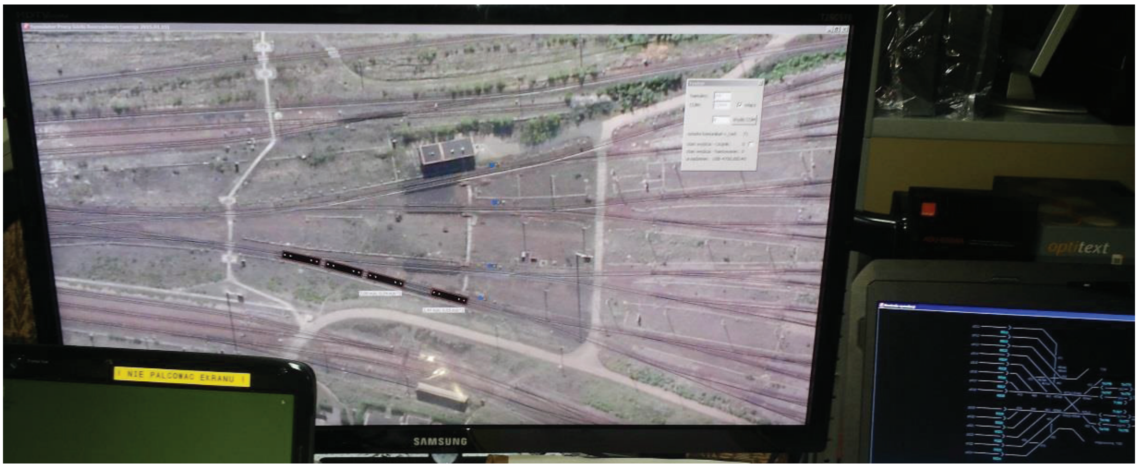

Fig. 4 Visualization of the marshalling process on the simulator screen

Tests performed using the simulator allow you to check the functioning of the system:

– during the marshalling of wagons with different traffic parameters;
– at different speeds of run into the rail brakes;
– at different required exit speeds from the brake;
– for different time sequence of the wagons rolling down from the hump;
– for rolling stock diversified in terms of quantity and technical parameters (mass, length, running resistance, number of axles, etc.);
– in various, typical and rarely seen, as well as dangerous movement situations.

During the research on the new asc system, the simulator was mainly used to define the correctness of the rail braking algorithm. The experiments also allowed to evaluate the effectiveness of speed regulation in various movement situations. In particular, they allowed to check:

– correctness of the implementation of braking when the actual wagons speeds exceeded the set values;
– correctness of brake release when the real speed of the wagon reached a value close to the set speed;
– correct system response in the event of wagon acceleration in the braking zone (function of additional braking) and exceeding the required speed;
– correctness of the system response in the event that the system detects the entry of the next wagon into the braking zone during the stay in this zone of the previous wagon (overtaking function).

The use of a simulator make it possible to carry out a large number of experiments. Performing this number of tests in real conditions at the marshalling yard would be very expensive. Making them would require many months of work. Some experiments could lead to dangerous situations. It could be a threat to people, used rolling stock and the marshalling yard infrastructure.

Positive results of tests carried out with the use of a simulator allowed to start field tests of the ASC system installed at the marshalling yard.

4. Conclusions

Each of shunting wagons can be treated as an entity that exists from the moment of train decomposition when it is pushed on to the hump until a new train is created on the marshalling track.

The entity (wagon) can be described by a set of attributes (technical parameters) and a set of features of its dynamic state (speed and position of the way of rolling down) [3].

The control system of the wagon shunting process (and in particular the automatic speed control system) should be a follow-up system. Speed regulation should take into account the values of the attributes of individual wagons and changes in their dynamic state caused by external and internal factors.

Field tests of new automatic marshalling systems should be preceded by laboratory tests using mathematical modeling. Experiments made by using the simulator significantly speed up the research process and reduce its cost. They allow you to check the effectiveness of the system in various, often unusual or rare scenarios of the wagon shunting process. They also enable the analysis and assessment of the system operation and optimization of the control algorithm and its adaptation to the local parameters of the marshalling yard.

They allow you to eliminate unacceptable behavior of the control system, guaranteeing its safe operation in real field conditions.

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Modelling of Selected Logistic Process in Logistic Centre Using Dynamic Simulation

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Abstract

Today's turbulent and highly competitive market environment forces companies to continually improve and streamline their processes. One of the management and planning tools is modelling and dynamic simulation of business processes. It allows to model selected processes and simulate various proposed changes in processes in order to determine if these changes will improve the current situation. Logistic centres are one of the most important points of the logistic infrastructure, as they are usually supplied with different modes of transport. There are many logistic processes in logistic centres that need to be constantly monitored, analysed and improved. The logistic process of sorting consignments for further distribution is modelled and dynamically simulated using Witness Horizon Manufacturing Performance Edition software within this article. The aim of this paper is to improve the logistic process of consignments sorting using modelling and dynamic simulation.
KEY WORDS: *dynamic simulation, logistic process, consignment, logistic centre*

1. Introduction

In today's globalization, logistics has become one of the value added generators for the customers. Deconcentrating of demand and supply, increasing customer's demands lead to increased logistic costs. It leads to a decrease in the sales margin or an increase in prices. It is therefore necessary to improve logistic processes. Simulation is an effective tool for improving logistic processes [1]. The use of analytical techniques alone cannot completely analyse and optimize the logistic system. However, the simulation technique can show a specific state and identify the obstacle and idle source of the system, which provides a detailed description of the actual process information and production of the logistic system. Nowadays, simulation tools can replace experiments, design and improve systems, train and learn operators. All measures are designed to operate in an environmentally friendly and cost-effective way [2]. Simulation tools are becoming increasingly knowledge warehouses that flexibly and extensively guide the entire life cycle of a device from planning to dismantling. The isolated solution of partial tasks reaches its limits: complex manufacturing processes require a comprehensive view of the system and interdisciplinary work. This is especially true for process engineering (unit operations) and logistics (material and information flow). In addition, it is known that an economically successful process alone is not the sum of optimally functioning components. Understanding the interdependencies of all process subsystems enables trouble-free and convenient production. In this context, it is essential that holistic evaluation and improvement develop an integrative linkage of the corresponding simulation tools already used successfully in sub-disciplines. The assessment of overarching strategies and boundary conditions is another necessity.

With the rapid development of the economy, the development of logistic companies around the world is facing a major challenge, in particular, logistic companies generally lack basic competitiveness, efficient logistic processes and awareness of service innovation is not strong [3].

Logistic processes exist, directly or indirectly, in any business operation. More than ever, the complexity of logistic operations is increasing as they are influenced by changes in technology, business globalization, the nature of the workforce, and political and environmental factors. As these logistic processes become more complex, they are more difficult to analyse and modify to achieve optimal business logistic operations [4]. Today, many business-modelling tools are available to assist in analysing and identifying logistic processes. Although considerable progress has been made in supporting supply chain modelling and logistic network optimization, there is still a need for integrated modelling of logistic processes.

The aim of this paper is to improve the logistic process of consignments sorting using modelling and dynamic simulation using Witness Horizon Manufacturing Performance Edition software.

2. Theoretical Background

Process modelling plays an important role in any organization. One of the potential area of modelling is logistic

process. Understanding these processes and presenting them as models allows to identify possible problems and provide solutions. Modelling requires the acquisition of skills to describe the studied reality in a way that reflects its most important characteristics but is not very complex. Simulation offers many potential solutions and allows iteration of a previously developed model. This can help optimize all logistic processes [5]. Simulation models are important for the planning, implementation and operation of logistic systems because they can display their dynamic system behaviour [6]. Computer simulation is a well-accepted tool for modelling the behaviour of large or complex operational logistic systems [7]. Logistic systems and processes are exposed to a number of risks that may arise from various negative scenarios. A characteristic feature of these risks is that they often simultaneously have an impact on both goods and the environment. A key parameter in the reliability assessment is the selection of appropriate methods, techniques and models in relation to the specific characteristics and characteristics of the logistic system under consideration and the available information and resources. Risk modelling is a dynamic process that involves a wide range of activities and skills, including system or process analysis, development, testing, simulation and application of methods and models, and periodic enhancements and fixes. Logistic processes often have considerable uncertainty associated with their complexity, the reliability of available information on current risks, and the availability of various statistical parameters from the previous period [8]. Distribution logistics is the last link in online shopping, whose importance grows with increasing demand from the company. Whether the goods can be delivered to consumers on time affects consumer satisfaction with this purchase directly [9].

Simulation modelling techniques are one of the basic tools used to identify, analyse and optimize logistic processes and systems [10]. Many modern logistic process simulation tools use discrete event simulation. References to discrete event simulation applications in logistics can be found in [11-14]. This kind of simulation is very useful and often the only tool supporting analysis of complex logistic systems, including their dynamics.

The logistic industry has also transformed itself into a rapid development phase. Distribution costs are estimated to account for more than 50% of total operating costs. This problem needs to be urgently addressed. In addition, distribution logistics as one of the three main logistic content (distribution, warehousing and management) includes planning management, distribution tools, distribution routes, delivery time, natural environment, human resources, etc. More important is the distribution logistics. Therefore, today it pays great attention to optimizing and analysing distribution logistics, shortening delivery times, improving distribution efficiency and reducing distribution costs [15]. Distribution tools are essential throughout the process, which takes up considerable resources under uncertainty of requirements. To dramatically reduce logistic costs, this reduction is significant through optimization [9, 15].

Foreign scientists have often discussed and studied factors affecting the core competencies of logistic companies from different angles and methods for improving the core competencies of logistic companies in the field of logistic processes [16-19]. Distribution logistics costs represent the highest proportion of total logistic costs and its rationalization can bring great business and competitive advantages [20]. Resource planning as well as proper distribution logistics are critical steps in managing complex logistic networks [21].

3. Methods

Authors used method of dynamic simulation using simulation software which is called Witness Horizon Manufacturing Performance Edition software (hereinafter referred to as Witness Horizon). Dynamic simulation enables to virtually streamline processes before their implementation. It is important that processes can be simulate without unnecessary risks and needless waste of money.

Authors created layout of logistic centre which is focused on the logistic process of sorting consignments. Figure 1 shows layout of the logistic process of sorting consignments. The aim of this paper is to improve the logistic process of consignments sorting using modelling and dynamic simulation. Logistic centre uses a high level of automation (primarily automatic identification technology – bar codes and QR codes and system of belt conveyors).

The simulation model consists of following basic elements:

- consignments;
- input gates;
- system of belt conveyors;
- machines (bar code scanners);
- output gates.

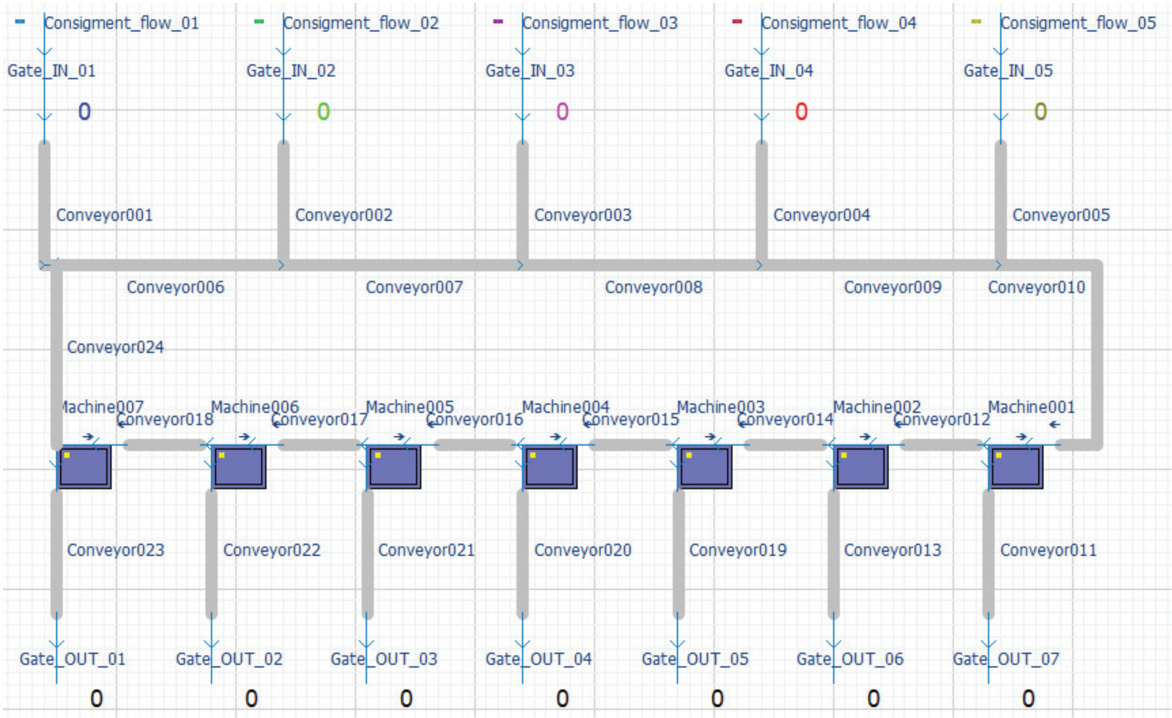

Fig. 1 Layout of logistic centre (simulation model) with Witness Horizon software

The second [s] is the base time unit of the model and the conveyor speed [m/s] is the basic variable parameter of the model. There are listed parameters of the simulation model in Table 1.

Table 1

Parameters of the simulation model

Simulation parameters	
number of input gates	5
number of consignments per gate	5 000
number of output gates	7
time of picking one consignment at the input gates [s]	Triangle distribution (8, 12, 17)
number of consignments picked at one time per gate	1
the first consignment picked up in time [s]	0
001 – 005 conveyor speed [m/s]	s_1
006 – 009 conveyor speed [m/s]	s_2
010 conveyor speed [m/s]	s_3
012; 014; 015; 016; 017; 018 conveyor speed [m/s]	s_4
011; 013; 019; 020; 021; 022; 023 conveyor speed [m/s]	s_5
024 conveyor speed	s_6
scan speed of 1 consignment by reader (machine) [s]	2
reader failure rate (frequency)	Uniform distribution (175, 360)
fault repair time of reader (machine) [s]	10
total simulation time [s]	28 800

The total simulation time was 28 800 s which is 8 hours (one shift). The aim of the dynamic simulation was to find the optimal speed of the conveyors in the individual groups (variable $s_1 - s_6$) in order to sort the maximum number of consignments during the total simulation time. The authors performed several simulations and based on the evaluation of statistics of individual elements of the model, the variables $s_1 - s_6$ were adjusted.

There are listed parameters of individual simulations in Table 2.

Table 2

Parameters of individual simulations

Simulation parameters	**Simulation 1**	**Simulation 2**	**Simulation 3**
number of input gates		5	
number of consignments per gate		5 000	
number of output gates		7	
time of picking one consignment at the input gates [s]		Triangle distribution (8, 12, 17)	
number of consignments picked at one time per gate		1	
the first consignment picked up in time		0	
001 – 005 conveyor speed [m/s]…….. s_1	5.6	4.7	2.8
006 – 009 conveyor speed [m/s]…….. s_2	2.8	2.8	3.0
010 conveyor speed [m/s]…………… s_3	2.2	2.8	2.1
012; 014; 015; 016; 017; 018 conveyor speed [m/s]…… s_4	3.0	2.6	2.8
011; 013; 019; 020; 021; 022; 023 conveyor speed [m/s]…. s_5	6.9	4.2	3.0
024 conveyor speed …………….. s_6	3.0	2.8	2.8
scan speed of 1 consignment by reader (machine) [s]		2	
reader failure rate (frequency)		Uniform distribution (175, 360)	
fault repair time of reader (machine) [s]		10	
total simulation time [s]		28 800	
sorted consignments in total [pieces]	10 859	**11 660**	9 432

Witness Horizon enables 2D visualization of the dynamic simulation of the model (see Fig. 2) and thus it is possible to identify bottlenecks and subsequently to improve the logistic process of sorting consignments.

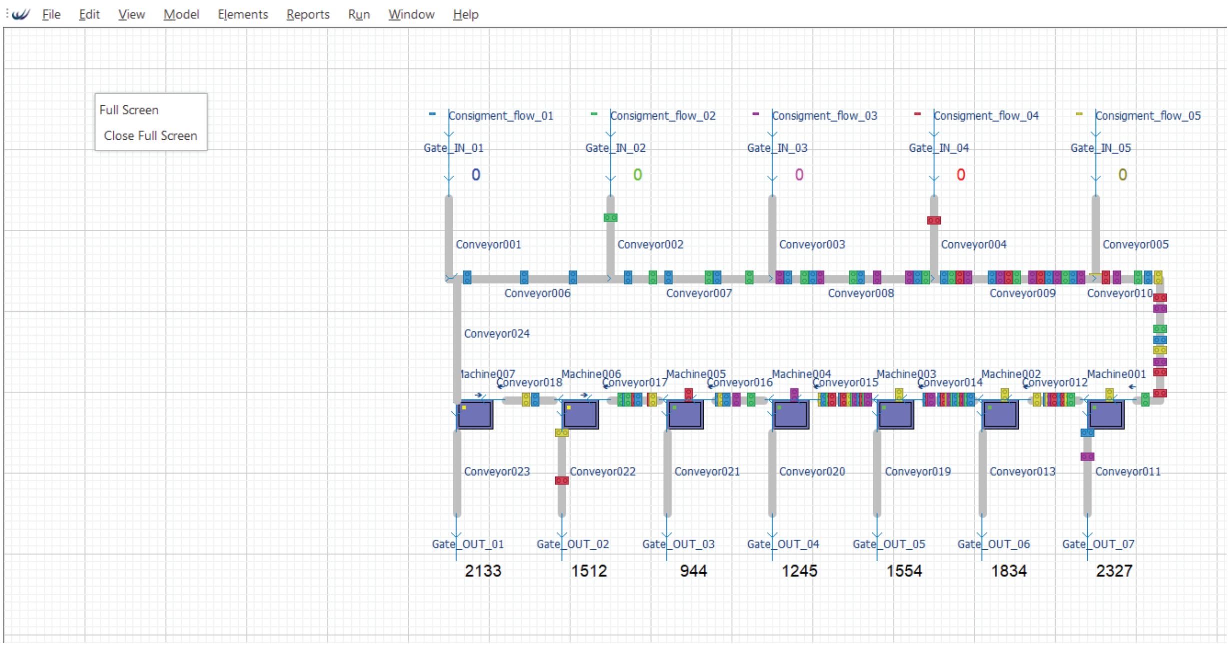

Fig. 2 Demonstration of simulation in software interface of Witness Horizon

4. Results and Discussion

Individual simulations were evaluated according to conveyor´s statistics (see Figure 3). The activity of conveyors during the total simulation time can be divided into three parts:

- % Empty – the conveyor moves without consignments;
- % Move – the conveyor moves with consignments;
- % Blocked – the conveyor is temporarily blocked.

Furthermore, authors evaluated according to the maximum number of sorted consignments during the total simulation time.

Witness

Conveyor Statistics Report by On Shift Time

Name	% Empty	% Move	% Blocked
Conveyor024	85.58	13.99	0.43
Conveyor001	54.34	38.85	6.81
Conveyor002	52.07	38.94	8.99
Conveyor003	48.18	38.89	12.92
Conveyor004	43.03	38.65	18.32
Conveyor005	45.34	38.59	16.07
Conveyor006	0.02	93.01	6.97
Conveyor007	0.02	87.42	12.57
Conveyor008	0.02	81.13	18.85
Conveyor009	0.02	76.64	23.34
Conveyor010	0.02	79.58	20.40
Conveyor011	42.01	57.99	0.00
Conveyor012	0.13	96.67	3.19
Conveyor013	50.90	49.10	0.00
Conveyor014	0.28	97.70	2.02
Conveyor015	0.42	98.20	1.38
Conveyor016	0.63	98.60	0.76
Conveyor017	1.26	98.15	0.59
Conveyor018	5.08	94.68	0.24
Conveyor019	56.73	43.27	0.00
Conveyor020	63.82	36.18	0.00
Conveyor021	71.26	28.74	0.00
Conveyor022	58.02	41.98	0.00
Conveyor023	46.12	53.88	0.00

Fig. 3 Conveyor´s statistics - simulation 2

The best results were obtained in simulation 2 (see Table 2). 11 660 consignments were sorted for the total simulation time (8 hours). This simulation also showed the best results in terms of conveyor´s statistics (no value % Blocked was extremely high).

5. Conclusion

The simulation of the production process is an excellent tool for the data analysis, which takes place in almost every production company. It is possible to monitor all areas in the company that produces any product through the dynamic simulation. The aim of this article was to improve the logistic process of consignments sorting using modelling and dynamic simulation. Authors performed several simulations which were evaluated and compared with each other. Using modelling and dynamic simulation were found the optimal speed of the conveyors in the individual groups (variable $s_1 - s_6$) as shown in Table 2.

Witness Horizon software is an important tool to support logistic planning and optimization of logistic processes because dynamic simulation enables to virtually streamline processes before their implementation in practice.

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Possibilities of Reduction Theft of Motor Vehicles in the Selected Region

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Abstract

One of the aspects that negatively affects the quality of peoples' life is a crime and other anti-social activities. The offenders of such activity use a variety of forms that are specific and in many cases sophisticated. Unlike other anti-social activities, crime has a criminal character. In most cases, the economic but also social consequences of crime are much greater than those of other anti-social activities. However, the negative impact on the quality of life is primarily caused by crime, of which people have the knowledge and feels himself. Subjective feeling often does not correspond to the real state, which can be expressed based on objective crime statistics. The most common type of crime that occurs in society is property crime. This type of crime may include crimes related mainly to theft. A typical feature of theft is the appropriation of unauthorized property benefits without the use of violence. The offender's subject of interest may be varied. Where the finances themselves are not of the offender's interest, the offender is mostly interested in the theft of valuable and easily monetizable articles. Such articles include motor vehicles. Theft of motor vehicles is one of the most common forms of theft. The paper focuses on the investigation of the theft of motor vehicles and articles them from the objective and subjective side in the selected region. The aim of the paper is to confront objective statistical data on the theft of motor vehicles with the subjective perception of such thefts by citizens in the selected region
KEY WORDS: *motor vehicle, theft, region, crime prevention*

1. Introduction

Crime and other anti-social activities belong among the phenomena that significantly negatively affect the quality of life of each individual. This negative phenomenon is influenced by many aspects, which can be sociological, psychological, but also economic. The process of globalization, coupled with technological progress, has caused offenders of crime and other anti-social activities to use new, more sophisticated methods, which is also linked to the emergence of new forms of crime. Despite the emergence of new forms of crime, there is still a crime in society, which can be considered traditional.

The most widespread type of crime in Slovakia is property crime. Despite its annual decline, property-related crimes belong among the most numerous types of crime. Property crimes can also include theft of motor vehicles, their parts or things from these vehicles. An objective view of the mentioned thefts is provided by crime statistics. However, in order to know the real situation, it is necessary to supplement this objective side of thefts with a subjective side. An objective view of the thefts of motor vehicles and things from them can be found on the basis of a survey. By finding out the real state of the issue, it is possible to propose new and effective forms of crime prevention, which could be implemented by state or private entities in practice.

2. Crime and Other Anti-Social Activity

Crime is a special phenomenon that disrupts the harmonious functioning of society and takes various forms. It negatively affects the life and health of the individual, population groups, but also the whole society and causes material, spiritual, mental, physical and other damage [1]. Criminal law can define crime as an illegal act, the features of which are listed in the Criminal Code [2, 3]. As other anti-social activity it is possible to consider the conduct that is an offense or other administrative offense, or conduct that is not an offense or other administrative offense, but has a negative effect on society [2]. Crime can, therefore, be considered more serious than other anti-social activities. The seriousness of this type of illegal act can be manifested not only in terms of damage to property, but especially in harm to the health or life of the victim.

Criminology is a specific scientific discipline that deals with a crime as a social phenomenon, the investigation of the causes and conditions of its origin, the issues of its prevention and the issues of the investigation of victims of crime. The study of criminological factors creates a precondition for criminological research, on the basis of which it is possible to propose effective and efficient measures for crime control [4]. Crime control (also called fight against crime) involves prevention and repression. Crime prevention (and other anti-social activities) means targeted, planned, coordinated and comprehensive action on the causes and conditions that cause or facilitate crime (and other anti-social activities), with a view to preventing and suppressing it [2]. Crime repression (and other anti-social activities) is the opposite concept to crime prevention (and other anti-social activities). Crime repression (and other anti-social activities)

means its suppression using violent but legal means.

In order to examine the regularities between crime and other social phenomena, it is necessary to observe and describe the crime. The first task of any sociological, and therefore also criminological, research is to describe crime through criminal statistics. In this context, it is necessary to distinguish the phenomenology of crime from the etiology of crime. The crime phenomenology deals with the study of both quantitative and qualitative variables of crime, which can be expressed exactly. The crime etiology deals with the study of the very causes and conditions of crime [5]. In the phenomenology of crime, it is necessary to examine 5 variables, which are shown in Fig. 1.

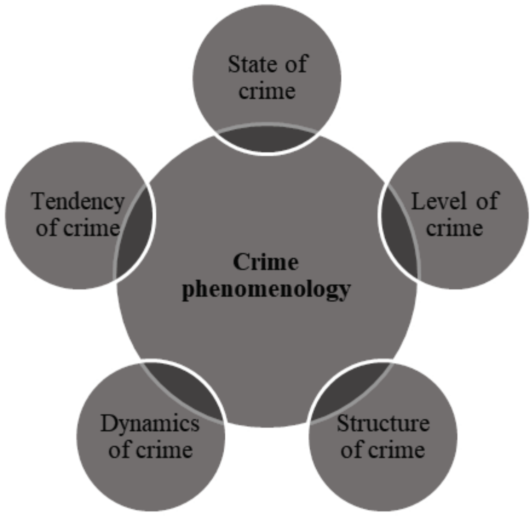

Fig. 1 Variables of crime phenomenology research [1]

The state of crime indicates the number of committed crimes or the number of persons who committed these crimes at a certain time in a certain place. The state of crime is given in absolute numbers. The level of crime is calculated from the number of crimes committed at a certain time in a certain place with respect to the population. The level of crime is usually expressed by a coefficient per 10,000 or 100,000 inhabitants, called the crime index. The dynamics of crime characterizes the development of crime within a certain period of time (e.g. 10 years). The tendency of crime expresses the future development of crime as well as the direction of its change (decreasing, stagnant, increasing). The structure of crime determines the share of individual types and groups of crimes in the total number of all crimes committed in a certain place during a certain period of time. It, therefore, expresses the qualitative aspect of the state of crime [1,4,7]. In the conditions of Slovakia, there are distinguish the following types of crime [5, 8, 9]:

- Violence crimes – Murder, robbery, organized crimes, extremism;
- Moral crimes – Rape, sexual abuse, human trafficking;
- Property crimes – Theft;
- Other crimes – Drug crimes, illicit armament, arson, rioting;
- Remaining crimes – Military crimes, crimes against the republic, traffic crimes;
- Economy crimes – Corruption, embezzlement, fraud, copyright infringement.

Among the mentioned types of crime, the most frequently occurring type of crime in Slovakia is property crime. Property crime occurs despite the enormous security of homes with mechanical barriers, cylindrical inserts, video surveillance systems or alarm systems [10, 11]. The motive for property crime is most often [1]:

- acquiring movable property for oneself or others;
- causing damage to foreign movable and immovable property;
- securing an above-standard way of life other than one's own abilities.

The goal of property crime is profit by obtaining cash, securities and lucrative tangible assets. Property offenders can be classified according to various aspects. One of the classifications is the division of offenders according to the subject of interest. The offenders are mostly interested in the theft of funds, jewelry, works of art, antiques, collections, electronics, luxury clothing, but also motor vehicles and their parts. According to the method of committing, it is possible to divide the offenders of property crimes into offenders who perform the crime in a professional way and offenders who used the current situation to commit the crime. A typical offender of property crime is a novice male offender, young under the age of 30 with basic education, unemployed, addicted to alcohol or drugs, extrovert (social, accessible, sensitive, carefree) with elements of choleric (lability, impulsivity, dissatisfaction, mood swings) [1, 12, 13]. Fig. 2 shows the share of property crime in total crime and the share of selected types of property crime (theft of motor vehicles, theft of things from them and theft of their parts) in total property crime in Slovakia.

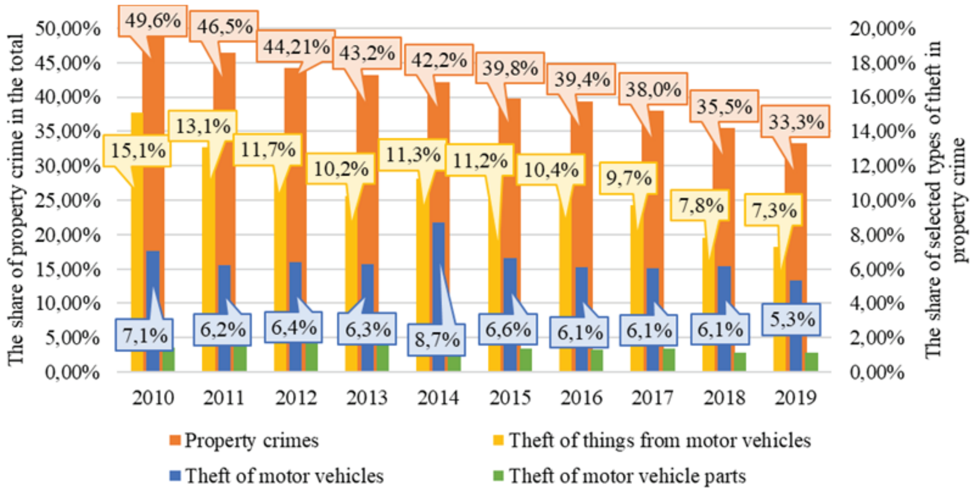

Fig. 2 The share of selected types of crimes in total and property crimes in Slovakia [14]

Almost half of all crimes recorded in Slovakia in 2010 were related to property crime. In the observed period, the share of property crime in total crime gradually decreased. In 2019, one third of all recorded crimes were property crimes. By analyzing property crime, it is possible to find out how many crimes were related to thefts related to motor vehicles. The most numerous group is represented by the theft of things from motor vehicles. In the monitored period, the share of thefts of items from motor vehicles related to property crime decreased by half. However, in absolute numbers, this type of theft decreased from 6,631 recorded crimes to 1,431. The share of thefts of motor vehicles related to the total number of property crimes is stable and does not change significantly in the observed period. The number of such thefts decreases in direct proportion to other property crimes. In the observed period, the number of these thefts decreased from 3,104 to 1,042. The smallest group of property crimes related to motor vehicles are thefts of their parts. The share of these crimes related to property crime is less than 2 percent and is slightly declining. In absolute numbers, it can be said that the number of recorded thefts of vehicle parts in the observed period decreased from 624 to 219. Fig. 3 shows the share of property crime in total crime and the share of selected types of property crime (theft of motor vehicles, theft of things from them and theft of their parts) on total property crime in the Žilina Region.

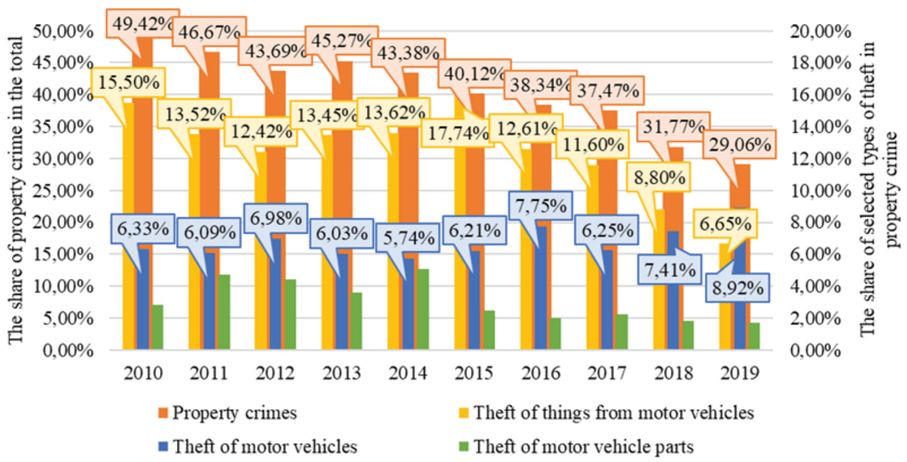

Fig. 3 The share of selected types of crimes in total and property crimes in Žilina Region [14]

Also in the Žilina Region, at the beginning of the observed period, the share of property crime in total crime was almost 50 percent. Every year (with the exception of 2013), this share of property crime in total crime decreased and in 2019 it fell below 30 percent. In absolute numbers, the number of recorded crimes decreased from 10,551 to 6,983 in the observed period, while property crime decreased from 5,214 property crimes to 2,029. However, the share of thefts from motor vehicles in relation to total property crimes was above national average. In 2015, this share reached a value of almost 18 percent. However, the share of the number of thefts of motor vehicles in relation to total property crime has recently started to increase. Although at the beginning of the observed period this share fluctuated between 6 and 7 percent, in 2016 this share exceeded 7.5 percent and in 2019 it climbed to almost 8 percent. However, in absolute numbers, there is a decrease in these crimes from 330 to 181. Thefts of vehicles parts in the Žilina region were above the national average at the beginning of the observed period. From 2010 to 2014, the share of thefts of vehicles parts in relation to total property crime was around 4 percent. From 2015 to 2019, this share fell to an average of less than 2 percent. In absolute numbers, almost 200 cases of these thefts were recorded per year in the first half of the observed period, while in the second half of the observed period they fell to around 60 cases per year.

3. Survey of the Perception of Motor Vehicle Theft

The subjective side of the perception of the state of crime can be found on the basis of a survey conducted among citizens. Based on the survey, it is also possible to detect a latent form of crime (crimes that citizens did not report). By combining the objective and subjective side, it is possible to create a realistic view of the issue [15]. To examine the subjective perception of theft of motor vehicles, a survey was conducted on a sample of 206 respondents living in the Žilina Region. Fig. 4 shows the type of crime that respondents consider to be the most serious.

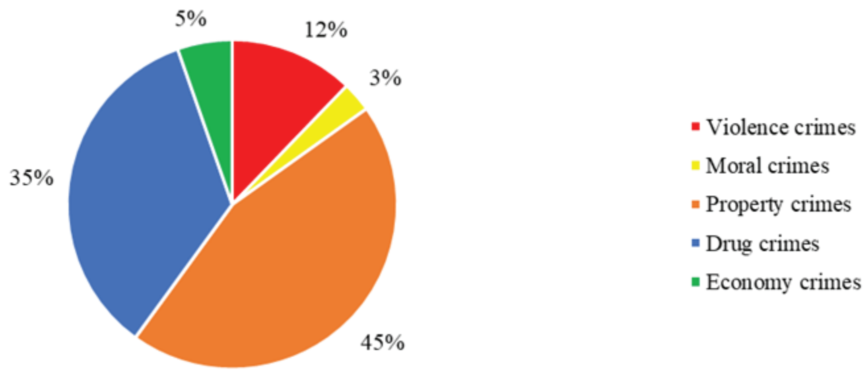

Fig. 4 Respondents' perception of the crime severity

Based on the results of the survey, it can be stated that citizens consider property crime to be the most serious type of crime that occurs in their surroundings. A major problem for respondents is also the occurrence of drug crime. Other part of the survey focused on property crime in terms of theft of motor vehicles. Fig. 5 shows the subjects of interest that were most frequently stolen from respondents.

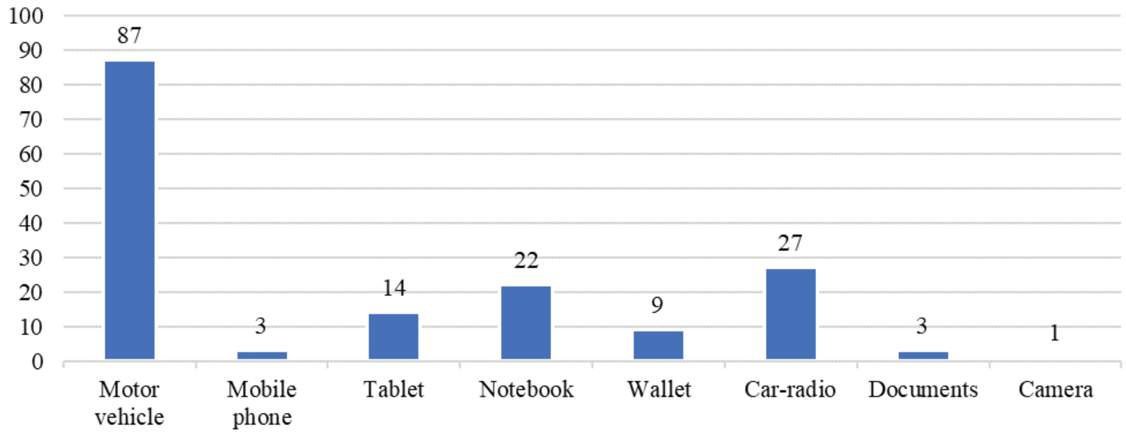

Fig. 5 Subject of interest of offenders of property crime

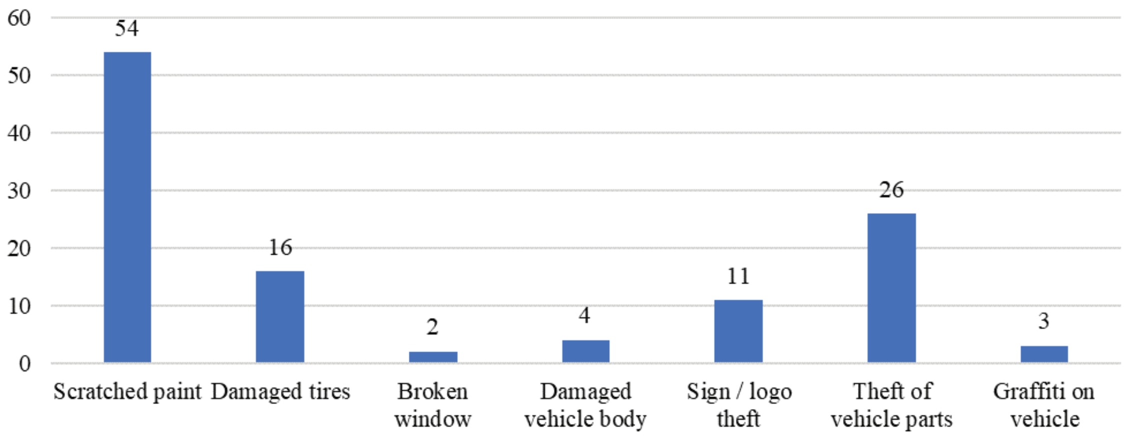

Fig. 6. Type of vandalism on a motor vehicle

According to the respondents, the most common subject of interest of offenders of property crime was a motor vehicle. The second most common answer - theft of car-radios, is very closely related to the theft of motor vehicles. A large number of property crime offenders also focus on the theft of electronics - notebooks, tablets, mobile phones etc. Fig. 6 shows the form of vandalism that respondents encountered in their motor vehicles.

Vandalism is a very common type of crime or other anti-social activity. The most common form of vandalism encountered by respondents is scratching the paint. Theft of vehicle parts is also a very common type of vandalism. Uncommon responses include tire damage (puncture or deflation) and theft of vehicle signs or logos. Rarely, respondents also encountered car body damage and broken windows. Fig. 7 shows the amount of financial damage caused to the respondents by the damage of the vehicle.

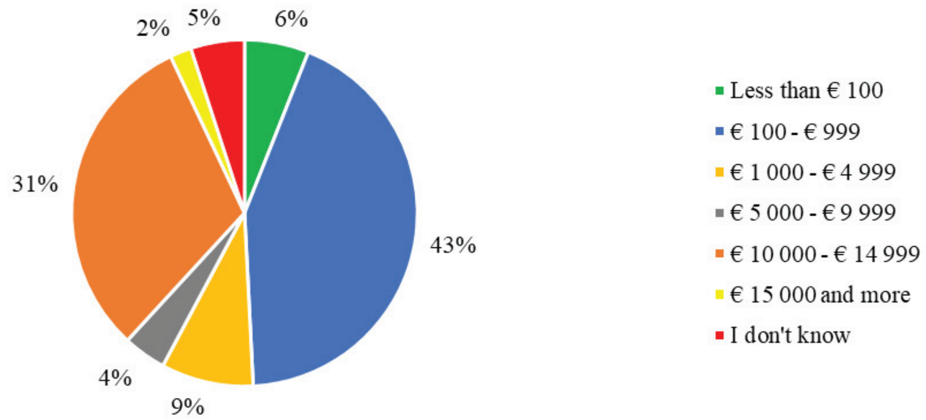

Fig. 7. The amount of damage caused to the vehicle

The offenders of property crime, by their activities, in most cases caused only small-scale damage in the amount of € 100 to € 999. Damage in the amount of € 10,000 to € 14,999, which was identified by almost a third of respondents, is also highly represented. Public car parks are among the places where car thefts are most common. There is also a small representation of parking lots of companies, garages, hotel parking lots, or even parking lots at gas stations. Very striking information from the survey is that almost 60 percent of motor vehicle thefts occurred during the day. This fact confirms the unwritten rule that theft occurs mostly during the day, not at night. More than 90 percent of thefts of motor vehicles and their things from them were reported to the police. Nevertheless, it is necessary to encourage the reporting of all types of such thefts, as they may also be related to other property crimes.

4. Conclusions

Crime can be considered a phenomenon that negatively affects a person's quality of life [16, 17]. Crime occurs at a certain time and place. The role of the state security forces is to take measures to minimize this anti-social activity by effective measures. It is possible to propose and implement such measures only on the basis of knowledge of the regularities of committing this activity. Crime can be examined on the basis of objective indicators of crime - statistics. However, crime statistics can be greatly influenced by latency. In order to know the real state of crime, it is necessary to reveal the subjective perception of this phenomenon by citizens through a survey [18, 19].

One of the types of crime that negatively affects each individual is property crime. This fact is also confirmed by the realized survey. Based on official statistics, it is possible to confirm that thefts related to motor vehicles have a large share in the total property crime. Damage caused by crime related to the theft of motor vehicles, their parts or things from them in most cases ranges from € 100 to € 999. Vandalism also plays an important role in these types of crime, which most often manifests itself in the form of paint scratches, theft of vehicle parts, or tires damages. The conscientiousness of citizens in reporting this form of crime can be described as very positive. State security forces, as well as private entities, should develop measures to reduce this type of crime and raise citizens' awareness of how to effectively defend against this negative phenomenon. It is also necessary to continue national projects such as "Car is not a shop window", which warn citizens not to leave valuables in cars in visible places.

Acknowledgement

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Innovative Risks of Introducing Advanced Technical Solutions in Transport

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Abstract

This article contains the analysis of possible investment ways for the development of industrial technologies on the example of railway transport and the associated decision-making process. A risk assessment method was used in this study when introducing innovative technical solutions for improving friction interaction in a two-point «wheel-rail» contact, which is based on the Monte Carlo method. The result of simulation modeling is forecasting of the most and least risky technical solutions for introducing them in railway transport and reducing such risks.
KEY WORDS: *making decisions, risk, innovation activity, studies, risk management, introduction, railway transport*

1. Problem Statement

Aging of Ukrzaliznytsya, JSC fleet of trains, the technical condition of which does not meet modern requirements, the end of the normative life of most locomotives, freight, passenger cars and other rolling stock require the introduction of innovative technologies and technical solutions.

Investments are the main method of extended reproduction of capital stock. Innovative investment is one of the promising investment methods in the advanced countries of the world. A study of the state of innovation in the railway industry of Ukraine indicates that its level remains low. Namely, the share of enterprises that implemented innovations is about 11% - 12% [1, 2]. The main reason, which hinders innovation in industry was and remains the risk of introducing new technical solutions, according to the State Committee on Statistics of Ukraine [3].

Decision-making support suite of tools is essential for increasing the efficiency of decision-making on the implementation of innovative projects at a machine-building enterprise. It shall include an assessment of the level of risks and economic security, which shall be carried out using expert assessments and allows increasing the likelihood of making the right managerial decision.

2. Actual Scientific Researches and Issues Analysis

A study of foreign experience indicated that investments in innovative activities of enterprises are on average highly cost-effective, despite the significant risk of such investments and a long payback period. Moreover, investments in scientific developments bring effect not only to a single enterprise, which implements them, but also to society as a whole [4]. While assessing the efficiency of investments in the innovative activity of enterprises, there is a risk that when choosing individual innovations for such studies, it is necessary to consider those that provide a high return on investment.

Traffic safety during the transportation of freight and passenger trains is the main criterion for assessing the risk in railway transport. It is customary to characterize the level of safety with the probability of the implementation of certain dangers and threats, occurring phenomena and processes that are accompanied by the formation of factors that negatively affect the person and the environment. This is the mathematical expectation of the most important types of damage [5].

Possible scenarios for the implementation of innovative technical solutions can lead to significant material losses. This has led to the creation and practical application of system approaches, methods and tools for assessing the risk of their introduction.

The risk assessment process includes the following:

- description of the system, hazard identification and generation of possible scenarios of accidents and the consequences of certain events that are related to the transportation process;
- assessment of the impact or consequences of influence of such events on people, tangible assets and the environment;
- calculation of probability of such an adverse result in practice and its consequences, depending on various operational and organizational safety measures;
- quantitative description of risk levels beyond the boundaries of the object in terms of consequences and

probability;

- assessment of risk levels by the means of comparing them with certain quantitative criteria.

Monte Carlo method is one of the methods that allows quantifying the risks of implementation, namely, simulating random variables in order to calculate the characteristics of their distributions. Simulation according to Monte Carlo method allows building a mathematical model for a process with uncertain parameter values. And, while knowing the probability distributions of process parameters, as well as the relationship between parameter changes (correlation), get the distribution of project profitability.

3. Materials and Results of the Study

Different types of projects have different vulnerability to risks. It is revealed during simulation. Simulation modeling according to Monte Carlo method has several stages.

Creation of a forecast model is the first stage of the risk analysis process. Such a model determines the mathematical relationships between numerical variables that relate to the forecast of the selected financial indicator.

The source data of the current forecast of economic benefits and expenses shall be indicated in the tables below (Table 1). Their maximum and minimum values, in which each of the technical solutions that were suggested for implementation was investigated, shall be taken from literary sources [6-9].

The model for calculating the NPV indicator (net present value) is usually used as a basic model for the analysis of investment risk. The NPV of the project will be positive, and the project itself will be effective in case if the calculations indicate that the project covers its internal costs, and also brings capital owners an income not lower than they set.

Simulating of a forecast model is the second stage. A sufficiently large volume of random scenarios is generated. Each of these scenarios corresponds to certain values of cash flows. The generated scenarios shall be gathered together and processed statistically in order to determine the share of scenarios that correspond to a negative NPV value. The ratio of such scenarios to the total number of scenarios gives an assessment of the risk of investment.

Distributions of probabilities of variable models impose the possibility of choosing values from certain ranges. Distributions are mathematical tools that help weighting all the possible outcomes. This controls the random selection of values for each variable during the simulation. Information, which is contained in a probability distribution with multiple values, is used during risk analysis.

Table 1

Initial data for forecasting the resulting economic benefits and expenses while introducing innovative solutions

Economic effect factors			Cost factors during introduction		
Designation	Name	Meas. unit	Designation	Name	Meas. unit
ES	Energy saving	UAH	IC	Intellectual expenses	man/hour
RS	Resource saving	UAH	MC	Material expenses	UAH
LS	Labor saving	UAH	LC	Labor costs	man/hour
EC	Environmental saving	UAH	SC	Maintenance service	man/hour

During the simulation, the values of the variables shall be randomly selected within the boundaries of the given ranges, according to the distributions of probabilities and correlation conditions. The value of the project efficiency indicator shall be calculated for each set of such variables. An example of calculating project efficiency is shown in Fig. 1. All obtained values shall be stored for subsequent statistical processing.

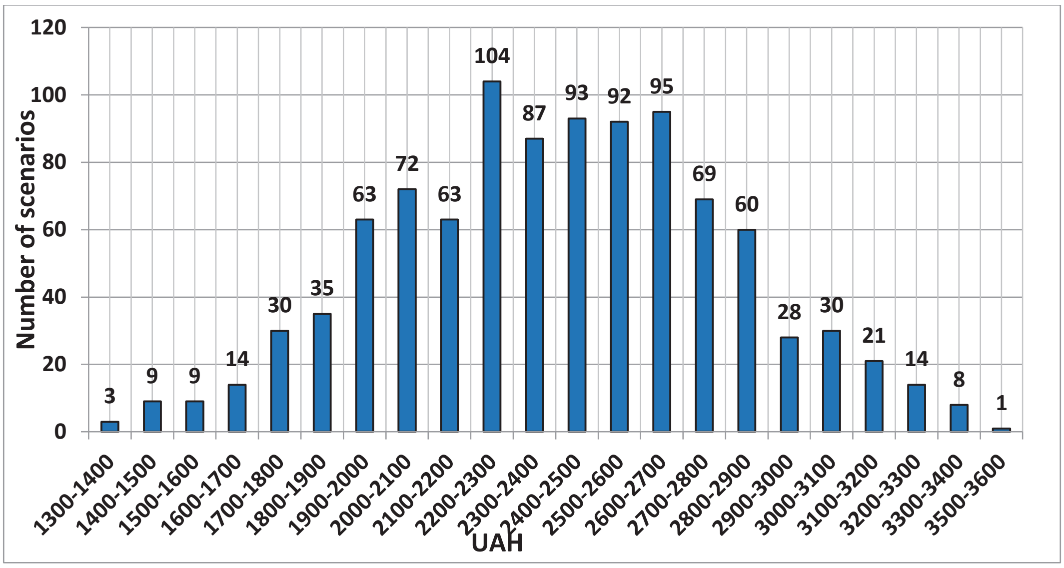

Fig. 1 Example of calculating project efficiency

For the practical implementation of the risk assessment of the introduction of new technical solutions in transport according to the Monte Carlo method, simulation shall be performed in the Microsoft Excel software package. This package generates random numbers that are calculated according to a specific algorithm based on the use of a pseudo-random number sensor. A feature of this package is the fact that it can generate correlated random numbers.

The processing and interpretation of the results obtained at the stage of model simulation is the final stage of risk analysis. Each simulation represents an event probability, which is equal to:

$$p = \frac{100}{n}, \tag{1}$$

where p – probability of a single prediction; %; n – sample size.

As a risk measure, it is advisable to use the security of the simulated project, which is expressed as a percentage, during investment designing (Fig. 2).

Fig. 2 An example of simulating the security of an investment project

For sake of graphic example, let's consider advanced technologies, namely, methods for optimizing the frictional interaction of a wheel with a rail, which is the basis for the safety of rolling stock. They are applicable in railway transport and theoretically are cost effective. However, in practice, the solution of these issues is associated with a certain degree of risk, which is currently difficult to predict and take into account. We will be based on methods for optimizing the frictional interaction of wheels with rails that are shown in Fig. 3 [9].

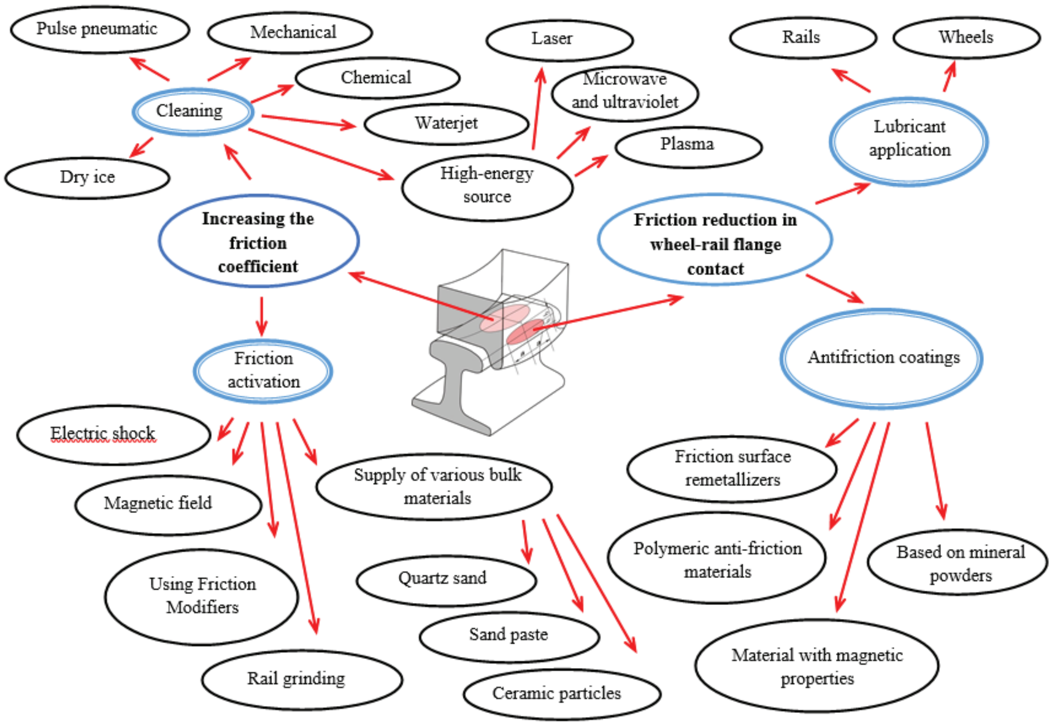

Fig. 3 Methods for optimizing the frictional interaction of wheels with rails

Risk assessment of the introduction of innovative technical solutions that are indicated above was carried out. The results of this are shown in Figs. 4 and 5.

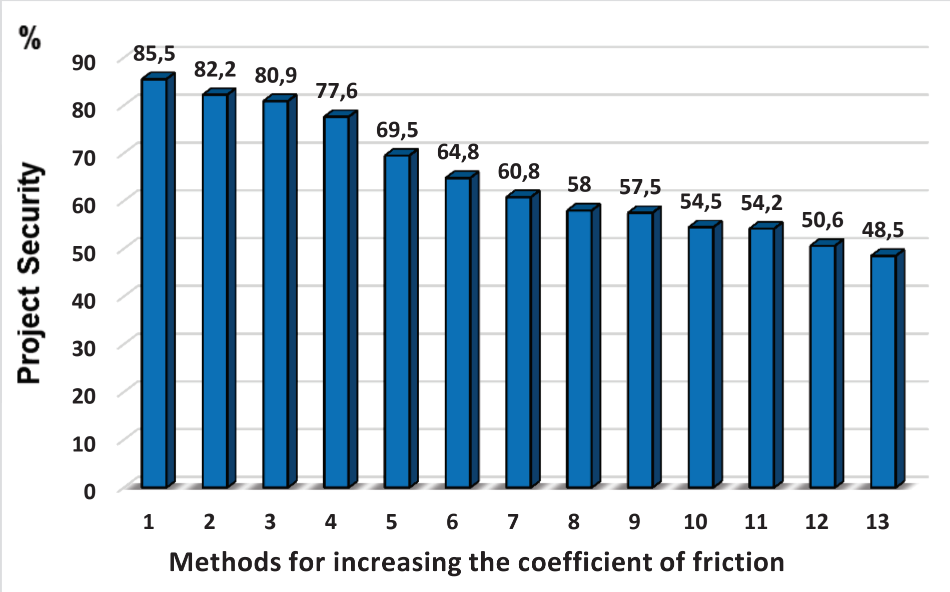

Fig. 4 Risk assessment of the introduction of innovative methods for increasing the coefficient of friction *1* – current electricity activation, *2* – pneumo-pulse cleaning, *3* – pneumo blasting, *4* – rail abrasion, *5* – dry-ice cleaning, *6* – laser cleaning, *7* – use of friction modifiers, *8* – plasma stripping, *9* – microwave and UV cleaning, *10* – supply of ceramic particles, *11* – chemical cleaning, *12* –cleaning using magnetic field, *13* – mechanical treatment

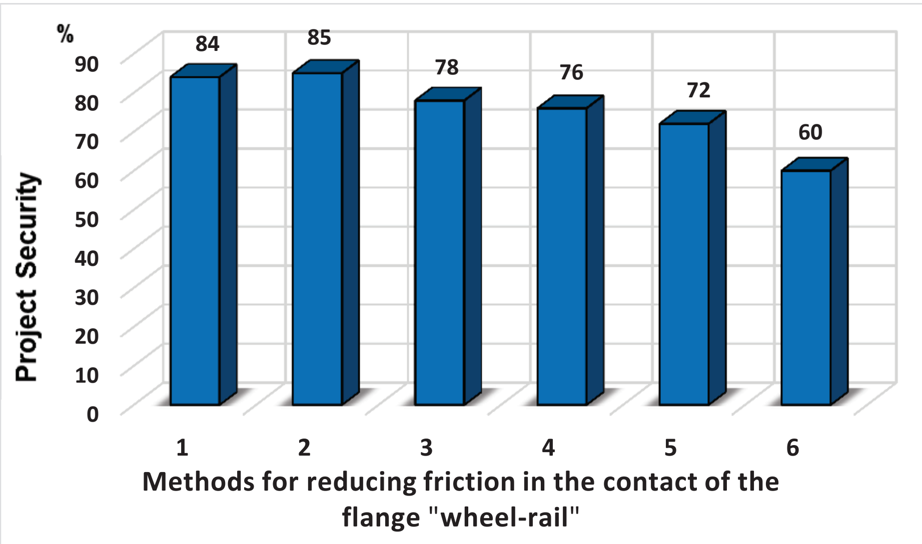

Fig. 5 Risk assessment of the introduction of innovative methods for reducing the friction in the «wheel flange – rail» contact: *1* – application of lubricants on flanges of set of wheels, *2* – application of lubricants on rails, *3* – application of lubricants that have magnetic properties, *4* – application of polymer antifriction materials, *5* – application of mineral-based powders, *6* – use of remetallizators on the friction surface

Use of the suggested decision-making procedure will increase the level of economic security during the introduction of innovative technical solutions in railway transport that are aimed at reducing real hazards and risks of economic security of the enterprise, the optimal distribution of resources for the innovative development of railway production.

A risk assessment method was used in this study when introducing innovative technical solutions for improving friction interaction in a two-point «wheel-rail» contact, which is based on the Monte Carlo method. In this case the results of the simulation coincide with the decision for choosing the most promising ways in order to improve the contact conditions in the «wheel-rail» tribocoupling using expert assessment [10, 11]. The least risky technical solutions for the introduction of railways that are aimed at reducing them were identified as a result of the simulation.

4. Conclusions

On the basis of the analysis of theoretical and experimental studies of friction contact, it can be stated that control of the mechanical component is not sufficient for achieving consistently high traction qualities of the rolling stock. Therefore, it is suggested to control the clutch of the tribological «wheel-rail» system by controlling and regulating the local-mechanical temperature component in the range from 250 to 450°C, depending on the frictional conditions of contact.

Based on the results obtained, an algorithm for controlling the thermomechanical loading of a local tribological contact was developed, consisting in cleaning and cooling the contacting surfaces with a two-phase flow of dry ice granules and forced cooling with compressed air using a Ranque-Hilsch tube in order to achieve a stable contact temperature.

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Comparison of the Degree of Flammability of Upholstery Selected Models of Cars

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Abstract

The scope of safety of vehicle use and its operation depends on both the design, efficiency of the steering and drive system, the tires used, but also on the interior finishing materials used. In addition to aesthetics, the materials used must be resistant to damage and have limited ability to sustain combustion in an emergency. Vehicle ignition is an extremely dangerous situation. The appearance of a flame is a threat to the driver and passengers and the environment due to the possibility of uncontrolled spread of fire, as well as the possibility of an explosion of fuel or operating fluids. The article presents the results of flammability tests, according to the requirements of PN-ISO 3795, of materials used inside vehicles from 15 different models of passenger cars randomly selected.
KEY WORDS: *flammability tests, material flammability, car upholstery, motor vehicles*

1. Introduction

Continuous automotive development and an increase in the number of vehicles on the road means a reduction in road capacity and a decrease in safety. Reducing the speed of travel is characterized by limiting the tragic effects of road incidents. However, it also causes drivers fatigue and frustration, which can translate into more accidents and collisions. Regardless of the type of traffic incident, one of the most dangerous is a vehicle fire. Car manufacturers already in the design of the interior of the driver's cabin have in mind the comprehensive safety assessment related to both the safety of users and rescuers. Rescuers' hazards include, for example: uncontrolled activation of an airbag, explosion of pyrotechnic loads tightening seat belts or electric shock [1]. The appearance of fire additionally causes the possibility of initiating an explosion of fuel and operating fluids and the formation of dangerous chemical compounds, e.g. during the burning of plastic parts [2-5] or the operating factor used in air conditioning in fire conditions can be broken down into toxic hydrogen fluoride [6] and in contact with water may form hydrofluoric acid. Vehicles with LPG or CNG installations are characterized by valves that release gas accumulated in the tank to prevent explosion [7, 8]. Released gas in such a situation is an additional source of danger.

A burning vehicle poses a great threat to users, surroundings and other vehicles [9, 10]. In Poland, an increase in road transport fires is noted and more than 8,000 are recorded annually (Figs. 1 and 2). It is estimated that the content of plastics in a passenger car is about 160 kg [11]. These items of equipment include, for example, plastic covers, gear belts made of plastic composites [12-14], rubber seals, tires [15-17], rugs and seat liners. They constitute a significant amount of potentially flammable material accumulated on a small area. The extent of safety depends significantly on the quality of the materials used in the vehicle. Bearing in mind, among other things, the flammability of materials, they must balance comfort of use, aesthetics, weight, safety and price, which is often the basic criterion for choosing a given material. However, it should be remembered that the use of materials with reduced flammability could contribute to slowing down the combustion process and reducing the negative effects of fire.

The assessment of the scope of safety for road vehicles has been unified in the European Union by the European Commission, which has developed legal acts regulating the criteria for assessing the flammability of products used inside vehicles. Requirements for the flammability of materials used in the construction of some motor vehicles and their resistance to fuels and lubricants are included in Regulation No. 118 of the United Nations Economic Commission for Europe. In the PN-ISO 3795: 1996 standard - Road vehicles and tractors, agricultural and forestry machines - Determination of the flammability of materials used inside vehicles [18], the methodology of flammability tests identical to the one contained in the Regulations is described. In Regulation No. 118 the limit of flame travel is determined, which is 100 mm / min.

Many research units perform tests in accordance with the procedure described in Regulation 118 or ISO 3795. Volvo has even increased the safety of the driver and passengers by tightening the requirements of the Regulations by an internal procedure setting the flame propagation speed to 80 mm / min. Car upholstery flammability tests were also carried out at the Fire Research Institute in Sweden [21]. 17 plastic products were used for the tests, which are used as finishing materials for the interior of buses. The tested materials were used in the passenger compartment for seat

upholstery, wall sheathing, dashboard, curtains, etc. The tests showed that product No. 3, being the sheathing of the interior wall and seat, did not meet the requirements of the criterion of flame spread speed specified in the Regulations and exceeded the value flame propagation velocity of 100 mm / min. The results of testing individual materials are shown in Fig. 3.

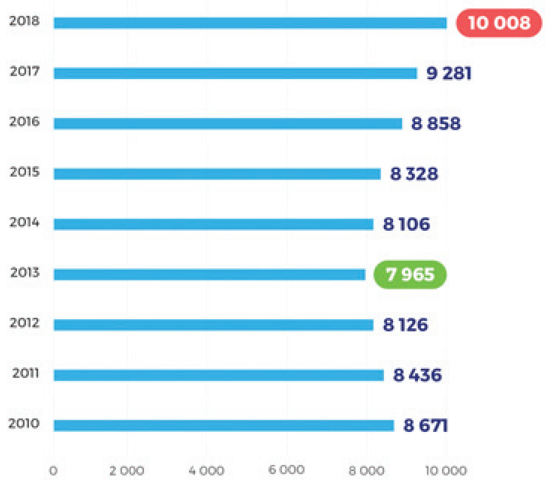

Fig. 1 Statistics on road fires of means of transport (motorcycles, buses, trucks and passenger cars) in 2010-2018 based on data from the National Headquarters of the State Fire Service [19]

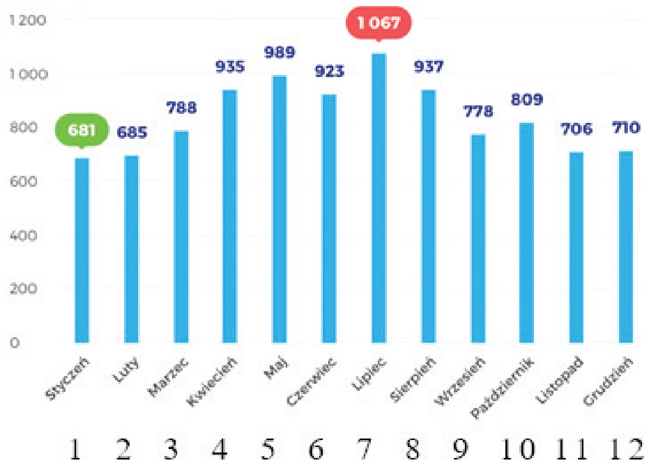

Fig. 2 Statistics of road fires of means of transport (motorcycles, buses, trucks and passenger cars) in 2018 broken down by month based on data from the National Headquarters of the State Fire Service [20]

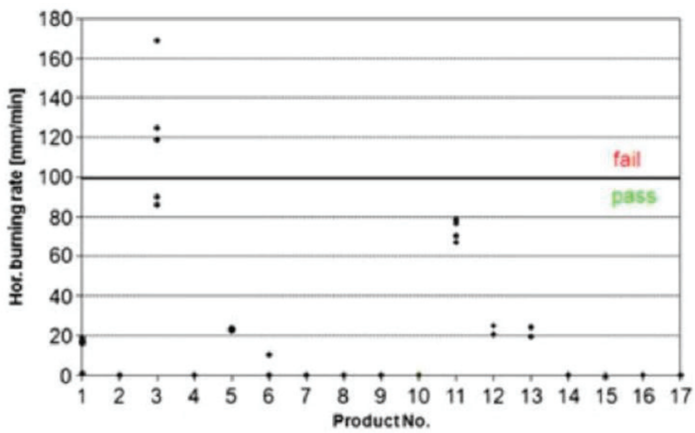

Fig. 3 Results of tests carried out in accordance with the requirements of ISO 3795 at the Fire Research Research Institute in Sweden [21]

At the Institute of Natural Fibers and Herb Plants in Poznań, comparative tests of flame spread velocity in leather-like and natural leather materials were performed [22]. Natural leather was self-extinguishing and the flame propagation speed was 0 mm / min. The artificial equivalent obtained a flame propagation speed of 66 mm/min.

Tests on the degree of flame spread for the EPP material (Expanded Polypropylene) were carried out in accordance with the method described in the Regulations at IZO-BLOK [23]. Foamed polypropylene is used in many industries, e.g. in construction or in the automotive industry, and is characterized by good flexibility, low weight, chemical resistance and the ability to absorb energy. For the selected material, tests were carried out on the effect of density on the flammability parameter. Tests have shown that as the product density decreases (lower mass), the speed of flame spread across the surface of the product increases.

The article presents the results of tests on the flammability of materials used inside vehicles from randomly selected 15 different models of passenger cars, according to the requirements of Regulation No. 118 and PN-ISO 3795.

2. Research Methodology

The test method consists of placing a 356 × 100 mm sample inside a U-shaped holder which, after entering the test chamber, is exposed to a standardized flame. The flame is generated using a Bunsen burner, and the tested material is exposed to flame for 15 s. The test determines:

- is the material self-extinguishing;

– at what time the flame goes out;
– whether there is propagation of flame spread;
– what is the speed of the combustion front spreading [mm/min].

The scheme of the test stand is shown in Fig. 4.

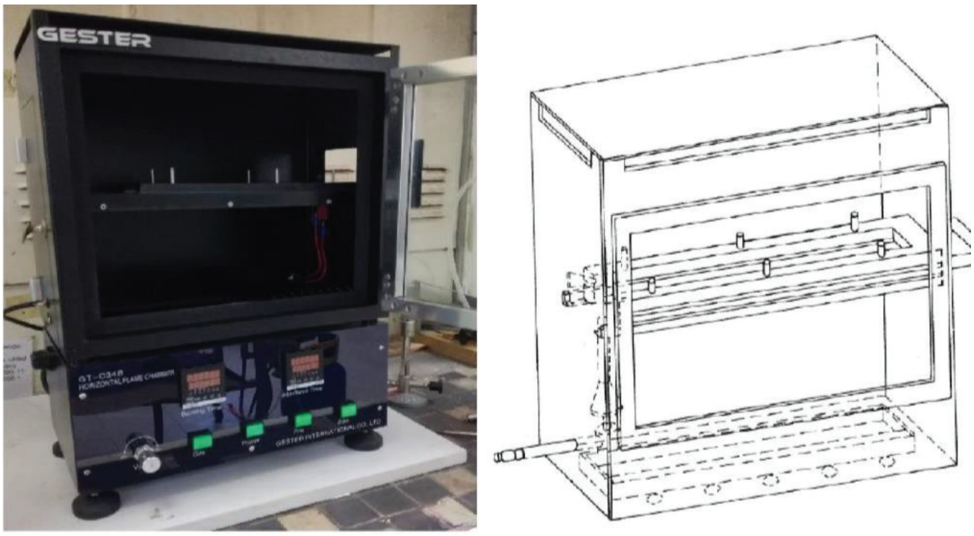

Fig. 4 Test stand made in accordance with the requirements of PN-ISO 3795 [18]

3. Test Results

Tests were carried out for 15 materials constituting the seat upholstery used inside commonly used passenger vehicles. Samples for testing were taken at the auto-scrap area from cars for cassation. Due to the fact that the car's history is unknown, it is not possible to indicate to what extent, conditions and period of time the vehicle was used and what detergents were used to clean the upholstery. The list of vehicle brands and test results is presented in Table and graphically in Fig. 5.

The purpose of these tests was to check whether the material used meets the requirements of UNECE Regulation No. 118 regarding the degree of flame spread. The tested samples were seasoned in a climatic chamber at (23 ± 2)°C and humidity (50 ± 5)%, in accordance with the requirements of PN-EN 13238: 2011.

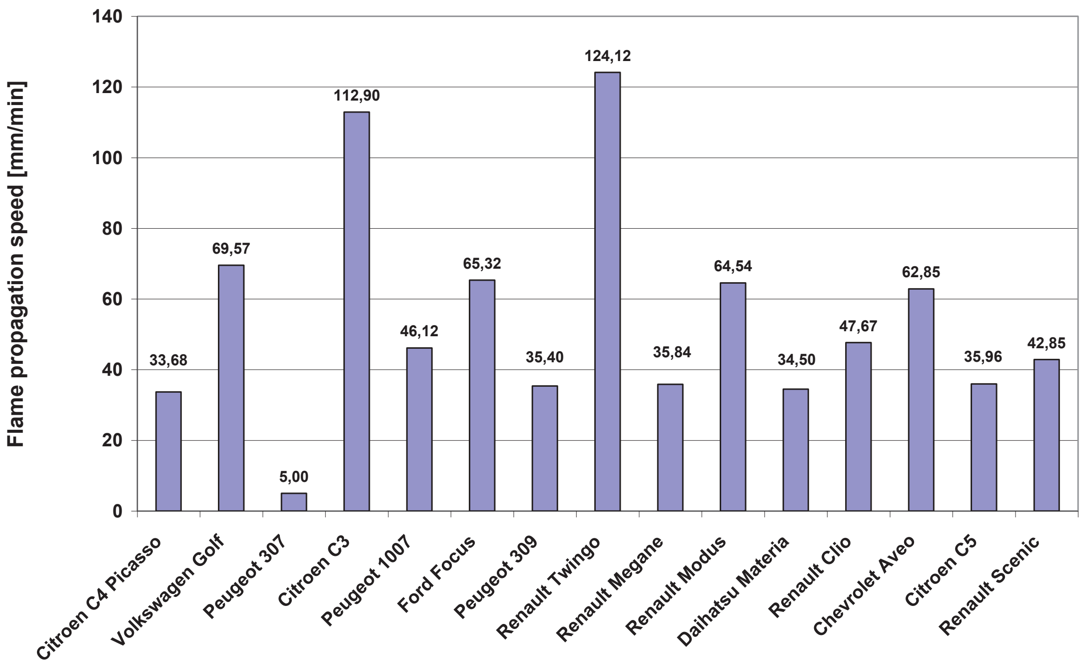

Fig. 5 List of vehicle brands as a function of flame propagation speed

Table

Comparison of vehicle brands and test results

Lp.	Car mark	Model	Time	Length burn out	Speed spread of	Material upholstery
			[s] / [min]	[mm]	[mm/min]	
1	Citroen	C4 Picasso	171 2,85	96	**33,68**	velours
2	Volkswsagen	Golf	3,45 0,058	4	**69,57**	leather
3	Peugeot	307	6,48 0,108	19	**5,00**	leather
4	Citroen	C3	73,34 1,222	138	**112,90**	velours
5	Peugeot	1007	179,53 2,992	138	**46,12**	velours
6	Ford	Focus	126,77 2,113	138	**65,32**	velours
7	Peugeot	309	152,53 2,542	90	**35,40**	velours
8	Renault	Twingo	66,71 1,112	138	**124,12**	velours
9	Renault	Megane	231 3,85	138	**35,84**	velours
10	Renault	Modus	128,3 2,138	138	**64,54**	velours
11	Daihatsu	Materia	240 4	138	**34,50**	velours
12	Renault	Clio	173,68 2,895	138	**47,67**	velours
13	Chevrolet	Aveo	131,74 2,196	138	**62,85**	velours
14	Citroen	C5	230,25 3,8375	138	**35,96**	velours
15	Renault	Scenic	193,25 3,221	138	**42,85**	velours

4. Analysis of Test Results

The tests showed that the leather upholstery (Volkswagen Golf and Peugeot 307) does not ignite after turning off the burner and, as a consequence, there is no flame spread on the surface of the material. The obtained result is in line with the results of tests carried out at the Institute of Natural Fibers and Herb Plants in Poznań [22]. Other upholstery materials of passenger car seats made of fabrics had a differentiated flame propagation range in the speed range from 33.68 to 124.12 [mm / min]. In this range, the flame propagation values of two samples did not meet the flammability criterion (100 mm / min) contained in Regulation No. 118 and PN-ISO 3795. It should be noted that materials made of fabric have always ignited and allowed the flame to spread to sample surface.

5. Conclusions

The tests were carried out to check whether the tested materials meet the criteria for flame propagation speed contained in Regulation No. 118 and PN-ISO 3795 after a few years of vehicle operation. 15 types of car upholstery were tested. In the case of two samples in the form of leather materials, the best results were obtained for which the flame propagation speed after the disappearance of the fire source was 0 [mm / min]. Two samples of upholstery made of fabrics did not meet the requirements of the Regulations, and the flame spread at a speed above 100 mm / min. However, it should be noted that materials can change their properties and properties during the operation process as a result of the use of cleaning and preserving agents, as well as exposure to atmospheric conditions.

Tests carried out according to ISO 3795, allow assessment of material flammability on a small scale (exposure to a flame 38 mm high), which allows to imitate / model threats caused by a small source of fire. This method may not be suitable for testing upholstery materials for all types of cars, in particular special vehicles, e.g. military vehicles, due to anticipated threats.

Proper confirmation of the combustibility of materials inside the vehicle is very important for the safety of

travelers. This parameter undoubtedly affects safe evacuation and reduces the likelihood of fire spreading.

Acknowledgement

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The Influence of Load Modes on the Resource Reliability of Engine Parts of Agricultural Machinery

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Abstract

The most common power unit for agricultural machinery is a diesel engine. The requirements for them are constantly being tightened. Modern diesel engines must comply with a wide range of requirements for ecology, efficiency and reliability. The article considers the impact of operational cycles of the agricultural machinery engines that operate in the Baltic countries, Poland, Ukraine and Kazakhstan on the design reliability of the piston engine. In view of this fact in the article the features of unsteady heat-stressed state of the piston and its impact on the time of trouble-free operation are considered.
KEY WORDS: *diesel engine, field furrow length, operation cyclicity, operation model, piston, combustion chamber edge, heat-stressed state, damage buildup, physical reliability*

1. Introduction

The use of internal combustion engines (ICE) is an indispensable feature of modern society. These engines are significant factor that have an effect on people's living standards. Therefore, with the improvement of ICE, the requirements for ensuring environmental friendliness and efficiency criteria become more stringent. Recent analysis shows that the problem of harmful emissions could be considered technically solved, and the ICE will continue to be regarded as a power generating means for long term [13, 20]. At the same time, increasing the energy efficiency of vehicles is inevitably associated with increasing the specific power of engines.

The efficiency of the internal combustion engine, at high levels of forcing, significantly depends on the ability to retain heat in the combustion chamber. But it significantly increases the thermal stress of parts of the combustion chamber. The materials of the parts begin to work at the limit of strength. Therefore, the problem of ensuring the physical reliability of these parts often comes to the fore [17].

The piston of the ICE is one of the highly heat-stressed parts of the engine. Further boosting of the engines leads to cases of cracking of the edges of the combustion chambers of the pistons. This is especially true for diesel engines, the operating conditions of which are associated with frequent changes in load modes [19]. Therefore, the purpose of the work is to determine the influence of diesel engine operating conditions on the physical reliability of the heat-stressed zone of the piston.

Long operating time of the diesel engine at high levels of loadings and high frequency of change of level of loading are a characteristic feature of technological cycles of work of agricultural machines [4, 12]. Therefore, the diesel piston of an agricultural tractor was chosen as the object of research. The main task of the work is to choose a theoretical model of engine load for the system for predicting the level of physical reliability of the combustion chamber parts of the ICE. Such a model must comply with the concept of guaranteed assurance of the design resource in the process of design or modernization of the ICE. This thesis means that when in the process of calculations the efficiency of the structure is established, then in real operating conditions its physical reliability will not be violated during the specified resource.

2. Formulation of the Research Task

Today there are a number of alternative routes for the design of pistons, they mainly differ in the level of detail

of the real physical processes that are modeled [5, 7, 9, 14, 15]. For refined models, the loss of strength of the material under non-stationary loads is associated with the notion of damage buildup. It is supposed that the magnitude of damage determines the part of exhaustion of physical reliability over the time τ and has a complex relationship with temperature *t* and stress σ. The design is operable if the condition is performed

$$d_{FS}(\tau)=\varphi\big(t(\tau),\sigma(\tau)\big)\le 1\,. \tag{1}$$

Among the factors which influence on the destruction of combustion chamber parts, the main ones are:

- fatigue of the material, which is determined by the high-frequency periodic change of the parameters of the working medium in the cylinder and the presence of transients of the engine load;
- creep process, which slows down or accelerates depending on the previously acquired state of the material;
- relaxation of thermoelastic stress, that accompanies the process of creep under conditions of deformation restrictions.

All these factors are directly determined by the specific technological cycles of a specific purpose engine, which is a function of the model of its operation:

$$\Xi=\{\xi_1,\xi_2,\ldots,\xi_k\}, \tag{2}$$

where ξ_i, $i=1,2,\ldots,k$. – representative transients of the engine of a specific purpose.

Taking into account (2), Eq. (1) acquires a concretized form:

$$d_{FS}(\Xi,\tau)=\varphi\big(\Xi,t(\tau),\sigma(\tau)\big)\le 1\,. \tag{3}$$

Then on the basis of (3) the equation for establishing the degree of damage to the material of the part for the intended service life *P* takes the form:

$$d_{FS}(\Xi,P)=\sum_{i=1}^{N_P}\frac{1}{N_{Fi}}+\sum_{i=1}^{N_P}\frac{1}{N_{Si}}\,, \tag{4}$$

where N_P – the number of all piston load cycles for the intended service life *P*; N_{Fi} – the number of cycles to failure from fatigue in a single load cycle *i*; N_{Si} – the number of cycles to failure from creep in a single load cycle *i*.

The corresponding blocks of the design analysis system are presented in Fig. 1. A review of the literature [4, 5, 8, 12] shows that the real problem of practical use of this system is the lack of reliable models of operation Ξ. For this reason, in [1] it is proposed to use its simplified equivalent instead of the complete model. The maximum possible simplification here is the use of one, the most important transition process ζ_1. Accordingly, the total resource of the structure *P* is proposed to be replaced by its analogue Π, which does not violate the concept of guaranteed assurance of the resource:

$$d_{FS}(\xi_1,\Pi)=\sum_{i=1}^{N_\Pi}\frac{1}{N_{Fi}}+\sum_{i=1}^{N_\Pi}\frac{1}{N_{Si}}\,,\ \Pi<P\,,\ d_{FS}(\Xi,P)\le d_{FS}(\xi_1,\Pi)\,. \tag{5}$$

The method of determining the value Π is known and is given in [1]. Then the practical application of approach (5) requires definition of the competing transient processes ξ_1^i, $i=1,2,\ldots,l$ and finding a solution.

$$d_{FS}(\xi_1,\Pi)=\mathbf{max}\big(d_{FS}(\xi_1^i,\Pi)\big),\ i=1,2,\ldots,l\,. \tag{6}$$

The influence of the transition process ξ_1^i on the results of the calculation d_{FS} is proposed to establish by equation:

$$f_1^i=d_{FS}(\xi_1^i,\Pi)/d_{FS}(\xi_1^{base},\Pi)\,, \tag{7}$$

where ξ_1^{base} – significant transition process of a characteristic group of a specific purpose engine.

Then expression (6) can be represented as:

$$d_{FS}(\xi_1,\Pi)=\mathbf{max}\big(f_1^i\big)\cdot d_{FS}(\xi_1^{base},\Pi)\,,\ i=1,2,\ldots,l\,. \tag{8}$$

Thus, the detected transient process is recommended for use as a theoretical model of engine load in the system of analysis of physical reliability of the structure, which is presented in Fig. 1.

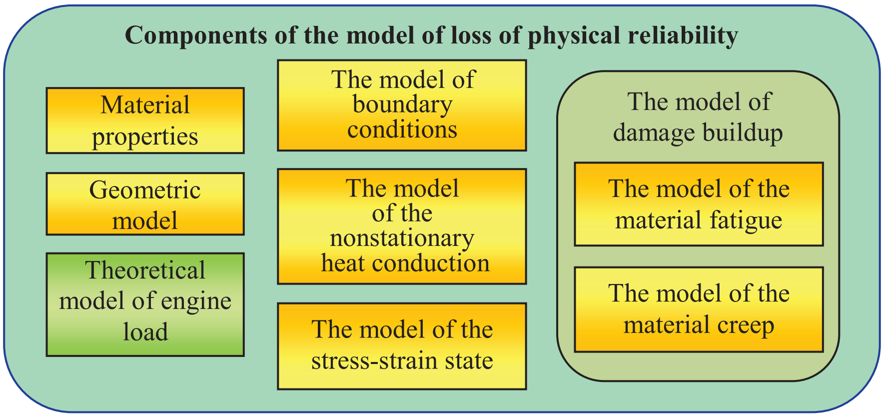


Fig. 1 The set of blocks of the system of analysis of the physical reliability of the combustion chamber of the internal combustion engine

Solution (7, 8) is a general statement of the research problem. Let's move on to its formulation relative to the engine parts of an agricultural tractor.

Cyclic operating conditions of the engine in the process of agricultural work are characterized by the presence of two main operating modes. The first is a difficult mode of performance of technological operation at movement on the field and the mode of turn of the unit which close to idling. Thus, the load model ξ_1 will be characterized by the operating time in these two stationary modes and the transient processes of heating and cooling of parts when changing stationary modes. The average statistical data of model ξ_1^{base} for the conditions of tractor use in Ukraine are known. The duration of the diesel loading cycle in Ukraine is 360 s with a field furrow length of about 600 m [5, 10]. On the other hand, in the economic evaluation of agricultural processes, the recommended range length is 1500-2000 m [16].Thus, the model ξ_1^{base} for the conditions of tractor use in Ukraine is not the only and optimal. This necessitates the formation of a plurality of transient processes ξ_1^i, $i = 1,2,\ldots,l$.

According to [10], in different regions of Ukraine and in different farms, the field furrow length is mainly from 200 m to 1000 m. In Kazakhstan, there are fields with a length of 300-400 m and 2000 m. In the Baltic countries there are mainly fields with a length of 150-200 m and 300-400 m. Consider in detail the indicator of the length of the furrow for Poland. Fig. 2 illustrates statistics on the distribution of croplands between Polish farms [6]. Similar data are presented in [2].Based on the recommendations [3, 16], we obtained the possible length of the corresponding croplands. The results of this assessment are presented in Fig. 3. It is obvious that different farms will have significantly different technological cycles and corresponding engine loading processes ξ_1^i.

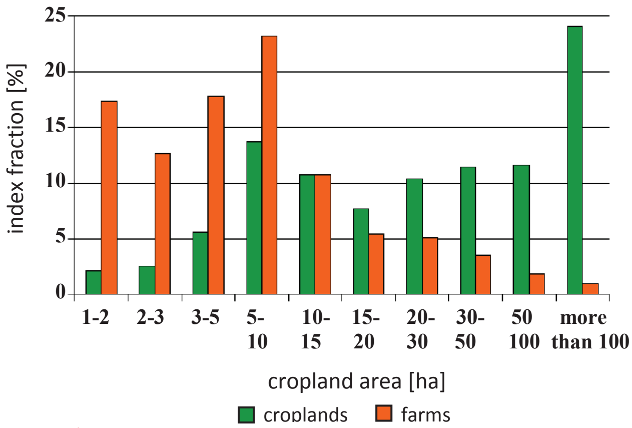


Fig. 2 Distribution of croplands and farms in Poland

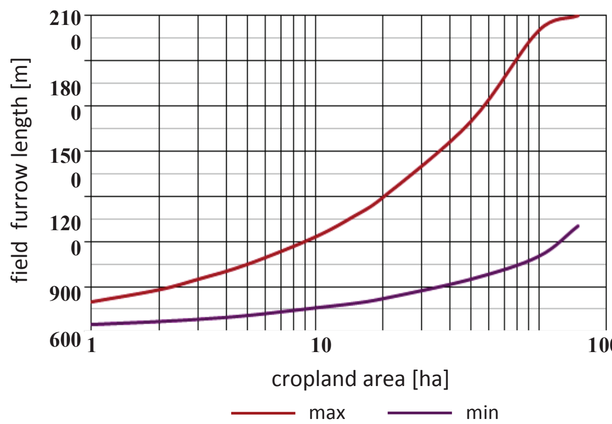


Fig. 3 Dependences of the length of the field furrow on cropland area

We limit the area of research from below to the value of the furrow of 150 m. This corresponds to the execution time of the technological operation lasting 60 s. The maximum execution time of the technological operation can be taken close to 1000 s. Such parameters of the set of possible models will correspond to the vast majority of cases for the countries considered above. This is enough to summarize the results. The turning time of the unit must be minimal. But

it depends on the characteristics of the fields and other technological factors. For models, take this time in the range of 30-60 seconds. On this basis, we can form a generalized set of competing transient processes ξ_1^i, $i=1,2,\ldots,l$. Table lists these processes.

Table

Array of the models of operation of the engine of an agricultural tractor

Model number, i	Time of technological operation, sec	Unit turning time, sec	Total cycle time, sec
1	60	30	90
2 (ξ_1^{base})	330	30	360
3	300	60	360
4	1050	30	1080
5	1020	60	1080

Thus, the formulation of the task is completed. It consists in establishing on the basis of a mathematical model (5), (7), (8) the most difficult transition process from the array given in the Table. The result of this search is not obvious. On the calculation base Π, as the total cycle time decreases, the effect of material fatigue increases, and as the cycle time increases, the effect of creep increases. The result also depends on the design of the combustion chamber parts and the speed of its heating and cooling.

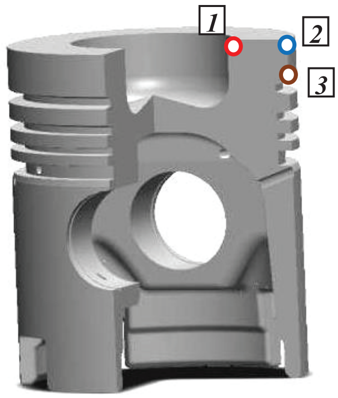
3. Research Results and Discussion

The calculated study was performed for a diesel piston boosted to 30 kW / l. Piston diameter 120 mm, piston stroke 140 mm, nominal crankshaft speed 2000 min-1. The load of 0.15 kV / l is accepted for the mode of turning of the unit. Analysis of the physical reliability of the piston was performed using a set of models presented in Fig. 1.

The piston material is aluminum alloy AK12M2MgH (Al25). The properties of the material are accepted according to the monograph [5]. At this stage of research, creep rates are adopted independent of the frequency of diesel load cycles.

To model the operation of the piston at the limit of strength adopted the design of the piston without the cavity for oil cooling. The piston and its geometric model are presented in Fig. 4. The points in Fig. 4, b indicate the control zones of temperature and thermal stress. The damage calculation (5) is performed for the edge zone of the combustion chamber (point 1).

a



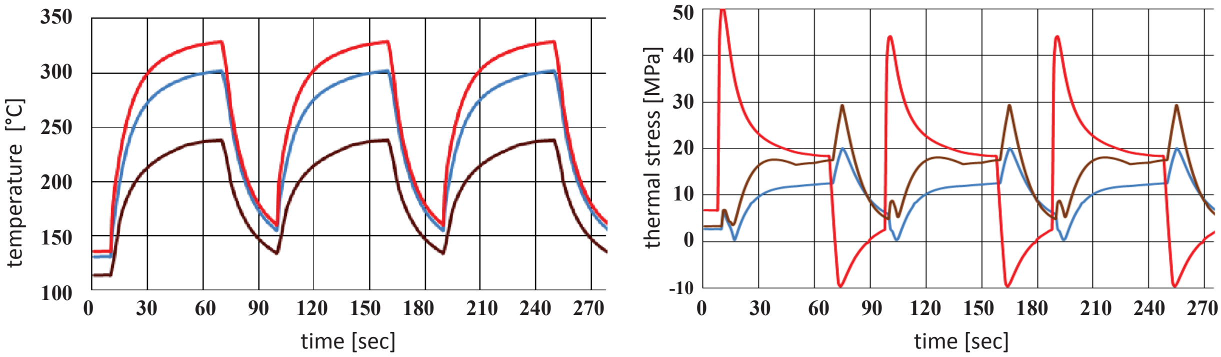
b

Fig. 4 General view of the investigated piston (a) and its accepted geometric model (b)

The boundary conditions of the nonstationary heat conduction problem are established on the basis of the experimental data presented in [8]. Mathematical models of problems of heat conduction and stress-strain state of a design are well known. High-frequency fluctuations in temperature and stress are taken into account [5].

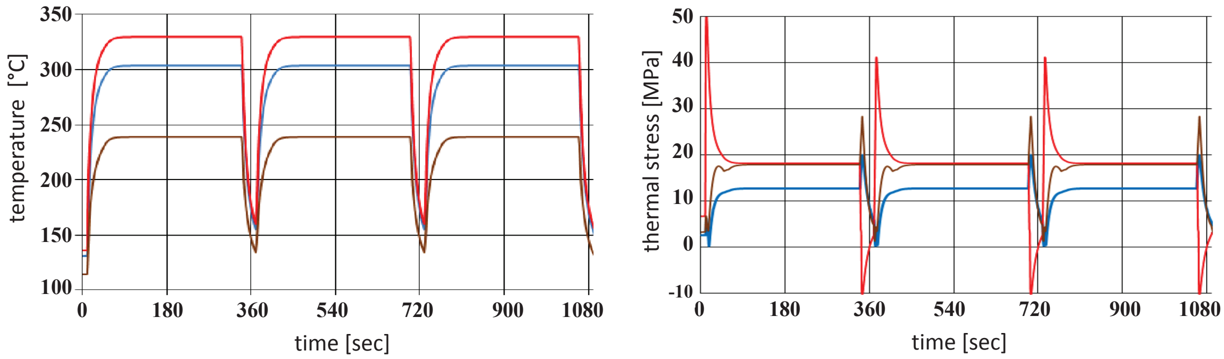
The damage buildup calculation for the specified time Π according to expression (5) was performed by the authors using the software tool RESURS [11]. Derivative values are accepted according to the work [1]. For a tractor diesel piston Π = 3500 hours.

Fig. 5 shows the change in the heat-stressed state of the piston at the control points for some of the load models of the diesel ξ_1^i. Fig. 6 shows the obtained values of the parameter f_1^i of the influence of the transient process on the damage buildup $d_{FS}(\xi_1^i,\Pi)$ for all considered models $\xi_1^i, i=1,2,\ldots,l$, relative to the base model. The components of parameter f_1^i from the factors of fatigue and creep of the material are also given. Consider the obtained results.



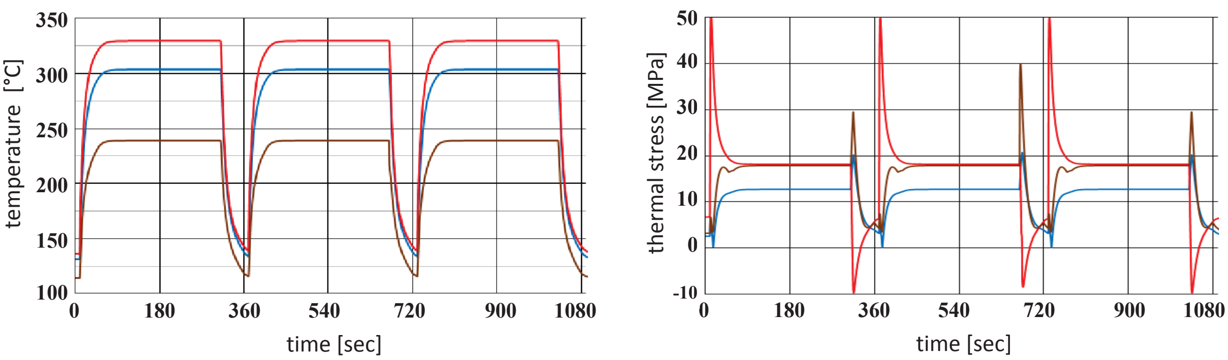
a b

model ξ_1^1 – technological operation time 60 sec, reversal time 30 sec



c d

model ξ_1^2 (ξ_1^{base}) – technological operation time 330 sec, reversal time 30 sec



e f

model ξ_1^3 – technological operation time 300 sec, reversal time 60 sec

point 1 point 2 point 3

Fig. 5 Temperature and thermal stress of the piston at control points

Fig. 5, a, b shows the change in the heat-stressed state of the piston at the control points for the model ξ_1^1. It is evident that during the technological operation for a period of 60 sec the piston does not have time to warm up to a state of heavy stationary mode. And during the turn of the unit for a period of 30 sec the piston does not have time to cool to the initial state. Under such conditions of cyclic loads, the maximum thermal stress in the area of the edge of the combustion chamber for the second cycle is less by 6 MPa.

Fig. 5, c, d shows the change in the heat-stressed state of the piston at the control points for the base model ξ_1^{base}. It is seen that during the technological operation for a period of 330 seconds the piston already has time to become heated up to a state of heavy steady state. But the change in thermal stress during transients is close to the previous version. The main difference here is four times less frequency of changing the load modes of the diesel engine.

Comparison of the values of the parameter f_1^i (Fig. 6) shows that reducing the load cycle 4 times (from 360 seconds to 90 seconds) increases the damage buildup 1.5 times. This is a significant result that should be taken into account for forced diesels when operating near the strength limit of materials. The main contribution to the increase in

damage is the process of creep.

Fig. 5, e, f shows the change in the heat-stressed state of the piston at the control points for the model ξ_1^3. It differs from the base model by increasing the turn time of the unit from 30 seconds to 60 seconds with a constant cycle time (360 seconds). In this case, the edge of the combustion chamber of the piston is cooled to 20°C more. This leads to an increase in thermal stress in each cycle to almost the stress of the first cycle. Fig. 6 shows that in this case the proportion of fatigue injuries increases. Some reduction in the effect of creep here is due to the accepted in the model reduction of the time of technological operation from 330 seconds to 300 seconds.

Fig. 6 also shows that reducing the frequency of the transients significantly reduces the value of the parameter f_1^i. Thus, increasing the load cycle by 3 times (from 360 seconds to 1080 seconds) reduces the damage buildup 0,4 - 0,5 times. The nature of the ratio of damage to fatigue and creep remains similar to that discussed above.

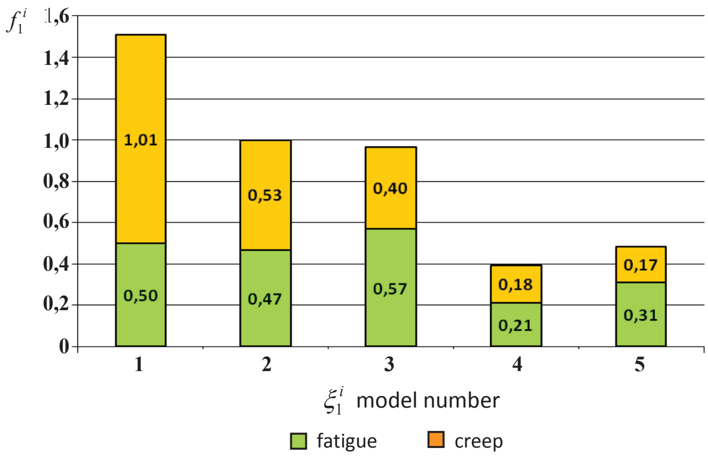


Fig. 6 Influence of the transient process on the damage buildup in control points 1

Based on the obtained results, it can be seen that model ξ_1^1 should be used for the general theoretical model of the tractor engine load for the system of forecasting the level of physical reliability of the combustion chamber parts of the internal combustion engine. It corresponds to the time of technological operation of the agricultural unit lasting 60 seconds and the time of its turn of 30 seconds. For some regions, such as Kazakhstan, as well as some large agricultural firms, the model of diesel load may be different with a different result of the design of combustion chamber parts. The choice of the updated model can be made on the basis of use of the interactive map of agricultural fields (Agricultural OneSoil Map) in which 42 European countries and the USA are included [18]. In our opinion, such a progressive approach will help increase the energy efficiency of the full life cycle of structures designed for individual segments of the consumer market.

4. Conclusion and Future Scope

On the example of the analysis of conditions of operation of agricultural machines the technique of formation of model of operation of the engine for system of forecasting of physical reliability of details of a combustion chamber is presented. The method is proposed for use at the stage of development of new engines or their modernization, taking into account the concept of guarantying the resource.

The influence of the characteristics of the diesel load cycles on fatigue and creep damage buildup has been established for the edge zone of the combustion chamber of the piston. It is shown that the value of the parameter of the influence of the transition process on the damage buildup can vary in the range of 0,4-1,5 relative to the mean data for the conditions of tractor use in Ukraine. This discrepancy between the physical reliability of the pistons is significant. Therefore, we can conclude that for some cases it is advisable to use different models of loading of diesel engines with a different result of the design of combustion chamber parts.

Further areas of work are listed further. Development of a theoretical model of the engine for the conditions of specific agricultural firms with small field sizes and high frequency of technological cycles of agricultural units. Establishing the level of physical reliability of pistons depending on the diameter of the cylinder and other design features. Development of an adaptive piston cooling control system. Development of a control system and extension of the appointed piston life.

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Selection of Handling Equipment in Warehouse Using Multi-Criteria Decision-Making

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Abstract

The handling equipment is more modern and companies pay more attention to the safety of the warehousing operator every day. Every company which is using handling equipment is constantly renewing them for this reason. Handling equipment is used for professional relocation, loading and directing of material in production, warehousing and cycle. The handling equipment form a whole for a certain area of transport handling, including organization. The aim of this article is the selection of handling equipment in the warehouse using multi-criteria decision-making. Choosing the right handling equipment in the warehouse is based on the number of pallets, the position behind the steering wheel, the battery, speed, load capacity and manoeuvrability. Multi-criteria decision-making is a scientific discipline of operational research that deals with the analysis of decision-making situations in which decision-making variants are assessed not only by one but by several conflicting criteria. The article uses the weighted sum method, where alternatives are assigned numbers according to the order of individual characteristics, the highest sequence number has the highest alternative number.
KEY WORDS: *handling equipment, multi-criteria decision-making, warehousing*

1. Introduction

Material handling equipment, of which transport is an important part, is an integral part of virtually every technological process. It has a significant impact on quality, economy and safety in all areas of business throughout the globalized world. Material handling, as a set of operations required in manufacturing, has become an important field of modern technology. The field began to develop study and cover other major operations. Thus, all technological transport and warehousing and many other handling operations are routinely included in handling today.

Economic globalization and market liberalization have led to the separation of production and consumption places, which has led to significant growth in world trade and the intercontinental flow of goods [1]. Logistics is an area that represents an irreplaceable role in every business and society in today's globalized world [2].

The aim of this article is the selection of handling equipment in the warehouse using multi-criteria decision-making. Choosing the right handling equipment in the warehouse is based on the number of pallets, the position behind the steering wheel, the battery, speed, load capacity and manoeuvrability.

2. Theoretical Background

The conditions under which industrial enterprises are evolving today mean that advanced information technologies are evolving intensively and introduced into manufacturing processes to ensure greater flexibility and adaptability to the changing external environment. The problems associated with demonstrating the characteristics of the warehouse process in the relevant supply chains are therefore of particular importance [2]. This is due, on the one hand, to the need to minimize overall aggregate costs in terms of the whole customer satisfaction process to ensure the competitiveness of next-generation production systems and on the other to a high proportion of total logistics costs in supply chains of industrial enterprises [3-4]. Thus, one of the most important goals (from minimizing logistics costs of enterprises) is to document the fleet characteristics of the material handling equipment, which directly ensures the implementation of the material handling process and consequently significantly affects performance indicators of industrial supply chains [5-6]. The problem is also complex because warehouse performance indicators (including transport capacity and operating costs) depend on both the amount of material handling equipment and its technical characteristics [7-8].

The goal of almost every business is to optimize all logistics operations to minimize errors and gain a competitive edge despite other businesses in the industry [9].

Modernization of mechanical structures and structural components helps to mitigate the negative impacts of operating conditions and ensure the desired output [10]. Each moderation should be accompanied by a review of the maintenance strategy. The most effective, but also the most demanding, is proactive maintenance [11]. Warehousing logistics managers are interested in providing high quality services especially in handling equipment to their customers at an optimal price [12-13]. Logistics and express courier services companies have to strive to increase the level of the customer service provided with optimum pricing policy [14].

3. Methods

Multi-criteria decision-making is a scientific discipline of operational research that deals with the analysis of decision-making situations in which decision-making variants are assessed not only by one but by several conflicting criteria. The article uses the weighted sum method, where alternatives are assigned numbers according to the order of individual characteristics, the highest sequence number has the highest alternative number.

The AHP and WSA methods are used in this study. AHP is a decision support procedure developed by Saaty [15] to deal with complex, unstructured, multi-criteria decisions. AHP is based on three factors: model structure, benchmarking of alternatives and criteria, and synthesis of priorities. AHP has been widely used in the literature to address a number of complicated decision-making problems [16-19].

The Weighted Sum Approach, also known as the weighted partial order method, is also based on the maximization of utility, but assumes only a linear utility function. Using it, a normalized criterion matrix $R = (r_{ij})$ is created, whose elements are obtained from the criterion matrix Y and its rows corresponding to the ideal (I) and basal (B) variant. The matrix already represents a matrix of utility values of the *i*-th variant according to the *j*-th criterion. The option that reaches the maximum utility value is then selected as "best", or handling equipment are ranked based on a decreasing utility function value [15].

4. Results and Discussion

Electric pallet truck – Jungheinrich

With the designation ESE 533, the electric pallet truck (see Fig. 1) is suitable for long-distance transport with a large number of pallets. It can handle up to three pallets at a time and has an operator safety cabin. It is equipped with AC motors for smooth starting and high end speeds, ensuring a powerful 48 V battery with 1,000 Ah capacity. 360° steering range facilitates manoeuvrability between racks thanks to low steering wheel speed. The display shows the battery range, cruising speed, program selection, mileage, operating hours and total time. The load capacity is rated at 3,300 kg at speeds up to 20 km/h [20].

Fig. 1 Jungheinrich ESE 533 electric pallet truck [20]

Electric pallet truck – Still

The OPX 25 Plus from Still (see Fig. 2) is designed for horizontal order picking and for transporting multiple pallets at the same time. The weight of the load can be up to 2,500 kg at a speed of 14 km/h. Safe driving through curve speed control, which reduces speed depending on the steering angle, ensuring safe passage between shelves. The battery is 24 V with a capacity of 345 Ah [21].

Fig. 2 Still OPX 25 Plus electric pallet truck [21]

Electric pallet truck - Toyota BT

The Toyota BT Levio 3.0 t is a specific electric pallet truck (see Fig. 3) for two consecutive pallets with a load capacity of up to 3,000 kg and a traveling speed of 19 km/h. It is also designed for transport over long distances. It is equipped with a safety cabin with height-adjustable operator seat. The battery has a capacity of 840 Ah and a voltage of 48 V [22].

Fig. 3 Toyota BT Levio 3.0 t electric pallet truck [22]

The selection of the Milk run electric pallet truck (see Table 1) for each manufacturer Jungheinrich, Still and Toyota BT is compared by: number of pallets, driving position, battery, speed and load capacity.

Table 1

Comparison of electric pallet trucks for Milk run; Source: Author based on [20-22]

	Jungheinrich	Still	Toyota BT
Number of pallets (pieces)	3	2	2
Driving position	Sitting	Standing	Sitting
Battery (V/Ah)	48/1000	24/345	48/840
Speed (km/h)	20	14	19
Load capacity (kg)	3 300	2 500	3 000

Selecting the electric pallet truck for the Milk run

The selection of the right electric pallet truck is based on the number of pallets, the position behind the wheel, the battery, speed, load capacity and manoeuvrability. For the criterion “number of pallets”, the author defined points 0-10 of the weight of the evaluation. The more pallets, the less points, as the length of the electric pallet truck affects manoeuvrability and passage between racks (see Table 2). The second criterion for points is “driving position” (also points 0-10). The best position is the sitting position, which increases the safety and comfort of the operator. The third criterion is “battery” - again rated by 0-10 weight points. The maximum score is for higher V/Ah. The fourth criterion is “manoeuvrability”. The better the manoeuvrability, the higher the score (0-10).

Table 2

Comparison of electric pallet trucks for Milk run with achieved criteria values; Source: Author based on [20-22]

	Number of pallets	Driving position	Battery	Speed	Load capacity	Manoeuvrability
Jungheinrich	5	10	10	20	3 300	2
Still	10	5	2	14	2 500	10
Toyota BT	10	10	5	19	3 000	7
Weight criteria v_K	0.03	0.35	0.07	0.25	0.20	0.1

For Table 2, the author defined weight criteria v_k ($\sum$ 1) according to importance. The weight criteria v_K is the most important to the least important: position behind the wheel v_K 0.35; speed v_K 0.25; manoeuvrability v_K 0.10; battery v_K 0.07 and number of pallets v_K 0.03.

A matrix (F) is created from Table 2 to form a normalized matrix (F'):

$$F = \begin{bmatrix} 5 & 10 & 10 & 20 & 3300 & 2 \\ 10 & 2 & 2 & 14 & 2500 & 10 \\ 10 & 10 & 5 & 19 & 3000 & 7 \end{bmatrix}. \tag{1}$$

The same principle as for the electric pallet truck from the column is the highest value that divides the other values in the column.

$$F' = \begin{bmatrix} 0.500 & 1 & 1 & 1 & 1 & 0.200 \\ 1 & 0.500 & 0.200 & 0.700 & 0.757 & 1 \\ 1 & 1 & 0.500 & 0.950 & 0.909 & 0.700 \end{bmatrix}. \tag{2}$$

For this task, the author also used the method of weighted sum order, where alternatives are assigned numbers according to the order of individual characteristics, i.e. the highest sequence number has the highest alternative number. For example, in the "battery" column, in the order 3-1-2 (see Table 3).

Table 3

Weighted sum method of the electric pallet truck for Milk run; Source: Author based on [23]

i/k	Number of pallets	Driving position	Battery	Speed	Load capacity	Manoeuvrability	$\sum_k v_k f'_{ik}$
Jungheinrich	1.0	2.5	3	3	3	1	4.455
Still	2.5	1.0	1	1	1	3	1.245
Toyota BT	2.5	2.5	2	2	2	2	2.190
Weight criteria v_K	0.03	0.35	0.07	0.25	0.20	0.10	

Calculation:

$$\sum_k v_k f'_{ik} \ [\text{-}] \tag{3}$$

For Jungheinrich $1.0 \cdot 0.03 + 2.5 \cdot 0.35 + 3 \cdot 0.07 + 3 \cdot 0.25 + 3 \cdot 0.20 + 1 \cdot 0.10 = 4.455$
For Still $2.5 \cdot 0.03 + 1.0 \cdot 0.35 + 1 \cdot 0.07 + 1 \cdot 0.25 + 1 \cdot 0.20 + 3 \cdot 0.10 = 1.245$
For Toyota BT $2.5 \cdot 0.03 + 2.5 \cdot 0.35 + 2 \cdot 0.07 + 2 \cdot 0.25 + 2 \cdot 0.20 + 2 \cdot 0.10 = 2.190$

According to the calculation $\sum_k v_k f'_{ik}$ the Jungheinrich electric pallet truck is the best one, but its disadvantage is its size and manoeuvrability. This electric pallet truck is only suitable for transport on long and straight tracks. The Jungheinrich ESE 533 has been selected according to multi-criteria decision-making.

5. Conclusion

High-quality handling equipment is an important part of the future-oriented intralogistics success in every company. Industrial manufacturing processes require a number of special handling equipment. It is currently used to support decision making by appropriate methods such as multi-criteria decision-making. Transport or more general material handling equipment involves not only solving technical issues, i.e. equipping business with suitable means of transport and handling equipment, but also problems associated with their purpose of utilizing and solving energy, economic and environmental aspects. The selection of the right electric pallet truck was based on primary criteria such as: number of pallets, position behind the wheel (driving position), battery, speed, load capacity and manoeuvrability. Jungheinrich's electric pallet truck was selected using the multi-criteria decision-making analysis and was recommended for further use.

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Threat Assessment of Railway Stations as a Tool for Increasing of Soft Targets Security Level

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Abstract

Railway stations are places with mass occurrence of people and a constant frequency of movement, but at the same time with deficient protection level. In the security community is considered as soft targets. The threat of attacks on soft targets is currently realized mainly through their vulnerability respectively weakness points in the complex of system object protection. In the conditions of the Slovak Republic, but also in other countries of the world, does not exist generally valid method for the effective protection of soft targets by assessing their vulnerability and the resulting soft target protection methods and techniques. For example, a methodology for evaluating the vulnerability of the soft target, valid in the Czech Republic, is freely available. Based on the principles and procedures defined in the above methodology, it is possible to quantify the degree of vulnerability of transport terminals, such as for example railway stations. The main goal of the article is to demonstrate the possibilities of using the above mentioned methodology for the quantitative evaluation of the railway station and its important systems and services threats and in this way help to effectively increase the level of railway stations operational safety and persons in them.
KEY WORDS: *soft targets, railway station, threat assessment, qualitative evaluation, security measure*

1. Introduction

Soft targets represent for a perpetrators of violent crime easiest and most vulnerable places available for a potential terrorist attack in society. The paper will define the term soft target and will present and apply to a particular object the approach to evaluating the threats of the railway station as a potential soft target. Authors of this paper chosen as an object of interest the railway station in the town of Zvolen.

There is currently no existing uniform definition of soft targets, but soft targets are generally considered to be insufficiently protected civilian objects in which gather large numbers of people. It is necessary to realize that soft targets cannot be completely secured only by means of video surveillance system, physical protection, alarm security system or other security systems and elements used in security practice. For example shopping center, as a potential soft target, may have the best modern and new security system on its premises against property crime, but even so it will be much more vulnerable to a violent or terrorist attack, than a state strategic army object.

Experts have in publications different opinions on certain definitions of soft targets. For example, we present Kalvach [1] states that in security circles, the term is used to refer to places with a high concentration of people and a low degree of protection against attacks, which creates an attractive target, especially for terrorists. Leitner et al [2] define a soft target as places with a large number of people and a low level of security protection against violent attacks. These are transport terminals and stations, tourist attractions or larger events for the public. In a broader definition, it also considers schools, hospitals or swimming pools to be a soft target. Maláník [3] argues that soft targets can be characterized by different perspectives and divided according to different criteria. In his opinion, these are primarily places with a mass occurrence of people (crowded places).

It is important to define the difference between critical infrastructure and soft targets. In the protection of soft targets the purpose is to protect the lives and health of people, in the protection of critical infrastructure the primary purpose is to protect the element of critical infrastructure and to ensure the continuity of its activities. The threat of attacks on soft targets is currently realized mainly through their vulnerable resp. weaknesses within their complex protection system [4]. Based on the publicly available methodology for assessing the threat of a soft target [5], valid in the conditions of the Czech Republic, it is possible to define the basic principles and procedures for assessing the threat of objects with a mass occurrence of people, such as. also railway stations. The aim of the paper is to options the possibility of using the above-mentioned, publicly available methodology for quantitative assessment of threats to the railway station, its premises, key systems and services and thus help to effectively increase the level of operational safety not only of railway stations but especially persons working in them.

2. Methodology for Soft Target Threat Assessment

When evaluating the threat to a soft target according to [5], it is important to identify two basic variables:

- **the probability** of an attack that a particular variant of the relevant way of attack may exist;
- **the impact** of the attack that the variant of the attack considered in this way would have on the object if it were

carried out.

By evaluating these variables, it is possible to estimate the overall threat of a soft target, usually by violent attack. Both the probability of execution and the impact of a particular attack can be examined by appropriately selected subcategories, which will be gradually scored during the evaluation. This enables not only the prioritization of threats in terms of probability and impacts, but also the objectification of proposals for protective measures and efficiency in the application of methods of securing and protecting a particular protected interest. The purpose is not to try to statistically determine the parameters - how, when and where an attack can be carried out, but especially to think about each possible way of attack, analysis of relevant scenarios and prevention options and measures for their disallowing.

2.1. Determining the Probability of a Particular Way of Attack

Estimation of the probability of a particular way of attack can be performed using subcategories (Fig. 1).

Estimation of the probability of a particular way of attack

the availability of resources for a considered way of attack	the occurrence of the considered mode of attack	the complexity of carrying out the considered way of attack

Fig. 1 Subcategories for estimating the probability of a particular way of attack

Availability of resources for the intended way of attack

In the evaluation, the assessor focuses mainly on the weapon used or other means to carry out the attack. When estimating points evaluation it is necessary to consider whether one or more types of weapon are used (knife and firearm or vehicle and explosives). It is considered whether it is a weapon that can be used by any attacker, or it requires some type of trainging. Another factor is the fact whether the weapon is freely available or people need a specific permit for use. (for example firearms license with a permit) or it cannot be obtained legally. An equally important factor is the attribute of availability and delivery time of the weapon. When quantifying the points evaluation, 1 is considered - as the most difficult weapon available, on the opposit 7 - as the most readily available weapon (Table 1) [5].

Table 1

Points evaluation of the quantitative scale of resource availability for the chosen way of attack [5]

Points	1	2	3	4	5	6	7
Availability of resources for the intended way of attack	Weapon obtained by criminal activity, need a professional training, long delivery time	Weapon obtained by criminal activity, need a professional training, short delivery time	A weapon obtained through criminal activity, without professional training	A weapon for a permit, or more these weapons	More commonly available weapons, or weapon less available (car)	A weapon that is commonly available (knife)	Without weapon

Occurrence of a particular way of attack

By evaluating the occurrence, the evaluator determines how the chosen way of attacking the considered soft target for different categories of attackers is "favorite" either in a given location or at a specific time. It is also considered whether this way of attack has already happened or was being prepared on a similar target and in a similar location in the past. It is examined whether this is a way of attack that has not yet occurred in the area, but has occurred in a nearby region or neighboring country, or it is only a hypothetical threat. The occurrence of a particular type of attack is also assessed by a qualified estimate in the range 1 to 7, where 1 - represents the attack with the lowest frequency and 7 - the attack with the highest frequency (Table 2) [5].

Table 2

Points evaluation of the quantitative scale Occurrence of a particular way of attack [5]

Points	1	2	3	4	5	6	7
Occurrence of a particular way of attack	It has never occurred in the Slovak Republic or in nearby countries	It occurred rarely happens in nearby countries	It occurred rarely happens in the Slovak Republic	He appeared several times in nearby countries	He appeared several times in nearby countries	It has occurred several times in nearby countries	It has occurred several times in Slovakia

The complexity of carrying out the potencional way of attack

When evaluating the complexity of the implementation of an attack, we focus on the complexity of the preparations for the attack, as well as the mode in the building and its security against specific types of attacks carried out at a certain time and place. The evaluator assesses whether the attack must be carried out by an individual, group or organization. It also assesses whether the attack requires short-term or long-term preparation and cooperation of persons in its preparation. An important factor is also whether the attacker must cooperate with criminal or terrorist groups, in particular in obtaining weapons or other appropriate means of attack, whether such cooperation is one-off or longer-term cooperation, and so on.

Other evaluated parameters and attributes can be e.g. whether the attack requires penetration into the regime environment of the target, whether it takes place in a public place, whether it requires realization in a short narrow time, at a precisely determined place, or whether successful execution of the attack is possible even after a longer period, or in several places. The complexity of the implementation of the attack is also evaluated in the range of 1 to 7, where 1 - represents the most complex attack and 7 - the simplest enforceable attack (Table 3).

Table 3

Points evaluation of the quantitative scale the complexity of carrying out the potencional way of attack [5]

Points	1	2	3	4	5	6	7
The complexity of carrying out the potencional way of attack	An internationally coordinated, long-prepared event of a terrorist group, accessible or inaccessible to the public	Coordinated action at the local level of cooperation with a terrorist group, place inaccessible to the public	One-time cooperation with a local terrorist group, place inaccessible to the public	More complex or long-term cooperation with a criminal group, a place inaccessible to the public	Simple or one-time cooperation with a local criminal group, a place accessible to the public	It requires the involvement of more people, a publicly accessible place	Individual without the help of other persons, publicly accessible place

The total estimated probability of a particular attack can therefore have a value of a maximum of 7 + 7 + 7 = 21 points.

2.2. Determining the Impact of a Particular Way of Attack

The impact of an attack is meant to be a negative impact that could be caused by carrying out a particular way of attack on the intended soft target.

As we address the issue of soft targets, a potential attack will be expected to focus on people's lives and health, not on the movable and immovable assets of transport infrastructure. It is obvious that the intended attack usually has a negative impact on other socially significant values, such as. material damage, economic consequences, damage to the environment and more. The values of the impact of a particular attack on an object must therefore also include these, usually negative, effects. As well as the probability of an attack, determining the impact will be expressed using selected sub-categories, which may vary depending on the specifics of the evaluated object. However, the generally valid - basic subcategories [5]. Which should be considered in each case are shown in Fig. 2 :

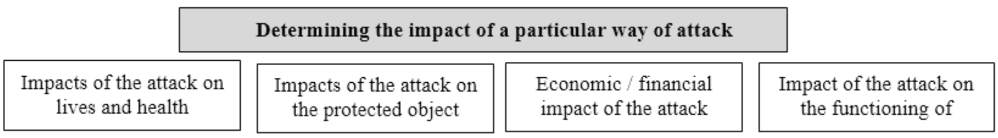

Fig. 2 Subcategories for estimating the impacts of a particular way of attack

These subcategories are again evaluated quantitatively - on a scale of 1 to 7. In many cases, the more precise determination of impacts depends on circumstances that cannot always and unambiguously be determined. The evaluator must therefore realize that the purpose of the threat assessment is not to obtain a table with the most accurate numbers possible, but rather to think about relevant way of attacks and to systematically identify soft target vulnerabilities [6].

Impacts of the attack on lives and health

When assessing the impact on lives and health, we focus on the number of people who may be affected by an attack in a given variant (at a certain time and place) and the severity of the consequences for the life and health of people. For the quantitative scale on a scale of 1 to 7, point 1 - means only psychological shock or. minimal injuries, on the contrary, but with a maximum evaluatio of 7 - these will be serious injuries and deaths of a larger number of people [5].

Impacts of the attack on the protected object

By assessing the impact on the building, we focus not only on the technical damage to the building, but also on the impact of the attack on the operation of the object and the possibility of resuming activities after the attack, especially with respect to damage to the building and disruption of services [7]. In the range of the quantitative evaluation scale on a scale of 1 to 7, point 1 -will be minimal to no damage to the building and operations, and opposite point 7 - will be the

complete destruction of the building, or. damage to its statics to such an extent that the object will no longer be able to operate.

Economic / financial impact of the attack

The impact on the economy has several levels. It is up to each entity whether to choose the assessment of the short-term impact associated with reconstructions, short-term limited traffic, etc., or whether it will take into account the long-term impact on traffic, economy and transport services of the affected site and many other factors. In this quantitative assessment, the need to adapt it to the specific reference object of the survey, the situation in the object and its immediate surroundings and the financial possibilities of its operator is particularly important.

With the selected scale 1 to 7, the point 1 means - represents either minimal or no impact, on the contrary, with the point 7 - it will be only the liquidation impact, which will terminate the further operation of the building in the long run [5].

Impact of the attack on the functioning of society

The evaluation focuses on the impact of the attack on the community immediately affected by the attack. It can be, for example a community of school which consist from pupils, teachers, other staff, or and parents. With regard to the focus of the contribution, it will be mainly the employees of the railway station and the people who were currently using the building as a boarding / alighting or transfer station. In the quantitative evaluation of scales 1 to 7, the point 1 - will have a minimal impact on society and its functioning, on the contrary, the point 7 - presupposes the termination of the activity of the affected entity or society [4].

In contrast to the probability calculation, the impact assessment for different types of soft targets will differ significantly. The resulting estimated value of the impact of the attack can be obtained by the sum of the expected values of the impact on lives and health, the object, the economy of the subject, the functioning of the object and society. The total estimated impact rate of a particular type of attack, therefore, can have a maximum value of 7 + 7 + 7 + 7 = 28 points.

Indicative scores according to Table 4 are used to evaluate the subcategories of the potential impact of the attack.

Table 4

Points evaluation of the quantitative scale subcategories of impact assessment [5]

Points	1	2	3	4	5	6	7
Impacts of the attack on lives and health	Shock, minor injury	Minimal injury to individuals	Minimal injuries to a large number of people	Serious injury to individuals	Serious injuries to a large number of people	Serious injuries to more people and deaths of individuals	Serious injuries / deaths of a large number of people
Impacts of the attack on the protected object	No possible minimal damage to the building or operation	Minor damage to the building or disruption of operation without limiting functionality	More serious damage to the object or disruption of the action without limiting functionality	Local restriction of the functionality of a room or part of an event	Limiting the functionality of a part of an object or part of an action	Extensive limitation of the functionality of the object or the possibility of operation	Destruction of the object or disruption of its statics without the possibility of its further operation
Economic / financial impact of the attack	No impact, or up to 500 €	Impact up to 5000 €	Impact in the order of tens of thousands of €	Impact over 500,000 € solvable by insurance	Impact over 1 million € unsolvable by insurance	Impact over 4 million € unsolvable by insurance	Impact economically liquidating
Impact of the attack on the functioning of society	No obvious impact on society	Weak impact at individual level	Minor activity restrictions	General fear of being active, greater restriction of activities	Real risk of endangering persons when participating in other activities	Temporary suspension of community activities	Termination of Community activities

2.3. Method of Calculation for Total Threat

The total threat level (T) is calculated using the mathematical relationship $T = P \times I$, where the variable P is the sum of all probabilities and the variable I is the sum of all impacts. In order to determine the overall threat level, we set, in addition to the resulting quantitative relationship, also semi-quantitative threat limits:
12-119 very low threat, 120-239 very low threat, 240-359 medium threat, 360-479 high threat, 480-588 very high threat.

3. Case Study - Zvolen Railway Station, Slovakia

To demonstrate the applicability of the above method of assessing the level of threat to a soft target, the Zvolen

railway station was chosen as the object of research. Fig. 2 shows the immediate surroundings, the interior, the entrances to the building, the tracks belonging to the track and the adjacent bus station.

Fig. 2 Railway station Zvolen, its interior, near surroundings, entrances

Based on the agreement and permission by superintendent of the Zvolen railway station were search of premises, the available safety documentation was analyzed and security incident records through the Checklist were identified problems and risks in the security of the station , guided interview provided practical suggestions and warnings about shortcomings in the security system of the building [2], etc. Based on the above activities and a personal detailed inspection of the building, its immediate surroundings and the current state of its safety, it was possible to carry out an expert point evaluation of the basic variables and their subcategories. When conducting a threat assessment, it is important to know, in addition to the sources of threats, also the relevant ways of carrying out the attack. The ways of attack may differ for individual specifics of the reasearch objects. For the evaluated object of the railway station, they were also with regard to the fact that they may occur or have already occurred several times in the premises of the railway station Zvolen, or were performed in its immediate vicinity or the following ways of attack, were chosen for a similar railway station in the Slovak Republic:

- attack with a cold weapon (stabbing, cutting, etc.);
- attack with a firearm (short, long);
- intentional arson;
- crowd attack on the object (eg violent gathering of ultras fans, etc.);
- imitation of explosive;
- fake notification of an explosive;
- explosive placed in a certain space;
- abduction of a person;
- verbal aggression with the possibility of physical attack in the vicinity of the building;
- physical assault without the use of a weapon;
- a suicide attack using an explosive.

Options for estimating the location of the attack:

- in the building - semi-public spaces (as the station spaces close from a certain hour) [6];
- in close proximity to the premises (eg entrances);
- in the vicinity of the building (eg near a car park, a park in front of a station, etc.).

Expected variants of attack timing:

- during daily operation, when the building is open to the public;
- at night during the closing of the station, when travel documents are not sold in the building and the interior of the station is closed to the public.

4. Evaluation Threat of the Research Object

The value of the variable probability and the variable impact can be calculated as the sum of the points within the individual subcategories characterized above. The total threat level of the object is then determined as the product of the sum of the points of the subcategories the probability of attack and the subcategories the impact of the attack variable. The results obtained by inspection, analysis of documentation and recorded security incidents, interviews with employees and security audit of the reference object of the railway station Zvolen were used to assess the level of threat and are in the event of a potential attack the most threatening for human health and lives, but also for railway station. (Table 5).

Table 5

Results of quantitative threat based on variables and their subcategories

Identification of potential ways of attack	Location	Timing	Evaluation		
			SUM probabilities	SUM impacts	Threat level
Cold gun attack	in the building	during daily operation	6 + 7 + 6= 19	4 + 4 + 2 + 3 = 13	19 × 13 = 247
	in close proximity	during daily operation	6 + 7 + 6 = 19	3 + 2 + 1 + 4 = 10	19 × 10 = 190
	in the vicinity	in night	6 + 7 + 6 = 19	3 + 1 + 1 + 4 = 9	19 × 9 = 171
Assault with a firearm	in the building	during daily operation	3 + 4 + 7 = 14	4 + 3 + 3 + 4 = 14	14 × 14 = 196
	in the vicinity	in night	3 + 4 + 6 = 13	4 + 1 + 1 + 4 = 10	13 × 10 = 130
Intentional arson	in close proximity	in night/ during daily operation	7 + 7 + 7 = 21	1 + 2 + 1 + 1 = 5	21 × 5 = 105
Crowd attack on the object	in the building	during daily operation	7 + 7 + 6 = 20	5 + 6 + 3 + 6 = 20	20 × 20 = 400
Imitation of explosive	in close proximity	during daily operation	7 + 4 + 7 = 18	1 + 2 + 3 + 6 = 12	18 × 12 = 216
	in the vicinity	during daily operation	7 + 4 + 7 = 18	1 + 2 + 2 + 6 = 11	18 × 11 = 198
	in the building	in night / during daily operation	7 + 4 + 7 = 18	1 + 6 + 3 + 6 = 16	18 × 16 = 288
Fake notification of an explosive	in the vicinity	during daily operation	7 + 5 + 7 = 19	1 + 5 + 3 + 6 = 15	19 × 15 = 285
Explosive placed in a certain space	in close proximity	in night / during daily operation	7 + 6 + 7 = 20	7 + 6 + 5 + 6 = 24	20 × 24 = 480
Kidnapping of a person	in the vicinity	during daily operation	5 + 2 + 4 = 11	4 + 1 + 1 + 4 = 10	11 × 10 = 110
Verbal aggression with the possibility of physical attack	in the building	during daily operation	7 + 7 + 7 = 21	5 + 2 + 1 + 3 = 11	21 × 11 = 231
	in close proximity	in night / during daily operation	7 + 7 + 7 = 21	5 + 1 + 1 + 3 = 10	21 × 10 = 210
Physical assault without the use of a weapon	in close proximity	In night / during daily operation	7 + 7 + 7 = 21	4 + 1 + 1 + 4 = 10	21 × 10 = 210
	in the building	during daily operation	7 + 7 + 7 = 21	4 + 2 + 1 + 4 = 11	21 × 11 = 231
Suicide attack using an explosive.	in the building	during daily operation	3 + 2 + 7 = 12	7 + 6 + 3 + 6 = 22	12 × 22 = 264

We determined the calculation of the total risk level on the basis of the calculation in subchapter 2.3. From the results of the semi-quantitative determination, it is possible to evaluate that the probable attacks will most often have a low threat for the investigated object. According to the examination, the medium risk of potential attacks, is not an exception for this reason, so it is necessary to take protective measures, which should aim to improve this current state of protection. Very high threat and high threat came to us only two separate potential attacks.We get very high threat level and high threat only in two separate potential attacks. Prevention of possible potential attacks of various kinds is a matter which needs to be given special importance. In order to be able to effectively protect the object from an economic, social, material or other point of view, it is necessary to determine the priority of individual attacks.

After evaluating the results, the following measures were proposed to the railway station management:

- regular patrol from the city police in the vicinity of the railway station during the day and a continuous inspection of the surroundings between 0 and 6 am;
- video surveillance system for the entrances to the railway station [8], which will be connected to the monitoring desk of the centralized protection of the city police;
- higher involvement of the railway police in the areas of the track and railway underpasses;
- abolition a gambling facilities (at least listed near the railway station) according to the example of other places in the Slovak Republic, which abolished this type of gainful business activity in their scope;
- solving the issue of inadaptable citizens from apartment buildings in the vicinity of the railway station at the level of the city of Zvolen, the Banská Bystrica self-governing region and the Higher Territorial Unit.

5. Conclusions

On soft targets and particular transport objects have been attacked more and more frequently last recent years, mainly by metro or railway stations. In the conditions of the Slovak Republic, such an attack has not yet been recorded, but there have been several serious events abroad associated with attacks on transport infrastructure and its facilities. Based on the application of the methodology for the assessment of the threat to soft targets [5] and its subsequent modification and application to the selected reference object of the railway station Zvolen, it is possible to say several conclusions. The most risky potential attack on the station object was identified attack by an explosive placed in a specific area. Such an attack can also be carried out by an individual who does not need additional weapons, acts alone, usually with the aim of maximizing damage to health, lives or destruction or long-term restriction of operation, services and activities of individual facilities. The building can only implement building protection concepts and positions of inputs and technical means so as to minimize the effects and consequences of this type of attack. Similar attacks are very difficult to predict not only in terms of time but also in space, (places of attack).

Another way of attack with a high probability and impact was the attack of the object by a crowd. This case has occurred several times in the past when moving hockey fans from Banská Bystrica from or to a railway station, especially when confronted with home fans. Other threats, such as verbal attacks with a potential escalation into a physical attack, physical attacks without a weapon, attacks with a weapon are to some extent frequent and primarily specific to the object chosen by us because in the past there were several outbreaks of crime in its vicinity (game room, housing estate with inadaptable citizens). However, these usually do not endanger the building or its functionality and operation.

Acknowledgments

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Piston Pneumatic Engine – Preliminary Research

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Abstract

The restrictions in emission standards which are introduced for a longer time have been defining the primary direction of development in the automotive industry. Manufacturers compete in developing innovative solutions to reduce emission or usage of alternative sources of propulsion to power the vehicles. One of the least developed propulsion systems are the pneumatic drives. The paper presents the preliminary researches of a pneumatic engine developed by the conversion of a two-stroke internal combustion engine. The components allowing to modify the compression ratio were made as well. The original engine dynamometer constructed for testing purposes, dedicated to low power units, was described. The engine adjustment characteristics were determined for different supply pressures. For the purpose of identifying the external parameters, speed characteristics for the different compression ratios were determined and compared with respect to each other. The obtained results demonstrated the validity of modifying the compression ratio. Load characteristics were also drawn up, by determining the ratio of the volumetric flow rate of air supplying the engine to the obtained power. The torque in the best of the examined cases was similar to the serial value, however, it occurred at a lower rotational speed. A significant decrease in the engine power was observed. Preliminary tests indicated that further research is necessary regarding the realisation of the variable engine compression ratio in order to cope with the temporary power demand.
KEY WORDS: *mechanical engineering, pneumatic engines, testing*

1. Introduction

Over the past several years, the main trend in automotive development is striving to reduce fuel consumption and emissions of harmful substances. Manufacturers compete in developing new systems and solutions to ensure lower fuel consumption and thus lower level of emissions, while maintaining or improving performance parameters. Mainly it is caused by the continuous tightening of the exhaust gas emission standards [1, 2], as well as the introduction of new, increasingly accurate test procedures World Harmonized Light Vehicle Test Procedure (WLTP) and Real Driving Emissions (RDE) [3, 4]. The automotive companies adopt various strategies in order to comply with the approval requirements [5-11]. Systems such as SPCCI (spark controlled compression ignition) prove that it is still possible to work on improving the efficiency of the internal combustion engine [12]. The use of the particulate filters for spark-ignition engines also became increasingly common [13]. A separate group of emissions issues are engines of working machinery and non-road vehicles [14, 15].

Despite this, the most popular solutions are hybrid systems, which combine the combustion engine with the electric motor that supports it [16]. This type of drives are available from a majority of the manufacturers. Some of the companies launched work on the use of the fuel cells to power vehicles [17, 18]. Less popular combination of the drive is a hybrid system using a combustion engine and a pneumatic engine [19-21], works on the development of this technology are still underway.

The first records of the pneumatic engine used to power a vehicle are from the late 19th century. Over the years, many concepts for engines powered by compressed air were presented, the main ones being vane engine [22, 23], rotary engine [24], piston engine [25, 26], unconventional engine [27]. Nowadays, only few commercial companies offer drives units powered by compressed air [28, 29]. In a economic or functional aspects, they are fully comparable with the electric drives [30]. In terms of the ecology, they transfer emissions directly from the vehicle to the place where the compressed air is produced. It is important to note that the compressed air is used for many other applications, including powering machines and equipment in production plants, which allows existing networks to be used for filling the tanks.

To determine the external parameters of pneumatic engines, usually the methods used for combustion units are applied [31]. The basic assessment criterion is the engine speed characteristics presenting the dependence of indicators such as power output and torque from the engine speed. This enables to know the course of the torque curve, which among other things allows to evaluate the elasticity of the engine. In addition, for research purposes, the load, adjustment and idle speed characteristics are determined. In an internal combustion engine, the load characteristics describe the dependence of the fuel mass flow rate and Brake-Specific Fuel Consumption (BSFC) from the engine

power at a constant engine speed. In the case of a pneumatic engine, the Brake-Specific Fuel Consumption is replaced by the Brake-Specific Air Consumption (BSAC) indicator [32], which is the ratio of the mass flow rate supplying the engine and the engine power. Using the adjustment characteristics, it is possible to determine the influence of the selected adjustable parameter on the examined indicator. An example can be the dependence of the composition of the supply mixture in relation to the engine power. In turn, for a pneumatic engine, it may be a dependence of the rotational speed from the engine supply pressure.

2. Subject of the Research

The engine from the Romet 50 T-1 moped was selected as the research object. It is a single-cylinder, two-stroke construction with the engine displacement of 49.8 cm^3 [33]. The base engine parameters were presented in Table 1. In order to adapt the engine to the compressed air supply, a series of design changes were made, described in detail in [34]. The primary problem in modifications of this type of propulsion units is to ensure fuel dosage at the appropriate timing due to the lack of a valve timing system. For this purpose, the described solution used valve *8* in Fig. 1 screwed in place of the spark plug, opening of which is forced through a pin attached to the piston *7*. The valve is built from a ball, which is pressed against the valve seat by the engine supply pressure, and a perforated pipe which is used as a guide. As the piston approaches the Top Dead Centre (TDC) position, the pin presses on the ball in the valve, displacing it and simultaneously resulting in a gradual opening of the valve. During the piston return movement, the valve is closed as a result of the air pressure acting on the ball. The valve lift can be adjusted to a small extent by screwing it in or out of its seat in the head. The advantage of this solution is a simplicity of design, while the disadvantage is the symmetry of supply in a relation to TDC. This causes a phenomenon of compression of the air that enters the cylinder. The original supply system using the carburettor was removed, and the intake channel was blinded *6*. Additionally, it was necessary to blind the scavenging ports in cylinder *5*, and to ensure lubrication of bearings *1* of the crank-piston system *2* and *3* using hole *4*. Custom plates were also made, mounted between the cylinder head and the cylinder in order to change the engine compression ratio. The power supply is regulated by valve *9* providing air from the tank *10*.

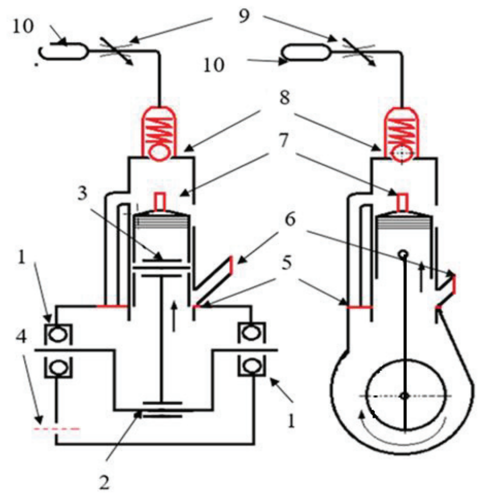


Fig. 1 Diagram of the engine modification range [34]

Table 1

The basic engine technical data [33]

Parameter	Value
number of cylinders	1
type of engine	two stroke
displacement	49.8 cm^3
bore / stroke	38 mm / 44 mm
compression ratio	8:1
max. power at rotation speed	1.84 kW at 5200 r./min
max. torque at rotation speed	3.5 N·m at 4500 r./min

3. The Test Stand

Experimental tests were conducted on an engine dynamometer (Fig. 2) created for the purpose of testing a low power engines [34]. As a load generating element, drum brake *1* was used. The brake drum was fixed to the dynamometer shaft, which in turn was connected to the engine crankshaft. To the brake base, on which the brake shoes were attached, rod *2* was mounted, acting on a weight *3* (measuring range up to 0.5 kg, accuracy 1 g). During the engine

operation, the brake drum rotated together with the crankshaft.

As a result of brake application with the brake cable tensioning mechanism, the brake shoes exerted pressure on the drum, thus generating braking torque on the engine. The moment also acted on the base with the rod at the end of which the pressure on the weight was measured. From the pressure on the weight, the force was calculated and then, knowing the length of the bar, the torque generated by the engine was calculated. The engine speed was read using a Hall effect speed sensor *4* (measuring range 5-9999 r./min., accuracy ±3 r./min.) which uses a magnet mounted to the brake drum. Apart from the dynamometer, the test stand consisted of a pneumatic system whose function was to ensure appropriate, adjustable engine supply conditions. For the purpose of enabling the adjustment of the air pressure of the engine supply, a pressure regulator and a pressure gauge *5* were used. For flow rate measurement the Bronkhorst High-Tech F-106BI *6* flow meter was used (measuring range up to 500 m^3/h, accuracy ±1% FS). Tests were performed using measurement card *7* and laptop *8* with dedicated software. Pneumatic system hoses before and after the flow meter were selected in order to avoid pulsating phenomena.

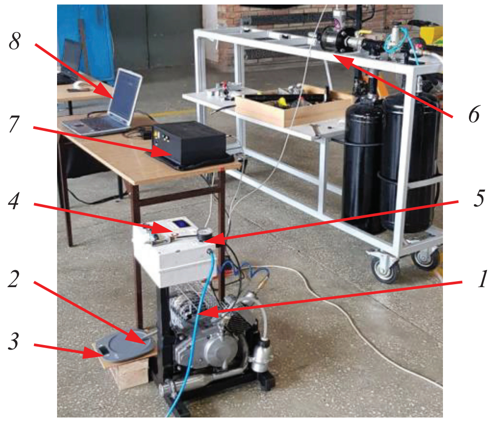


Fig. 2 The test stand

4. The Test Results and discussion

In the first stage of the research, the engine adjustment characteristics at a different pressure of the air supply were determined. The purpose of this test was to determine the appropriate supply pressure for conducting subsequent tests. Each time supply pressure value was determined and it was expected for the engine speed stabilization. Analysing the research presented in [32, 34] the decision was made to use custom plates under the cylinder head changing the compression ratio to $\varepsilon = 7.04$. The obtained results (Fig. 3) indicated that the rotational speed increases with the increase of the supply pressure. Attempts below 4e5 Pa and above 7e5 Pa were not recorded due to incorrect operation of the engine within these pressure ranges.

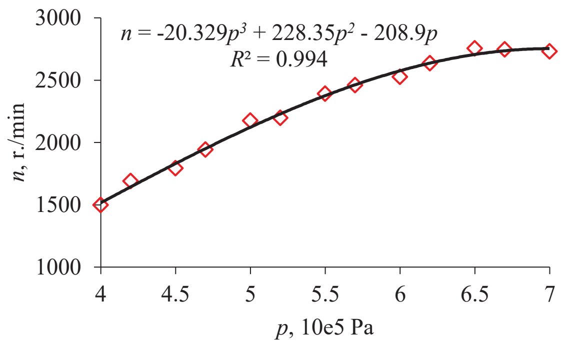


Fig. 3 Adjustment characteristics of pneumatic engine

The character of rotational speed changes (Fig. 3) was approximated using non-linear regression, the least squares method and the function of 3rd degree polynomial, obtaining determination factor $R^2 = 0.994$. On the basis of the coefficients of polynomial, it is possible to conclude about the character of rotation speed changes in respect to supply pressure. The maximum rotation speed was $n = 2731$ r./min for supply pressure $p = 7e5$ Pa.

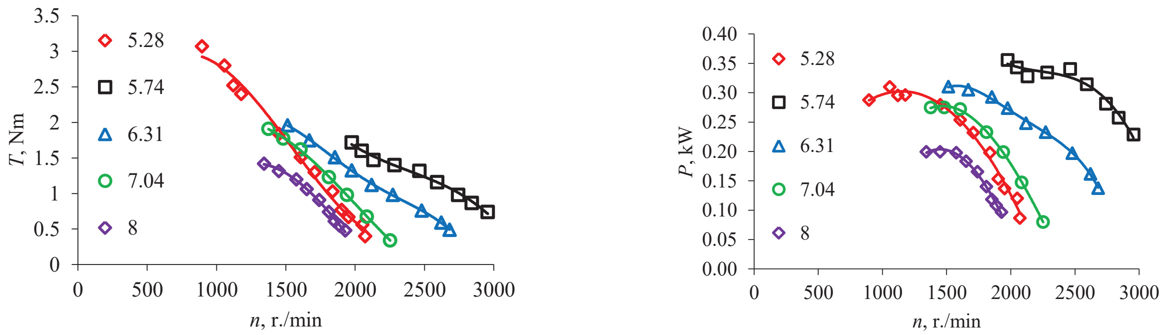
Subsequent tests were aimed to determine the speed characteristics of the pneumatic engine. Decision was made to test the engine at the highest supply pressure value, i.e. 7e5 Pa, at which the engine operated steadily. Additionally, the compression ratio ε was adjusted. Changes in the compression ratio were achieved using custom plates mounted between the cylinder head and the cylinder of the engine. Each time the height of the valve lift was adapted through regulation of the appropriate threaded connection tightening angle to maintain the same timing phases. The resulting compression ratio depending on the number of used custom plates is shown in Table 2.

Table 2

Dependence of the compression ratio on the number of custom plates

Number of plates	1	2	3	4	5
Compression ratio ε, -	8.00:1	7.04:1	6.31:1	5.74:1	5.28:1

The procedure during the test was the same every time. The supply pressure was established up to the specified value of 7e5 Pa, then using the brake, successive rotational speeds were obtained. The measurement was realized in the direction of increase and decrease of rotational speed, and in Fig. 4 average values were presented. When the engine operation was not stable, the measurement was interrupted and these points were not included in the characteristics.



a b

Fig. 4 Received speed characteristics of pneumatic engine for different compression ratio

The tests showed the highest operating speed range with compression ratio $\varepsilon = 5.28$. However, in this case the engine did not run stable. The most stable operation of the engine was with $\varepsilon = 7.04$. In other cases, it was difficult to establish a rotational speed below 1500 r./min. The engine obtained the greatest power with $\varepsilon = 5.74$ and the highest torque with $\varepsilon = 5.28$. The high torque value was a result of the lower rotational speed values achieved by the engine. The obtained speed characteristics demonstrate that, in the case of pneumatic engines, with increasing rotational speed, its operating parameters significantly deteriorate. It is consistent with the results of the mathematical modelling presented in [32]. The maximum torque value $T_{p\max} = 3.07$ N·m was obtained for a configuration with a compression ratio of $\varepsilon = 5.28$. Compared to a torque value of $T_{p\max} = 3.50$ N·m for the base combustion engine, this value is 12.3% lower. The maximum torque for the pneumatic engine occurred at $n_{Tp\max} = 894$ r./min, which is significantly lower than for the combustion engine $n_{Tc\max} = 4500$ r./min. The maximum power was obtained at a compression ratio $\varepsilon = 5.74$ and was $P_{p\max} = 0.36$ kW, which relative to the power of the combustion engine $P_{c\max} = 1.84$ kW was 80.4 % lower. In this case, again, the rotational speed was decisive factor, which for the pneumatic engine was $n_{Np\max} = 1975$ r./min, and for the combustion engine $n_{Nc\max} = 5200$ r./min.

Due to the fact that with a compression ratio of $\varepsilon = 7.04$, the engine operated most steadily this value was used to determine the load characteristics. The test speed was set to $n = 1500$ r./min, as it corresponded approximately to the maximum power. In this case, the test consisted of changing the engine load with maintaining constant rotational speed. A torque was read and then power was calculated using the rotational speed. In turn, the value of mass flow rate was determined using the Bronkhorst High-Tech F-106BI flow meter. The subsequent step was the determination of the value of the Brake-Specific Air Consumption (BSAC) parameter from Eq. 1:

$$\mathrm{BSAC} = \frac{Q}{P}, \tag{1}$$

where Q – volumetric flow rate; N – power.

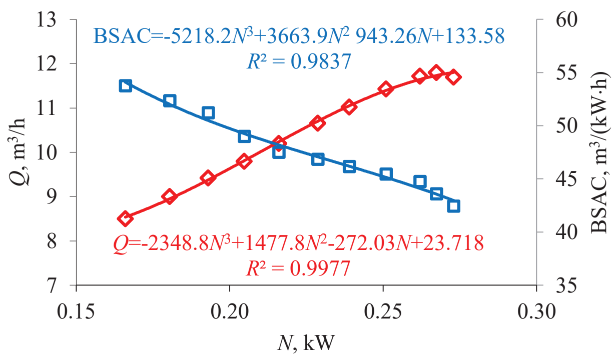


Fig. 5 Received load characteristic of pneumatic engine

Similarly to the regulatory characteristics, the variability of load characteristic parameters (Fig. 5) was approximated using non-linear regression, the method of smallest squares and the function of 3rd degree polynomial, obtaining the coefficient of determination $R^2 = 0.994$. The mean of the volumetric flow rate was $Q = 10$ m^3/h, which gives an average BSAC = 48 m^3/(kW·h).

Analysing the test results, it is important to note that the maximum engine speed was relatively low for the speed and adjustment characteristics. Mostly it is caused by problems with air dosing due to the reduced filling time of the cylinder at higher rotational speeds. In the low rotational speed range, the symmetry of the inlet valve with respect to the TDC generated a counter-pressure in the cylinder, which increased the resistance in the compression stroke. It can be prevented by using the solenoid valve [32], or by using a valve with piezoelectric transducer [35, 36]. The flow properties of valves, including prototype ones, can be initially determined using CFD (Computational Fluid Dynamics) [37], eventually using indirect dynamic methods [38]. In the course of the research, a problems with movement resistances resulting mainly from the friction process was found. In case of considering the possibility of using new friction pairs in pneumatic engine systems, the methods presented in [39] may be used to assess friction.

5. Conclusions

The presented research demonstrates that pneumatic engines can be an alternative to the other sources of propulsion. The minor modification range needed to adapt the engine to this type of power supply is an additional advantage. The engine dynamometer developed for the purposes of researches allowed to determine the fundamental characteristics of this type of engine. The conclusions are as follows:

1. The maximum rotational speed of the pneumatic engine was 2731 r./min. for a supply pressure value of 7e5 Pa, at compression ratio 7.04.
2. The highest torque value obtained with the compression ratio of 5.28 was 3.07 Nm, which is 12.3 % less than in the combustion engine. The maximum torque occurred at 894 r./min versus 4500 r./min for the combustion engine.
3. The maximum power of 0.36 kW was obtained with a compression ratio of 5.74, which is 80.4 % lower value than in the base combustion engine. In this case again, the rotational speed was lower, it was equal 1975 r./min compared to 5200 r./min for the combustion engine.
4. The mean of volumetric flow rate was 10 m^3/h which gives an average BSAC value of 48 m^3/(kW·h).

More detailed study of the impact of the supply conditions may allow to improve the obtained parameters. Moreover, a change in the design of the air dosing element (valve) shall be considered in order to obtain greater possibilities of controlling the opening time or supply phases. This might also enable an increase in the supply pressure range at which the engine operates correctly.

Acknowledgment

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System Model of Information Flows in Networks of the Electric Supply System in Transport Infrastructure Projects

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Abstract

The power supply system in transport infrastructure projects, namely railways and subways, requires constant monitoring of network operation to display information links between system components and facilities. Monitoring is carried out constantly in real time, as there is a need to capture large amounts of information from sensors, this requires a large amount of memory and the complexity of its analysis. Due to which we obtain primary data that reflect the processes of mode to pre-emergency, emergency and post-emergency. The development of a system model will allow to register primary information that reflects synchronously temporal processes pre- abnormal, abnormal, post- abnormal, as well as ways to organize synchronously recorded primary data and ways to form them into a single information space from the system general point of view. Based on models, methods and techniques, there is a possibility of modern computer monitoring, namely the formation of management decisions that will affect its object, along with the functions of analysis and processing of collected data. Therefore, studying the system model of information flows in the networks of the power supply system under such conditions, namely the organization of monitoring, it should be considered from a system-wide point of view within a single information space of the power supply system in transport infrastructure projects.
KEY WORDS: *information, methods, monitoring, project, system model, computer network, energy-saving technologies*

1. Introduction

Today, dictates completely new requirements for the management of processes in production, as well as the analysis and processing of information from the means that directly participate in the process. Therefore, there is a need monitoring of systems, which is an integral part of the processes of automated control of production and technological processes. Therefore, for the processes of electricity supply of the power supply system in transport infrastructure projects there is a need to capture a large amount of information from devices, which requires a large amount of memory and the complexity of its analysis and processing [1]. The complexity of the analysis and processing is that the processes of electricity supply of the power supply system of the subway and railway transport have a number of features. Namely, the information, as a result of the monitoring process, which comes from the sensors, in terms of analysis of abnormal modes of the power supply network, are primary data that reflect the modes of operation of the power supply network: pre-emergency, emergency and post-emergency. As a result, there is a need to develop models and such methods of continuous monitoring, through the use of which the registration of primary information is realized, which reflects synchronously over time pre-abnormal, abnormal and post- abnormal processes.

The process of monitoring the state of the power supply network in transport infrastructure projects, namely in the framework of railway transport and subway projects, which we will consider, is carried out continuously over time.

2. Research of Information Flows in Power Supply Network Networks

Recently, due to the expansion of the scope of microprocessor devices in intelligent energy, there is a tendency to consider the functions of monitoring and control as a whole. For example, in [2], based on the fact that the basic concept

of monitoring in all branches is "monitoring the state of the object for management purposes", the authors introduced the definition of "monitoring in electricity" and noted that this concept should include assessment object and its forecasting, which is already one of the management functions. Therefore, it is better to consider the monitoring system and the automated process control system in a complex. As an object of monitoring and control we will consider any device involved in the intelligent power supply network, technological processes occurring in it, processes that have a significant impact on them, as well as the power supply network in transport infrastructure projects in general [3, 4].

To solve some problems of intelligent energy requires the processing of primary data, which will allow on the basis of the found relationships to build models that can describe the features of the functioning of power supply systems in transport infrastructure projects.

According to the results of the monitoring process, the primary data recorded at the outputs of sensors of the power supply network and power equipment of traction substations, as well as relay and microprocessor protection systems of different segments of the electrical complex of the power supply network in transport infrastructure projects can be submitted in analog A_e and discrete D_e forms.

Based on this, we build a model of input data (1):

$$W(t) = \alpha_1(t), \alpha_2(t), \dots \alpha_n(t), \tag{1}$$

where $\alpha_1, \alpha_2, \dots \alpha_n$ – monitoring objects.

$$a_1(t) = \{(A_{e1}(t)), (D_{e1}(t))\}; \tag{2}$$

$$a_2(t) = \{(A_{e2}(t)), (D_{e2}(t))\}; \tag{3}$$

$$a_n(t) = \{(A_{en}), (D_{en})\}, \tag{4}$$

where $A_{e1} \dots A_{en}$ – the set of analog signals provided by the monitoring system; $D_{e1} \dots D_{en}$ – a set of discrete signals provided by the monitoring system.

$$A_e = \{I^*_{ze}, U^*_{ze}, A^*_{ze}\}; \tag{5}$$

where

$$I_{ze}^{\ *} = \Phi^i_{ze}\left(I^{pr}_{ze}, I^{em}_{ze}, I^{ps}_{ze}, t, q, K^i_{ze}, T\right); \tag{6}$$

$$U_{ze}^{\ *} = \Phi^u_{ze}\left(U^{pr}_{ze}, U^{em}_{ze}, U^{ps}_{ze}, t, q, K^u_{ze}, T\right); \tag{7}$$

;

$$A_{ze}^{\ *} = \Phi^A_{ze}\left(A^{pr}_{ze}, A^{em}_{ze}, A^{pt}_{ze}, t, q, K^A_{ze}, T\right); \tag{8}$$

$$D_{ze}^{\ *} = \Phi^D_{ze}\left(D^{pr}_{ze}, D^{em}_{ze}, D^{pt}_{ze}, t, q, K^D_{ze}, T\right), \tag{9}$$

where I^{pr}_{ze}, U^{pr}_{ze}, A^{pr}_{ze} – data of the pre-emergency state of the network; I^{em}_{ze}, U^{em}_{ze}, A^{em}_{ze} – data of the emergency state of the network; I^{ps}_{ze}, U^{ps}_{ze}, A^{ps}_{ze} – data of the post-emergency state of the network; K^i_{ze}, K^u_{ze}, K^A_{ze} – data of the instant state of the network; q – number of discrete for the period T; z – power supply network feeders.

As a result, we obtained a model of a single information space of the parameters of the modes of railway power supply networks (4).

Discrete and analog signals are data that are recorded in time instantaneous values of current, voltage or any other parameters that are registered by an extensive system of sensors and are of interest for solving a specific control problem.

When the normal mode of operation of the power supply system is disrupted, abnormal processes proceed at such a speed that it is impossible to stop them by personnel intervention, which is why there is a need for intelligent diagnostic systems.

The processed data carry information value, which is no longer data, but information.

The huge amount of information accumulated in knowledge bases can be useful in solving various management tasks. This requires effective means of comprehensive analysis of the collected data and finding patterns in them. This task due to its complexity requires modern information processing technologies.

For effective monitoring of the state of the power supply system network in metro and railway transport projects, it is advisable to use a distributed database and queries with a relational control system. In Fig. 1 shows a model of a system for collecting and processing information about network emergencies.

The peculiarity of this model is that it contains a subsystem for handling types of emergencies. Data processing is carried out in the regional database. Peripheral databases play the role of intermediate drives.

We see in Fig. 1 that the central table of the database and queries, and the peripheral tables of the database of each of the fragments are variable. They are, firstly, promptly created and filled with data coming from the elements of the database of the monitoring system Second, according to the results of processing, in accordance with the established algorithms, the modernization of these tables. Commands to execute shaping decisions can be generated automatically. However, the operator of the information collection center can always make his adjustments and send a priority team to the database of the monitoring and diagnostics system of the power supply system in transport infrastructure projects.

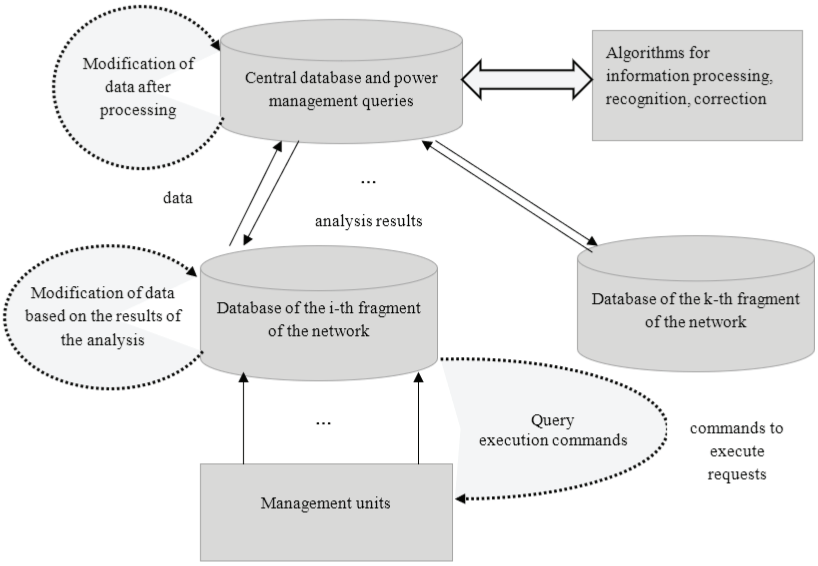

Fig. 1 A model of a system for collecting and processing information about network emergencies

The data in the repository is integrated into a single structure at different levels of detail, which provides the user with the necessary degree of generalization of information. In this concept, the main place is given to data. The repository also contains the results of information conversion, summarization and verification [5], which is the basis of data mining technology. The technology allows knowledge discovery in databases (KDD) and is included in the concept of information data warehouses and organization of intelligent computing, which is the basis for the creation of intelligent systems for monitoring and diagnostics of power supply systems in transport infrastructure projects.

KDD consists of data analysis processes, as well as detection algorithms, which, within acceptable limits of computational efficiency, create a list of templates (or models).

The step-by-step application of KDD to power supply management knowledge bases in metro and railway transport projects is conditionally shown in Fig. 2. The KDD process is interactive and iterative, including numerous steps with many user-made decisions.

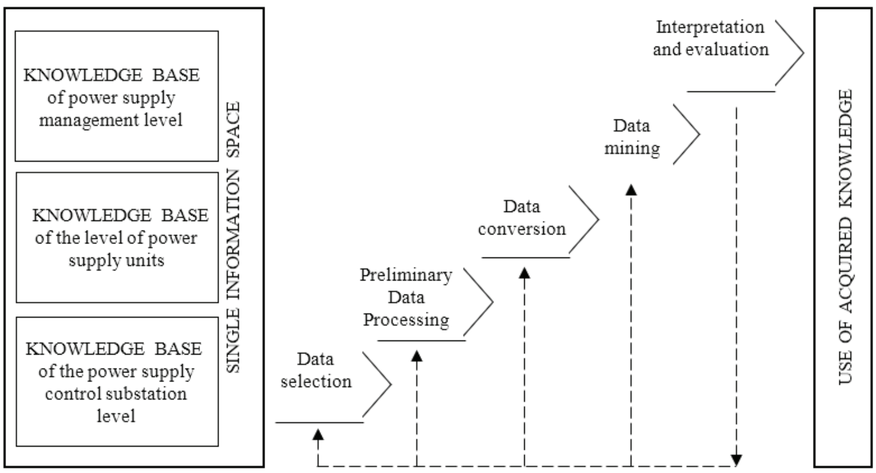

Fig. 2 The KDD process in knowledge bases of information space of power supply process in transport infrastructure projects

The use of classical methods of information processing, although not lost relevance, and narrow specialization does not allow them to be effectively used to solve problems of processing knowledge bases of power management units in transport infrastructure projects.

With the development of computer technology, a group of data mining (DM) technologies is gaining popularity,

which previously did not have wide practical application due to the large number of calculations required to perform algorithms. The increase in the computing power of processors has eliminated the gravity of this problem. Now a qualitative analysis can be performed in a reasonable time [6, 7], which is extremely important in emergencies that occur in the network of electricity supply to rolling stock [8-9]. The user, in our case the dispatcher or operator, can significantly help the data mining method by correctly following the previous steps.

The accumulation of a large amount of retrospective information was the impetus for the development of intellectual analysis, which is the basis for the construction of intelligent systems for monitoring and diagnostics of the power supply system in railway and subway projects.

Once new elements and aspects of data are identified, the approach to identifying data sources and formats and then comparing this information with a particular result may change. The more the user processes data, builds models, evaluates results, the better the result can be. Working with data becomes more efficient when the integration of such components is possible: visualization, graphical tools, query tools, operational analytical processing that allows you to understand the data and interpret the results and the algorithms that build models.

3. Conclusions

Prediction and description in practice are the main tasks of DM, the goal of which can be achieved by key means of DM, such as: classification, clustering, modeling of dependencies, regression, summarizing, identifying changes and deviations.

In any DM algorithm, there are three main components: the representation model, the estimation model, and the search.

The representation model is the language for describing the detected patterns. If the presentation is too limited, the exact model for the data cannot be presented, regardless of the amount of training time and examples.

The criteria for the evaluation model are quantitative judgments about how well a particular template (model and its parameters) meets the objectives of the KDD process. For example, forecasting models are evaluated by a test set for empirical forecasting accuracy; descriptive - in terms of prognostic accuracy, novelty, usefulness and clarity.

The search component in DM consists of parameter search and model search. Once the representation model and evaluation model criteria are normalized, the DM problem is reduced to the optimization problem: to find the parameters and models that optimize the evaluation criteria. The parameter search algorithm should look for parameters that optimize the evaluation model criteria, taking into account the observed data and the representation of the normalized model.

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Design of Sliding Frame System for Two-Wheeled Vehicle

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Abstract

The article deals with the initial design of a system for changing the adhesive force of two-wheeled vehicles. The system is designed for light off-road motorcycle KTM 250 SX-F. The purpose of the system is to allow the adhesive force transmitted between the motorcycle wheels and the road to be changed. The system allows the motorcycle rider to move the motorcycle at the stability limit at 'safe' speed. Both from the forward and especially the transverse direction. It also prevents damage to the rider's health and motorcycle if the limit value is exceeded. The system is designed as two hydraulically operated frames, one for the front and the other for the rear motorcycle wheel. The change in adhesive force is controlled by reducing the radial response transmitted by the motorcycle wheels. Depending on the desired situation, it is possible to simulate a reduction in adhesion by any value independently for the front or rear wheels or together for both wheels. A pair of drop frames comes into operation in the event of exceeding the limit state of the motorcycle in terms of transverse stability. They are individually placed on the sides of the motorcycle.
The use of the system is for the purpose of enhancing the skills of the rider for the purpose of becoming accustomed to the motorcycle. The rider will check the limit of the motorcycle without harmful consequences and thus gain important experience for safe movement on the road. In this way, it is possible to increase road safety indirectly. The paper aims to implement an initial design of a system enabling to change the adhesive conditions of a motorcycle so that when driving on an asphalt surface, it would allow simulating driving on a surface with reduced adhesion, such as wet asphalt.
KEY WORDS: *motorcycle frames, tires, adhesion, SkidMotorbike*

1. Introduction

With the growing number of road vehicles, current cities face the problem of limited parking options. At the same time, car occupancy is very low, averaging 1.8 people per car [6, 15]. One of the possible solutions is to use motorcycles as a means of transport. Along with the improving economic situation, many people buy a motorcycle as a means of spending free time. Motorcycle manufacturers address this trend by investing an increasing amount of money on the development of two-wheeled vehicles [4]. Despite this fact, it is still necessary to pay attention to the area of increasing the safety of these road users. After pedestrians and cyclists, motorcyclists are another group of the most endangered road users. The safety of two-wheeled vehicles can be enhanced by innovating the materials, construction, and implementation of new electronic systems [3, 5]. The second option is to increase the driving skills of motorcyclists. Both of the options should be initially implemented under conditions outside real road traffic [10, 12]. Electronic systems can be developed in laboratories and virtual reality, and subsequently tested. Driving skills can be improved on simulators. This is basically a model of reality [7, 8], which is more or less different from it. Therefore, this article discusses the possibility of increasing the ability of motorcyclists to control their machines. Excessive speed is a critical element that leads to the most common causes of a motorcycle accident. Due to the high speed and inexperience of the driver, the limit of stability of the motorcycle is exceeded, resulting in a skid. Skidding very often leads to a fall with an injury, at best only with damage to property. In many cases, experienced motorcyclists can prevent the fall in a marginal situation by timely and adequate intervention in the steering of the motorcycle. For the driver to intervene in time and to the correct extent, it is necessary to have maximum experience with the driving of the motorcycle.

Due to the initial design of the new system, we will use model conditions. The change of the adhesion force can be realized by reducing the coefficient of adhesion by using special tires [1, 2] or a special surface [11, 14]. The second option for reducing the adhesion force between the motorcycle wheel and the road is to reduce the radial reaction on the motorcycle wheels. This reduction can be achieved utilizing a frame with additional wheels as used in road vehicles [6, 13].

The SkidMotorbike subframe is an additional device that is intended for retrofitting to a motorcycle. The device makes it possible to reduce the radial reaction on a motorcycle wheel. From this principle, the wheels of the motorcycle can transmit a smaller maximum longitudinal and transverse force in contact between the tire and the road. Thus, the motorcycle reaches the limit of adhesion sooner at a lower, so-called safe speed. The SkidMotorcycle system allows changing the adhesion force, according to current requirements, even while riding the motorcycle. With the SkidMotorcycle frame, riders can learn from the very beginnings about motorcycle control to simulations of more demanding maneuvers without damaging the motorcycle or significantly endangering their health.

The paper proposes a design of an additional sliding frame used in a motorcycle. The design was created in the 3D CAD program SolidWorks. The purpose of the SkidMotorcycle frame is to create reduced adhesive conditions so that the

motorcycle moves at the limit of stability while going at a safe speed. The primary intention of the frame is to verify the stability of the motorcycle behavior and, at the same time, to have the rider get used to the motorcycle to know how the motorcycle behaves before reaching the limit state without the risk of damage to health or property. The SkidMotorcycle was designed for a motocross motorcycle, KTM 250 SX-F.

2. Materials and Methods

The essence of the change in the adhesion force F_{ad} lies in the reduction of the radial reaction Z_k, transmitted by the motorcycle wheels to the road [6]. This is done using a subframe for the front and rear wheels. When the radial reaction is reduced, the maximum adhesion force transmitted by the motorcycle is reduced, which is given by a simple formula (1), where φ is the coefficient of adhesion.

$$F_{ad} = Z_k \cdot \varphi \, . \tag{1}$$

The transverse skid of the motorcycle was chosen as the limit state. The skid occurs when the transverse force is greater than the lateral force transmitted between the tire and the road [6]. The magnitude of the contact force is given by the vector of the maximum adhesion force. In a double-wheel vehicle, the change of direction is caused not only by turning the steering wheels, as in a four-wheel car but especially by tilting the motorcycle about the axis connecting the front and rear wheels contact surface center of gravity. Therefore, the magnitude of the motorcycle lateral adhesion force when cornering is given by Eq. (2).

$$F_{ad_y} = \left(G \cdot \cos\beta + F_o \cdot \sin\beta \right) \cdot \varphi, \tag{2}$$

where F_{ad_y} – side force; F_o – centrifugal force, G – gravity of the vehicle; φ – coefficient of adhesion; β – slant slope of motorcycle.

Before designing the construction of the sliding frame, the basic dimensions of the motorcycle, which are necessary in terms of clamping to individual parts of the motorcycle and possible spatial arrangement of the SkidMotorcycle, were first established. The basis was the track width, front and rear wheels dimensions, wheel axles dimensions, motorcycle frame size, swingarm dimensions, and front shock absorbers. Subsequently, the motorcycle model was assembled. The motorcycle frame was modeled in a simplified form with a primary emphasis on the location of the sliding frame anchor points to the motorcycle frame. The resulting model of the motorcycle key parts can be seen in Fig. 1.

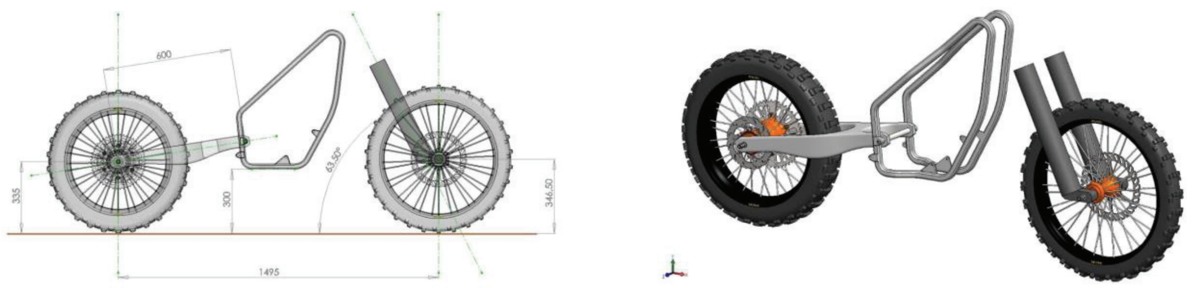

Fig. 1 Simplified model of a motorcycle concept

3. Results and Discussion

The slide frame consists of two separate parts for the front and rear motorcycle wheel. Each of these parts is formed by an upper and a lower part of the frame.

The first point of the design was to clamp and secure the slide frame to the front part of the motorcycle. The front part of the frame is connected to the wheel via an axle, which is inserted into the articulated heads locked with nuts. This solution was chosen because the frame is welded, and these heads will ensure the easy assembly of the frame. The upper arm weldment (Fig. 2) consists of a main tube and side U-profiles with welded plates. Articulated heads are clamped on these plates. For connection to the lower arm, eyes clamps are welded to the main tube, from the front to the tilt assembly, from the rear to the attachment of the hydraulic cylinder.

The lower arm (Fig. 3) is also a weldment, to which the support castors are then attached. It consists of a main lower tube to which the left and right side arms are welded. The front and rear plates are further welded to this skeleton. For connection to the upper arm, the tilt assembly mounts are welded to the sheets.

To connect the upper and lower arms, a tilt assembly, allowing the motorcycle to tilt when cornering, was designed. In the front part, both arms are connected with this assembly; a hydraulic cylinder is inserted in the rear part, allowing the setting of the required adhesion motorcycle conditions.

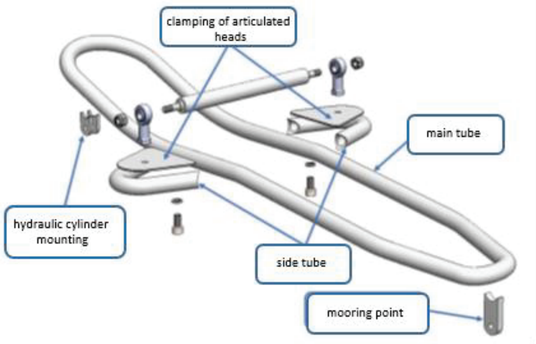

Fig. 2 Upper part of the frame

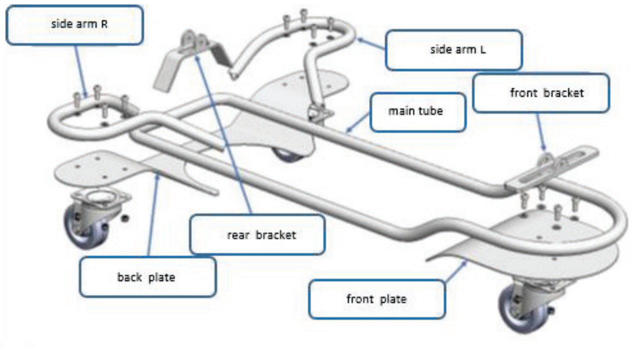

Fig. 3 Lower part of the frame

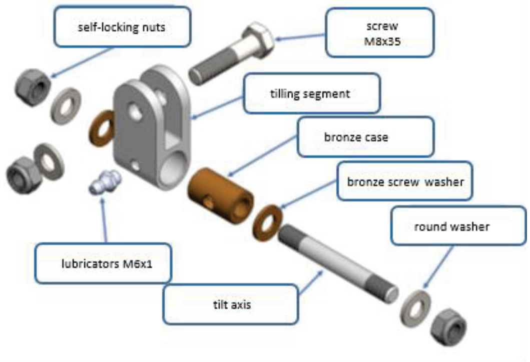

Fig. 4 Tilting element

Fig. 5 Front wheel frame assembly

The tilting element (Fig. 4) consists of a tilting segment into which a bronze housing is inserted. A lubricator was used to ensure trouble-free operation and sufficient service life. A tilt axis is inserted through this housing to get attached to the tilt assembly mount. The whole assembly is connected to the upper arm using a screw connection.

The rear wheel frame is designed according to a similar scheme as used in the front frame (Fig. 5). The rear frame assembly is shown in Fig. 6. The reason for the similarity of the front and the rear frame is the optimization of production costs in terms of materials used and also the assembly of individual parts. The aim was to minimize the number and variety of components of which the frame consists.

Fig. 6 Rear wheel frame assembly

The fall stabilizer arms are used to change the maximum inclination of the motorcycle and the subsequent capture of a possible fall of the rider together with the motorcycle due to exceeding the limit of stability. These arms are attached to the motorcycle frame and allow the setting of the required side tilt angle from 35° for beginners to 50° for experienced riders.

During the construction of the arm, sufficient support and possible adjustment of the tilting angle had to be ensured. The arm consists of a weldment with inserted bronze housings in its lower part to ensure smooth movement when changing the tilting angle setting. Mounting axes are inserted through these housings. Furthermore, a rotating wheel and a telescopic bar are attached in the front part, enabling to change the motorcycle tilting angle. The change in the motorcycle tilting angle size is adjustable according to the current riding situation and the abilities of the motorcyclist. The current design of the stabilizer arm is shown in Fig. 7.

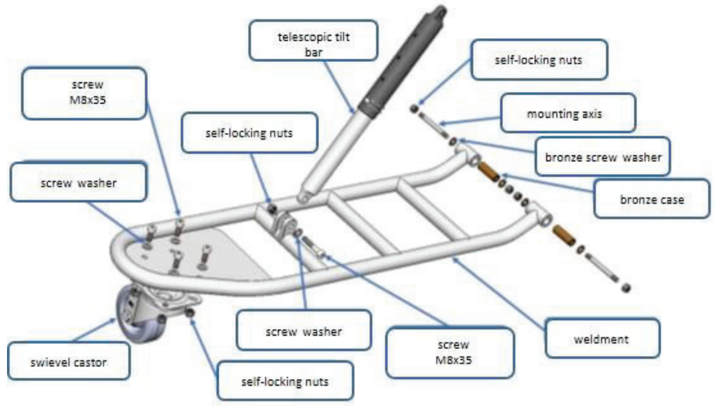

Fig. 7 Drop support arm

For attachment to the lower part of the motorcycle, a plate under the motor was designed, to which the eyes clamps are subsequently welded for attachment to the motorcycle frame and attachment of the fall stabilizer arms. The plate is mounted to the holes in the motorcycle frame with screws.

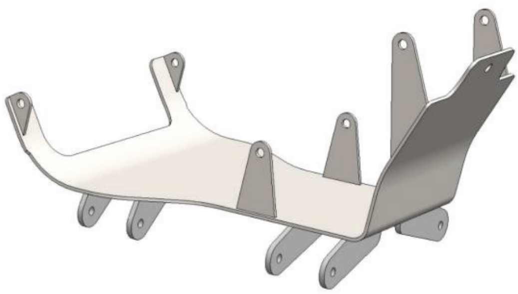

Fig. 8 Plate located under the motor

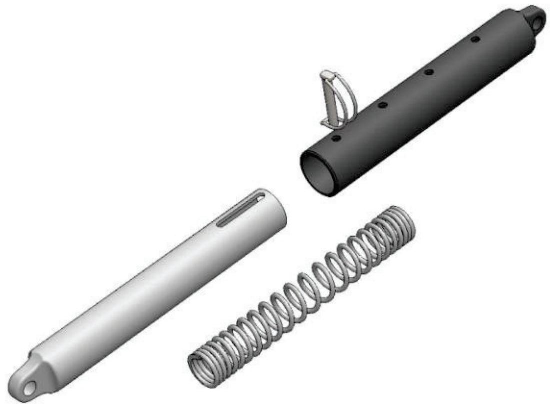

Fig. 9 Damping telescopic bar

The assembly of the middle part of the sliding frame and fall-protecting frame consists of clamping elements to the motorcycle frame and two fall stabilizer arms. The range of change in the setting of the angle of the SkidMotorbik fall stabilizer arms for the minimum and maximum motorcycle side tilting angle is shown in Fig. 10.

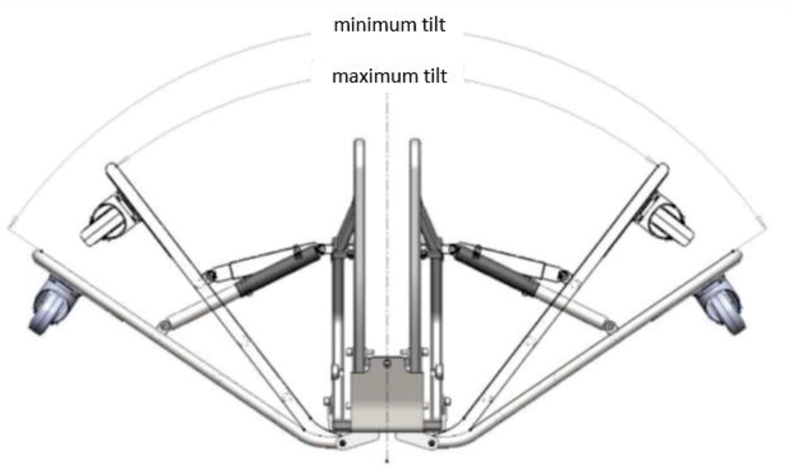

Fig. 10 Arm adjustment range

Since the SkidMotorcycle frame is sufficiently rigid, the magnitude of the impact that is transferred to the motorcycle when the fall stabilizer arm comes into contact with the road is given by the radial flexibility of the tires of the additional wheels. The deformation characteristics of the support unit tires were determined on a static adhesor, see Fig. 11. The data was obtained based on a gradual loading with a vertical force. At a specific load, the magnitude of the radial deformation was subtracted from the position of the static adhesor arm. The deformation characteristic is evident

in Fig. 12 and is described according to (3) on the confidence interval $R^2 = 0,9996$. Due to the rolling of the additional ASC wheels, there is an increase in the emitted noise, which is described in more detail in [9].

$$y = -0.3441x^2 + 5.8352x \,. \tag{3}$$

Fig. 11 Deformation of the support wheels on the static adhesor

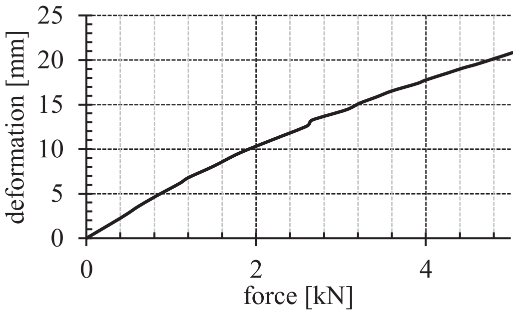

Fig. 12 Deformation characteristics of the wheel units of the Alternative SkidMotorcycle

When riding and exceeding the limit of stability, the fall stabilizer arms come into contact with the bar when the motorcycle reaches the marginal tilting angle. To eliminate the initial shock, a damping element was inserted into the telescopic bar housing. The construction consists of inserting a compression spring into the cavity in the inner tube of the telescopic bar. The inner tube has a modified hole in the shape of a longitudinal groove into which is secured with a locking tube pin. If the wheel rests on the road surface, this construction allows the inner tube to move towards the outer tube. The inserted spring is then compressed, dampening the shock (Fig. 9).

The change in adhesion force is solved using a pair of hydraulic cylinders. The stroke of the cylinders is determined by the pressure fluid and according to the position of the motorcycle wheels, under the load of one standard person until the moment of disengagement of the wheels from the pad. For the given motorcycle, this stroke is 20 mm for both the front and rear wheels. Additional ABS hydraulic units will be used as a source of fluid pressure for the hydraulic cylinders.

The resulting unit of the designed sliding and fall stabilizer frame systems called SkidMotorbike consists of a front-wheel frame, rear-wheel frame, fall stabilizer arms, and a hydraulic circuit. The total weight at maximum use of aluminum alloys is 52 kg.

Fig. 13 Mechanical part of the SkidMotorbike system

4. Conclusions

This paper presents the design of a sliding and fall stabilizer frame for the type of motorcycle specified above. The first step was to map the technical and dimensional parameters of the motorcycle. Subsequently, the arrangement of individual frames according to the identified parameters, was outlined. To design the SkidMotorbik system, the 3D software was used. The design solution of individual components was proposed concerning the availability of materials and the simplicity of production. The aim was the applicability of the system to other motorcycles after minor modifications. To change the adhesion conditions, the frame was equipped with a pair of hydraulic cylinders. For controlling the dynamic stroke according to the driving conditions, the SkidMotorbike system is also equipped with accelerometers together with electronic control for the correct function of these cylinders. Preparations are currently underway for manufacturing a prototype. In addition to teaching motorcyclists, the use of the SkidMotorcycle system can also be used for the needs of research and to compare the theoretical outputs from the models [16] with the real reduced adhesion. More detailed monitoring of the SkidMotorcycle system behavior is subjected to further research.

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Personnel Risks and Their Impact on Business in the Transport Sector in Slovakia

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Abstract

The main aim of the article is to analyze and assess the perception of identified personnel entrepreneurial risks in the transport sector in Slovakia. In 2019, the authors of the article realized empirical research in Slovakia, which was focused on assessing the current state of enterprise risk management application. It took part in research over 370 owners and managers of enterprises in Slovakia. The results were compared and evaluated with the results of similar realized researches in the world. The following statistical methods were used to assess the data: Analysis of variance, Bartlett's test, Levin test, the Agostini test and the Test of good fit to verify the normality of the data, to remove the extremes was used Grubbs test, it was used selected indicators of descriptive statistics – central tendency and variability. Based on the gained results was identified that there are significant differences in the level of personnel risks by the owners and managers of enterprises in terms of the length of their operation on the market in 2019. Based on the processed results it can be stated that it is necessary to constantly evaluate the impact of the human factor in enterprises e.g. it is important to assess human errors, insufficient employees´ qualifications, high fluctuation rate, a decline of working morale, and discipline, etc. The results of empirical research highlight the need to address the above issues in personnel risks in the business environment in the transport sector. The results are valuable material for managers and owners of the enterprise, Education institutes, and Consults institutions, which support entrepreneurship, too.
KEY WORDS: *personnel risks, impact, analysis, assessment, enterprises in the transport sector*

1. Introduction

The actual trends highlight the need to pay more attention to the enterprise risk management application and to be better prepared for the threats in the current business environment [1, 3, 5]. More and more businesses are beginning to realize the need and importance of risk management also in the transport sector [17, 14]. According to various global surveys and studies by various organizations such as e.g. Institute Penomon, Enterprise Risk Management Initiative, AMRAE, AICP, Deloitte Institute, etc. [6, 7, 9, 22, 23] it can be said that risk management means a significant contribution to increasing the performance, value, and competitiveness of enterprises in dynamic changes of both the external and the internal environment. This fact is confirmed also by the results of our research focused on the issue of enterprise risk management carried out by the authors of the contribution in 2017 – 2019 [8, 13]. The implementation of the risk management in a lot of enterprises in Slovakia, the Czech Republic, Poland, Hungary compared with the advanced countries has great shortages e.g. [8, 10, 11, 18-20]:

- Underestimation of risks arising from the internal and especially external environment, lack of early warning systems, inability to assess partial risks of key enterprise processes;
- Missing system of preventive measures to prevent and minimise the negative consequences of the problem;
- The lack of knowledge of risk management methods and tools is supported lack of availability of practical guidance on how to apply these methods and tools effectively;
- In many enterprises, risk management is unsystematic, not a complex process that is based on an enterprise vision and processed intention.

Although the owners, managers of the enterprise are intuitively aware of the common risks which affect their everyday life, it is very improbable they will realise such risks they have no direct experience with. Currently, managers pay more attention to external risks, e.g. market, economic, financial as internal risks, e.g. operational, personnel, security, etc. [2, 12]. Of course, it is important to assess the failure of the human factor, qualification level of employees, state of technology, level of innovation, product quality, etc. [15, 16, 21]. Therefore, the authors decided to assess the personnel risks, which are also important for achieving a competitive advantage and effective management for enterprises in the transport sector.

2. Research Methodology

It was realized empirical research in Slovakia within the project KEGA - Research of Risk Management in Enterprises in Slovakia to create a new study program Risk Management for the FBI University of Zilina in 2019. The main objective of the research was to identify the key business risks of enterprises in Slovakia, the current state of application of the risk management process in enterprises, and assess the level of ability and skills of managers to apply enterprise risk management.

The selected research questions in the area of enterprise risk management were taken part of the questionnaire, which was used to collect data. It was used as an electronic questionnaire, and data were collected in Slovakia. The main statistical units were managers and enterprise owners. Some information was gained by a structured interview with managers in selected enterprises. In 2019 participated in survey 370 owners and managers, who run an enterprise in Slovakia. The structure of the sector as following: 21.4% trade, 17.6% industry, 15.7% building industry, 11.1% transport and information, 10% other services, 6.2% agriculture, 5.7% accommodation and boarding, 3.2% trade services a 10% remaining services.

Various scientific methods such as baseline analysis, querying, comparison and statistical methods for data evaluation were applied to meet the stated objective of the paper. The baseline analysis was used in the process of identifying and solving various problems of the researched issue, e.g. analysis of knowledge from professional literature and scientific papers to elaborate the current state of the solved issue, analysis of results of our surveys assessing business risks in Slovakia.

The query method was applied using the online questionnaire tool. The online questionnaire allowed more efficient collection, sorting, and evaluation of data. The advantage of the online questionnaire is the more efficient collection in terms of time, location, and response speed. The online questionnaire was created using the Google Form platform, which provides a suitable environment for data collection, as well as their sorting and export to MS Excel. Google Form provides a convenient environment for questionnaire creation, data collection, presentation of results, and easy evaluation [4, 24].

The individual questionnaire questions correspond to the main objective of the paper. The composition of the questions was based on the authors' own experience with the above-mentioned issues within the framework of solving various projects at University in Žilina, an analysis of the current state of the solved issues in the world and the work experience. The questionnaire consisted of 24 questions.

It was used for hypothesis confirmation selected statistical methods mainly one-way ANOVA – analysis of variance, Bartlett's test of sphericity, D´Agostinov test and test of Goodness of fit for verification of normality. It was used the Grubbs test for assessment of outliers and selected descriptive statistics indicators. Using the calculation of parametric tests two basic conditions had to be met: the resulting p-value of the intensity of the selected risks of the homoscedasticity test (the identity of variances) and normality test to verify intensities of risks must be higher than the level of significance 0.05 that was chosen.

The comparison was used to evaluate and compare the processed survey results with the same survey results carried out by partner organizations. These are Faculty of Management and Economics, Thomas Bata University, Czech Republic, Warsaw School of Economics Poland, Faculty of Economics and Business, University of Debrecen, Hungary. Also, the results of surveys by authors who deal with the issue, for example, Belás, Kozubíková, Popp, Oláh, Pietrasieński, Ślusarczyk, and others [2, 12, 18-20].

Based on the process of the analysis of the knowledge from professional literature, analysis of the current state of enterprise risk management in the world, and the analysis of the results of own surveys, the paper objective was specified.

The main aim of the article is to analyze and assess the perception of identified personnel entrepreneurial risks in the transport sector in Slovakia.

This objective is reflected in the research question, which was the basis for the hypothesis.

Is there some significant difference in the perception of personnel risks by owners and managers in Slovakia in terms of the length of business in the transport sector?

There is a statistically significant difference in the level of perception of personnel risks by owners and managers of enterprises in the transport sector in Slovakia in terms of the length of business.

3. Results and Discussion

It is possible to summarize results based on the survey, which was realized in 2019. The addressed owners and managers of enterprises in Slovakia should identify a maximum of three risks from the selection of seven business risks, which they consider to be key (being the key) ones in their business. Of the total number of 370 of the addressed Enterprises, the share of identified key risks for enterprises in Slovakia was identified:

1. market risks - 27.70%;
2. economic risks - 18.54%;
3. financial risks - 17.63%;
4. **personnel risks - 15.23%**;
5. operational risks - 9.34%;
6. security risks - 6.77%;

7. legal risks - 4.8%.

Fig. 1 shows the percentage of identified key risks perceived by managers and owners of enterprises in Slovakia. The personnel risks were identified as the fourth most serious risks, which are perceived by owners and managers in Slovakia. Research suggests that personnel risks are frequently underestimated in the current entrepreneurial environment. This can be proved by the detected the most important sources of the personnel risks – the insufficient employees´ qualifications, high fluctuation rate, the decline of working morale and discipline, and human errors.

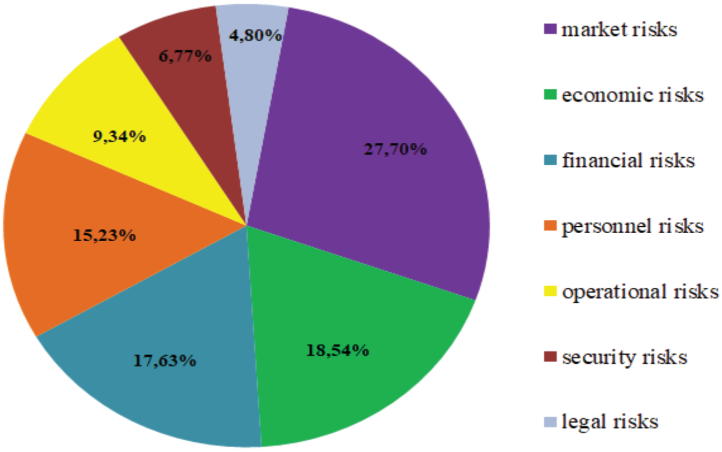

Fig. 1 Percentage of identified key risks perceived by managers and owners of enterprises in Slovakia in 2019

To verify the established hypothesis, it is necessary to use descriptive statistics to better analyze the assessed data. The basic statistics of the selected dataset are following: N – Number os statistical unit, μ – the average intensity of risk to the enterprise, σ – standard deviation of risk intensity to the enterprise, σ^2 – variance of risk intensity to the enterprise, ϖ – median, $\bar{x}$ – skewness and ι – kurtosis (Table 1).

Table 1

Basic statistical characteristics (BSCs) of personnel risk in four groups of the enterprise according to the length of business

Type of risk	Lenght of business	N	μ	$\bar{x}$	σ	σ^2	ϖ	ι
Personnel risks	less than 5 years	55	0.2306	0.10	0.2306	0.0532	1.35	1.23
	5-10 years	94	0.1362	0.10	0.2052	0.0421	1.56	1.20
	10-20 years	108	0.1685	0.00	0.2319	0.0538	1.34	1.23
	more than 20 years	113	0.1743	0.10	0.1940	0.0376	0.93	0.28

Based on the surveyed group of enterprises, which were obtained based on the performed survey, one of the important risks can be considered also personnel risks, which are most often perceived by enterprises in Slovakia based on length of business. Based on the Grubbson Test of outliers, were identified as any outliers. Barlett's test (p-value 0.0532), and Levin test of sphericity (0.128) confirmed the assumption of sphericity. Based on D´Agostins test of enterprises which run an enterprise less than 5 years (p-value 0.1260) and from 5 to 10 years (p-value 0.0950), and test of Goodness of fit, for enterprise, which run a business from 10 to 20 years (p-value 0.0108) and which run an enterprise more than 20 years (p-value 0.0750) can be considered as a presumption of normality of the file fulfilled.

Table 2

Analysis of the intensity variance of enterprise personnel risks using the F-test

Variance of enterprises according to the lenght of business	DF	SS	MS	F	p-value
Between groups	14	3.529	0.1304	8.09	0.039
Within groups	356	14.227	0.069		
Total	370	17.756	-		

Based on one-way ANOVA perceived intensity of personnel risks by owners and managers of enterprises in the transport sector in Slovakia was p-value 0.039 (Table 2). This value is less than the established level of significant $\alpha = 0.05$. Based on the results, it can be said that there is a statistically significant difference in the perception of personnel risks by owners and managers in Slovakia based on length of business. It is possible to accept the established hypothesis, i.e. that owners and managers of enterprises in the transport sector in Slovakia perceive different personnel risks according to the length of business. They perceive some risks at the beginning of their business, which changes during their length of run a business.

In the current strong competitive environment, it is also important that enterprises have new technologies, equipment with powerful systems and skilled employees. These are elements of the competitiveness of the company resulting from the internal environment, which companies must pay attention to improve them. Owners and managers should not forget the human factor, which is still an integral part of all processes in the enterprise. This is confirmed by the results of own empirical research.

Based on processed data, which were obtained form results in 2019, it is possible to say, that personnel risks were identified as the fourth serious risks, which owners and managers perceive. Similar results were in 2017. Furthermore, it was found that there is a statistically significant difference in the perception of personal risks by owners and managers of enterprises in the transport sector in Slovakia in terms of the length of business (less than 5 years, 5-10 years, 10-20 years, more than 20 years).

They perceive other risks at the beginning of their business, which gradually changes with their time in the market. Personnel risks are specific to individual areas of management, and this may also be due to the impact of sources of risk that are changing in the marketplace as the business operates. From the perspective of the most perceived sources of personnel risks in Slovakia by the owners and managers of enterprises in the transport sector in Slovakia in 2019:

1. the high fluctuation rate;
2. human errors;
3. the decline of working morale and discipline;
4. insufficient employees´ qualifications.

Based on the comparison in 2017 were:

1. the decline of working morale and discipline;
2. the high fluctuation rate;
3. insufficient employees´ qualifications;
4. human errors.

This result is confirmed by a lot of other authors who carried out similar investigations Kozubíková; Belás et al.; Popp et al.; Oláh et al.; Pietrasieński, Ślusarczyk [2, 12, 18, 19, 20].

This research can be of value to entrepreneurs, managers as well as to institutions that provide comprehensive entrepreneurship support in the transport sector. The overall results are significant at the regional, national, and international level and have the ambition to strengthen the competitiveness of entrepreneurs. It is important that managers are convinced that effective risk management provides less negative surprises, greater financial stability enterprise performance, and improvement in competitiveness. Improving the level of risk management requires enterprises, not only in the Slovak Republic, but also in other countries to acquire theoretical knowledge about the risk management process, methods, and tools that can be used in risk management.

4. Conclusions

The overall results of empirical research point to the significance and importance of addressing the assessment of personnel risks and their resources in the enterprises in the transport sector in the Slovak Republic. The processed research results show that entrepreneurs and managers in Slovakia are less concerned about personal risks connected with the production process and services. It follows that entrepreneurs and managers perceive the difference in personnel risks with their respective market presence.

The main benefits of the contribution are:

1. Study on key enterprises risks perceived by managers and entrepreneurs in Slovakia. Also, the assessment of significant determinants of the perception of the level of personnel risks by owners and managers in the enterprises in the transport sector in terms of the length of their market presence in Slovakia.

2. The improvement of awareness about Enterprise risk management in which supports the success of the business performance, the development of the regions, and last but not least.

The achieved results are the basis for the professional public as well as for organizations in the transport sector that are trying to help enterprises with the effective application of Enterprise risk management. Other the effort of the authors is to take gradual steps towards enforcement of the enterprise risk management for them to get closer to the global trends.

Acknowledgments

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Neck Protection in Autonomous Car Crashes

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Abstract

Autonomous cars which are expected to be on the market in the upcoming years, present new challenges to restraint system design since unconventional seating plans can put the occupants at more risk. For instance, an occupant sitting on a rear facing seat can experience higher risk of whiplash in a frontal impact considering the fact that statistically frontal impacts do happen at higher severities than rear impacts as seen in the crash test conditions of US NCAP. In this study, an improvement to car seat design is presented in which the seatback is automatically rotated into a more upright position prior to impact in order to increase the energy absorbing potential of the seatback. The study involves computer simulation of a seat-occupant system to demonstrate the benefits of the proposed system.
KEY WORDS: *autonomous car safety, whiplash, seat design*

1. Introduction

Rear impacts in road-traffic accidents create a high risk of whiplash which is the sudden movement of the head with respect to the torso. This sudden movement typically produces discomfort and pain in the head-and-neck system. A common cause of whiplash is thought to be the formation of S-shape-like deformation in the neck due to retraction of the head relative to the upper torso. Whiplash can be mitigated by car seats in which the seat and the head-restraint work together to absorb the crash energy effectively. Whiplash is mitigated when neck internal motion and neck forces are reduced throughout the impact [1].

According to the GIDAS (German In-Depth Accident Study) database between years 2005 and 2016, the majority of rear-end collisions occurred with for relative speeds between 10 and 45 km/h where the relative speed refers to the difference between the speeds of the interacting cars at the time of collision [2]. In another study [3], insurance injury claim rates in rear-end crashes and the corresponding seat/head-restraint ratings (by the Insurance Institute for Highway Safety (IIHS)) were compared for 2001-2014 model year passenger cars and SUVs. Vehicles with good seat/head-restraint rating had 11.2% lower injury rates than that of vehicles with poor rating. The GIDAS database was also studied for accidents between years 2000 and 2015 in order to assess whether an emergency braking with maximum deceleration produced a significant risk for whiplash or not [4]. This study [4] found 14,070 isolated frontal collisions out of which full braking (more than 6 m/s^2 mean deceleration) was involved in 4,690 cases and in these cases there were 6,473 occupants out of which 597 had sustained whiplash (corresponding to 9%). In an accident database study from year 2005 regarding single rear-end impacts, 77% of the cars experienced a delta-V lower than 15 km/h, 16% experienced a delta-V between 15 and 25 km/h, and 7% experienced a delta-V higher than 25 km/h [5]. Delta-V is the change of velocity experienced by a car in a collision and it is equal to the area under the acceleration versus time history of the struck car. The acceleration versus time history experienced by a car is called the crash pulse. In the EuroNCAP whiplash test [6], three tests with low, medium and high severities are applied to the seat-dummy system in which the high severity test involves the use of a crash pulse with a delta-V of 24 km/h, a mean acceleration of 6.5 g and a peak acceleration of 7.5 g.

Autonomous cars will involve unconventional seating plans in which the seats will be rotatable, foldable and expandable. The current restraint systems that have been optimised for so many years hence a change in seating plan will require different restraints. Occupants will also be using rear facing seats but sitting on such a seat can introduce higher risk of whiplash when a frontal impact occurs since frontal crashes generally occur at higher severities than rear-end crashes. For example, in full-width rigid barrier frontal impact tests of US NCAP, cars impact a fixed rigid wall with 100% overlap at a fixed impact speed of 56 km/h and this corresponds to a delta-V of around 60 km/h [7]. Therefore, the seat has to manage higher crash-energies in such cases. Rotating the seatback into a more upright position prior to impact is suggested in this study to increase the crash-energy absorbing potential of the seatback. Moon et al. [8] previously proposed the idea of turning the seatback to an upward position before unavoidable collision but they did not mention how this turning process would be realized.

In this paper, a mechanism which will turn the seatback to an upward position is proposed. This paper is organized into four sections. In section 2, presented mechanism is proposed. In section 3, differential equations of motion of the mechanism are obtained. In the following section, dynamics of the mechanism are examined. Finally, in the last section, computer simulations (crash tests) are presented.

2. Presented Mechanism for Neck Protection in Autonomous Car Crashes

The recommended mechanism to prevent neck injuries mentioned in the introduction is shown in Fig. 1. The mechanism, which will be driven with the release of a pre-tensioned spring, is expected to turn the seatback to the desired upright position.

The mechanism consists of a spring, damper, rack and pinion, gear pair connected with a chain, seatback and human-dummy model. The dummy represents a 50th percentile male. Rack is attached to the ground via pre-tensioned spring and damper. Releasing of the pre-tensioned spring will drive the rack to the left and rack will rotate the pinion clockwise direction. To achieve the desired upright position, a gear ratio is established between gear-2 and gear-3. Gear-3 will rotate in the same direction with gear-2 by the chain connection between them. With this driving motion gear-3 which is attached to the seatback will cause the rotation of the seatback to the upright position. Human-dummy model will rotate with the seatback as well. Normally, the seatback and gear-3 are attached to each other by a mechanical connection. Just before the impact, gear-3 suddenly rotates together with the seatback with the aid of the mechanism given in Fig. 1. When a predetermined forward rotation of the seatback (clockwise rotation in Fig. 1) is obtained, gear-3 is made to lock, this can be achieved by a locking mechanism which can be designed in several ways. Once gear-3 is locked and the impact starts, the mechanical connection between the seatback and gear-3 plastically deforms and absorbs energy. Penetration of human-dummy model into the seatback foam is modelled with a spring-damper system. This modelling causes a rise on the degree of freedom of the system. Degree of freedom of the system becomes two. Furthermore, a pre-compressed spring is used between the seatback and the head restraint which pushes the head restraint forward (towards the head) to reduce head retraction during forward rotation of the seatback.

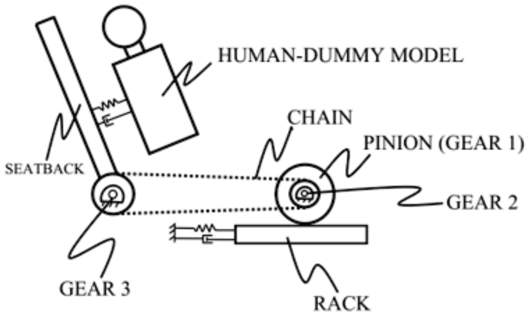

Fig. 1 Recommended mechanism

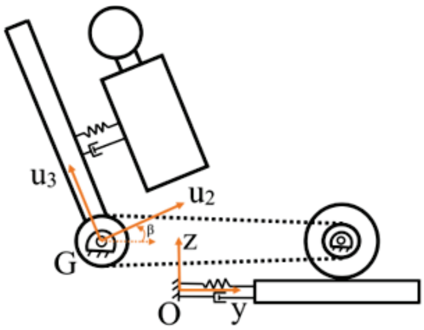

Fig. 2 Reference frames of the mechanism

3. Obtaining Differential Equations of Motion of the Mechanism

The differential equations of motion (DEOM) of the mechanism are required to be used later in the computer simulations. Newton-Euler equations of each pair will be examined separately below. The reference frames are introduced in Fig. 2. Motion of rack and gear-2 will be examined in the frame F (O; x, y, z) and motion of the gear-3-seatback pair and human-dummy model will be examined in the frame F (G; $\boldsymbol{u}_1$, $\boldsymbol{u}_2$, $\boldsymbol{u}_3$). Here, x and $\boldsymbol{u}_1$ always have the same direction and this direction is outward to the page. Pairs will be examined from the outermost to the ground. Frame G is attached to the seatback.

To obtain the Newton-Euler equations of the human-dummy model, the body center position vectors with respect to frame G are determined (Fig. 3). Vector $\boldsymbol{r}_4$ is expressed in frame G as shown in Eq. (1). Differentiating Eq. (1) twice and rearranging it yields Eq. (2). The Newton-Euler equations for body-4 using free-body diagram (Fig. 4) are presented in Eqs. (3) and (4). In these equations, F_s and F_d are the spring and damping forces between human-dummy model and seatback respectively; F_{r34} and M_{r34} are the reaction force and moment from the seatback to the human-dummy model respectively; $m_4 g$ is the weight of the human-dummy model and J_4 is the moment of inertia (around the centre of mass C_4) of body-4.

$$\boldsymbol{r}_4 = r_3 \boldsymbol{u}_3 + y_2 \boldsymbol{u}_2 \, ; \tag{1}$$

$$\ddot{\boldsymbol{r}}_4 = \left(\ddot{y}_2 - r_3 \ddot{\beta} - y_2 \dot{\beta}^2\right) \boldsymbol{u}_2 + \left(2\dot{y}_2 \dot{\beta} - r_3 \dot{\beta}^2 + y_2 \ddot{\beta}\right) \boldsymbol{u}_3 \, ; \tag{2}$$

$$m_4 \ddot{\boldsymbol{r}}_4 = -\left(F_s + F_d + m_4 g \, Sin\, \beta\right) \boldsymbol{u}_2 - \left(m_4 g \, Cos\, \beta + F_{r34}\right) \boldsymbol{u}_3 \, ; \tag{3}$$

$$J_4 \ddot{\beta} = -M_{r34} + F_{r34} y_2 \, . \tag{4}$$

In a similar way, the Newton-Euler equations for seatback (body-3) are obtained as follows (see Fig. 5). Here, θ_3 is measured from the z axis of the reference frame O and it does not involve the initial angle α of the seatback which is also measured from the same z axis. Total seatback orientation with the respect to z axis is indicated by β which is equal to the summation of θ_3 and α. Eqs. (5) and (6) describe the kinematics and Eqs. (7) and (8) show the Newton-Euler

equations for body-3. In these equations, F_{r43} and M_{r43} are the reaction force and moment from the human-dummy model to the seatback; T_3 is the carried torque from gear-2 to gear-3; m_3g is the weight of the seatback and J_3 is the moment of inertia (around the pivot centre of gear-3) of body-3. Vector $\boldsymbol{r}_3$ is expressed in frame G as shown in Eq. (5). Differentiating Equation 5 twice and rearranging it yields Eq. (6).

$$\boldsymbol{r}_3 = r_3 \boldsymbol{u}_3 ; \tag{5}$$

$$\ddot{\boldsymbol{r}}_3 = \left(-r_3 \ddot{\beta}\right) \boldsymbol{u}_2 + \left(-r_3 \dot{\beta}^2\right) \boldsymbol{u}_3 ; \tag{6}$$

$$m_4 \ddot{\boldsymbol{r}}_3 = \left(F_s + F_d\right) \boldsymbol{u}_2 + \left(F_{r43}\right) \boldsymbol{u}_3 ; \tag{7}$$

$$J_3 \ddot{\beta} = -T_3 + m_3 g r_3 \, Sin\, \beta - F_s r_3 - F_d r_3 + M_{r43} . \tag{8}$$

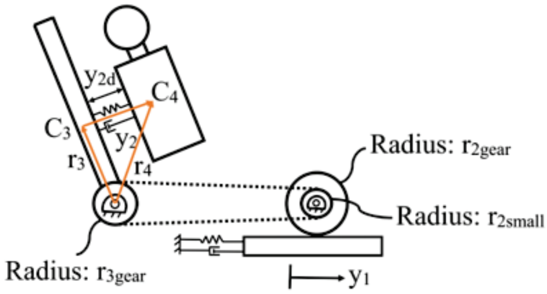

Fig. 3 Dimensional parameters of the mechanism

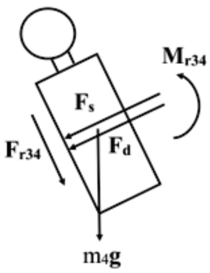

Fig. 4 Free-body diagram of body-4

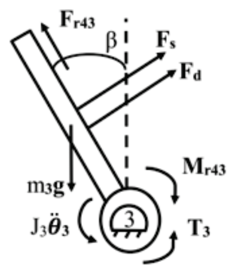

Fig. 5 Free-body diagram of body-3

The spring force F_s is a function of y_{2d} which is the the gap between the seatback and the human-dummy model as given in Table 1. The damping force F_d depends linearly on $\dot{y}_{2d}$ and the damping coefficient c_2 which is a function of y_{2d} as shown in Table 2. The data given in Tables 1 and 2 represent the seatback foam and suspension characteristics used in typical seats which is validated in a previous study [1].

Table 1

Spring force vs displacement relation between body-3 and body-4

F_s (N)	-6000	-3000	-1250	-700	-250	0	0
y_{2d} (m)	-0.06	-0.05	-0.04	-0.03	0	10^{-3}	0.06

Table 2

Damping coefficient vs displacement relation between body-3 and body-4

c_2 (Ns/m)	35000	25000	1600	0	0
y_{2d} (m)	-0.06	-0.05	-0.04	0	0.06

Forces and moments acting on gear-2 (body-2) and rack (body-1) can be seen in Fig. 6. Using the free-body diagrams of gear-2 and rack, the relevant Newton-Euler equations (Eqs. (9) and (10)) can be written. In these equations, F_c is the contact force between the rack and the pinion; J_2 is the moment of inertia (around the pivot centre) of body-2; gr is the gear ratio (selected as 12/1) between gear-3 and gear-2small (see Fig. 3); k_1 and c_1 are the spring and damping constants of the spring and damper at the left-end of the rack and θ_2 is rotation angle of body-2 and it is measured from the z axis of frame O. One should notice that, the kinematic relationship of rack and pinion must be used to convert rotational motion into translational one as given in Eq. (11). In order to transform the DEOM into a system of first order differential equations, Eq. (12) is written.

$$J_2\ddot{\theta}_2 = T_3 / gr - F_c r_2 \,; \tag{9}$$

$$m_1\ddot{y}_1 + c_1\dot{y}_1 + k_1 y_1 = F_c \,; \tag{10}$$

$$\beta = \theta_3 + \alpha \,;\; \theta_2 = y_1 / r_2 \,;\; \theta_3 = y_1 / \left(gr \cdot r_2\right); \tag{11}$$

$$\dot{y}_1 = v_1 \,;\; \ddot{y}_1 = \dot{v}_1 \,;\; \dot{y}_2 = v_2 \,;\; \ddot{y}_2 = \dot{v}_2 \,. \tag{12}$$

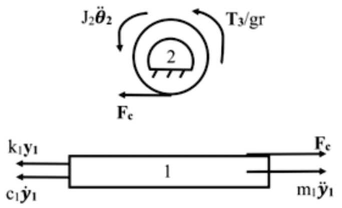

Fig. 6 Free-body diagrams of body-2 and body-1

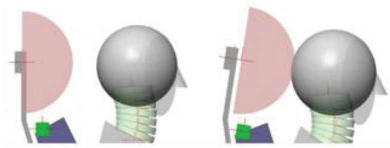

Fig. 7 Forward deployment of the head-restraint

Substitution of Eqs. (11) and (12) into the remaining equations and elimination of internal force and moments give the differential equations of motion. From the solution of this differential equation system, rack displacement, rack velocity, rack acceleration and rotation of the seatback with respect to time can be found.

Additionally, there is a pre-compressed spring-damper between the seatback and the head restraint. With the aid of an electrically activated switch, the head restraint can be allowed to travel forward as shown in Fig. 7. This forward travel of the head restraint helps to limit head retraction as the seatback is rotated forward prior to impact. The head restraint is designed to travel forward by an amount of 2 cm in 30 ms with respect to the seatback.

4. Obtained Dynamic Behaviour of the Mechanism

Differential equations of motion of the system are solved by MATLAB by using the ode45 function. It is desired to rotate the seatback nearly 10 degrees in 0.3 seconds to an upright position. For this purpose, the spring coefficient (22 kN/m) and the damping coefficient (1000 Ns/m) for the spring and damper at the left end of the rack are determined manually. The following figures show the displacement (Fig. 8) of the rack and the rotational displacement of the seatback (Fig. 9). A seventh degree polynomial is fitted to the seatback rotation data using least-squares regression to be used later in the Visual Nastran dynamic simulation software.

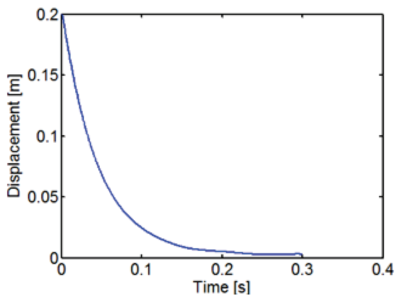

Fig. 8 Displacement of the rack

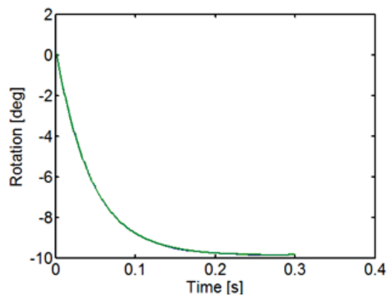

Fig. 9 Rotational displacement of the seatback

5. Performed Computer Simulations

Two different computer simulations are performed in Visual Nastran software with and without the presented mechanism to compare the results. Details of the used 50th percentile human-body model in Visual Nastran, are given in a previous research [9]. The rotational displacement of the seatback during forward rotation of the seatback was obtained using Matlab and a seventh order polynomial was fitted to this rotation data. This seventh order polynomial is imported into the Visual Nastran model to simulate the performance of the presented mechanism. An input rotation is given to the seatback in visual Nastran which is the same as the mentioned seventh order polynomial. This simulation is performed until the desired rotation (8.82 degrees at 0.100 seconds) of the seatback is achieved. At this point, computer simulation is reset with keeping the existing conditions as the initial conditions for the crash simulation. After keeping the existing conditions as initial conditions, the crash pulse (high severity pulse of the EuroNCAP whiplash test) is applied and the behaviour of the system is examined. Some of the assessment criteria of the EuroNCAP whiplash test [6] are selected and given as results in Table 3. A combination of the shear force and moment acting at the upper neck (which is denoted by OC (occipital condyles)) is an injury criterion called N_{km}. The N_{km} value should be below 1 for lower risk of whiplash. In rating the forces at the upper neck (i.e. at the OC), the IIWPG neck force classification [10], as shown in Fig. 10, is used. The forward (or clockwise) rotation of the seatback prior to impact and the motion of the seat-occupant system after the

onset of the impact are given in Figs. 11 and 12, respectively. The initial seatback angle is 20 deg from the vertical.

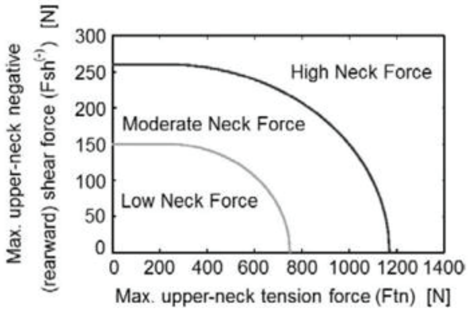

Fig. 10 IIWPG neck force classification (adapted from [10])

Table 3
Performance of the seat (without the presented mechanism (a), with the presented mechanism (b))

	(a)	(b)
Maximum shear force at the OC (N)	160.63	61.98
Maximum tension force at the OC (N)	73.66	252.9
N_{km}	0.46	0.17
Maximum rearward seatback rotation (°)	44.63	29.34

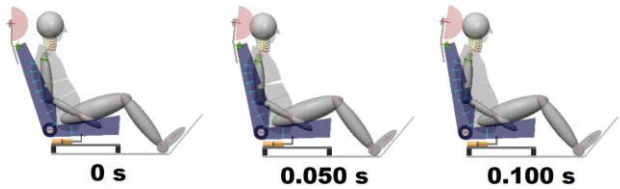

Fig. 11 Forward (clockwise) rotation of the seatback prior to impact

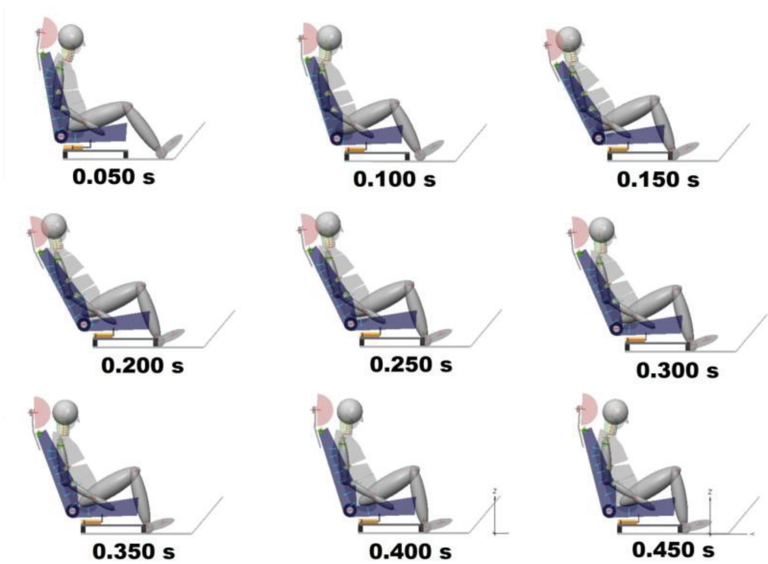

Fig. 12 Seat-occupant system during the impact (time is reset to zero at the onset)

6. Discussion and Conclusions

This paper presents a seatback rotating mechanism based on a rack-and-pinion driven by a pre-tensioned spring. When the crash is inevitable, the seatback is rotated forward to a more upright position prior to impact (approximately 100 ms before the onset of the crash). This mechanism can be activated by a sensor triggering a mechanical switch that releases the mechanism. The forward rotation of the seatback has a side effect which is head retraction since the upper torso is loaded by the seatback. This head retraction can cause whiplash if there is nothing to support the head. Therefore, the head restraint is propelled forward towards the head by an amount of 2 cm in 30 ms to support the head early and

limit head retraction as the seatback is rotated forward prior to impact.

Once the seatback forward rotation is completed, the high severity crash pulse (with a delta-V of 24 km/h) of the EuroNCAP whiplash test is applied. Such crash severities may be more common in the future with autonomous cars especially when the occupants start to use rear facing seats. Sitting on rear facing seats can lead to higher risk of whiplash when a frontal impact occurs since frontal crashes generally occur at higher severities than rear-end crashes.

In order to evaluate the effectiveness of the proposed mechanism (including forward deployment of the head restraint), a whiplash-mitigating seat is subjected to the high severity crash pulse with and without the proposed mechanism. The whiplash-mitigating seat without the proposed mechanism already shows low neck loading as indicated in Fig. 10 and Table 3. The whiplash-mitigating seat with the proposed mechanism obtains a reduction of about 62% in both N_{km} and upper-neck shear force, and a reduction of about 33% in the maximum rearward (counter-clockwise) seatback rotation. With the proposed mechanism, the upper-neck tension force increases but this tension force is still low as shown in Fig. 10. The reduced amount of rearward seatback rotation helps in two ways: First, the required amount of space behind the seat to be used for crash energy absorption, is reduced hence occupant compartment size can be reduced. Secondly the amount of ramping, which is the upward motion of the torso along the seatback, is reduced. Ramping can cause the head to move backwards over the head restraint leading to decreased support of the head by the head restraint.

The presented mechanism to rotate the seatback into a more upright position prior to impact improves significantly the performance of the seat which leads to better neck protection. With this mechanism, the seat can absorb higher crash-energies in higher severity crashes. The initial forward rotation of the seatback increases the energy absorbing potential during rearward rotation of the seatback which will be quite beneficial in autonomous car crashes.

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Optimization of Traction Power Supply System with Variation of Train Flow Sizes

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Abstract

Modern requirements for the operation of electrified railways are the efficient use of available technical means to ensure energy efficiency while increasing train traffic. The aim of the work is to substantiate the optimization of the structure of the DC traction power supply system with variation of train flows and traction loads. Such optimization should be performed after the reformatting of the train schedule and the subsequent impossibility of increasing the energy performance. The methodological basis for the optimization of the existing power supply system of the traction line is the use of a hybrid traction power supply system with an asymmetric arrangement of active generators.
KEY WORDS: *traction power system, train schedule, specific power, optimization of power supply of electric rolling stock*

1. Introduction

In modern conditions of railway transport operation it is important to increase the efficiency of the use of railway technical means and the quality of the organization of the transportation process. The choice of optimal train modes is one of the main tasks of railway transport. The problem of optimal train movement, first of all, is determined by the completeness of factors that characterize the section, the model of train movement, various factors and conditions of the process of train movement on a variable track profile, as well as the forces that arise [1].

Energy-efficient technologies for the implementation of the transport process primarily imply the introduction of rational forms of train schedules with optimal masses and intervals. Calculations show that optimizing the train schedule taking into account the existing tariff system can be found for the same freight flow option, in which electricity consumption will be lower, but in practice the actual change in train schedule may lead to different costs associated with increasing electric locomotive fleet, increasing the money spent on locomotive crews' salaries, etc. Increased traffic congestion on electrified railway sections leads to increased sensitivity of train schedules and to greater secondary delays that spread from train to train. The unevenness of the intensity of the train is explained by many factors. Objective reasons include track profile, differences in traction characteristics of different types of locomotives, distance between stations, etc. Subjective reasons are different qualifications of locomotive drivers, differences in the characteristics of locomotives of the same series, weather conditions.

The most significant external causes are fluctuations in the readiness interval for freight trains at stations, uneven timetables for passenger trains throughout the day, and "windows" for repair and track work. Changing the ratio of the proportion of trains of different types also affects the intensity of traffic, and therefore the interval between trains. All together the reasons for the unevenness of traffic intensity determine one of the properties of train movement - its uncertainty. Changing the position of trains while driving on a section is a stochastic process that is not the same in space and time.

Maintaining the optimal train density at the control station should be the primary task of managing the train operation and allow efficient use of the railway infrastructure and rolling stock capacity. It is necessary to take into account the real capacity of the electrified site.

The analysis of electricity consumption in recent years shows that the search for energy-saving technologies of the transport process on electrified lines should be conducted not only in the direction of the organization energy-efficient process of transportation but also by improving the electrical systems and their modes of operation. As a result of experimental studies, it was found that the voltage and power modes in the traction DC power supply system do not fully provide the necessary conditions for the introduction of high-speed or heavy traffic on existing lines, as packet trains have restrictions on voltage and specific power levels. Thus, there is a problem of optimizing the structure of the DC traction power supply system with variation of train flows and traction loads.

2. Methodology

The choice of optimal train modes is one of the main tasks of railway transport. The task of optimal train movement, first of all, is determined by the completeness of the set of factors that characterize the section, train model, various factors and conditions of the process of train movement on the variable track profile, as well as the forces that arise, etc. At some point, the increase in maximum capacity is achieved when the marginal increase in the operation of one additional train is lower than the cost of a longer trip time and increased sensitivity to delays. There is a conflict of interest between adding new routes to the train schedule to meet higher demand and maintain the quality of trains already scheduled. The need to resolve this conflict increases when the railway market is deregulated and service operators cannot abandon train slots due to capacity constraints [2]. Many rail lines already use the maximum capacity, and various measures are taken to meet new demand. Such actions include the construction of new railway infrastructure, the modernization of existing infrastructure or the more efficient use of existing infrastructure. Building new railway infrastructure is expensive, and it is therefore important that the right actions are taken at the right time. Coverage of the understanding of practical capacity in the documents of the International Organization of National Railway Companies in order to jointly address the challenges of railway transport development is presented in the standard that examines the capacity of UIC406-R [3]. This document uses a market-oriented approach to bandwidth determination. Studies show that in some cases, individual railway sections can be overloaded, even with a small number of trains. This standard is based on the compression of the train schedule, but to begin with, the section should be divided into smaller sections, which will be compressed separately. The schedule should be firmly adjacent to each other without breaking safety intervals. In other words, the train schedule should be "compressed" so that there is as little time as possible between the threads of the schedule. As a rule, spare time is introduced in order to reduce delays between trains in an emergency. Thus, the capacity depends on the location of trains in time, the number of trains of different speed categories, the length of the section, the accepted level of punctuality (accuracy of compliance with the schedule), the number of delays and stops, the required commercial speed and the specified interval of their departure. As a consequence, capacity can only be estimated after the establishment of a transportation plan, which is formed on the basis of traffic schedule requirements. Increasing the capacity of railway sections can be achieved by technical measures and by reconstruction [4]. Organizational and technical measures include the reduction of intervals between trains, the use of more efficient types of schedules, doubling and connection of trains, increasing the number of rolling stock, increasing the total mass of rolling stock. These measures are the most efficient and cheapest way to solve the problem, but allow to improve the situation to certain limits and do not exclude the possibility of further reconstruction (replacement of interlocking devices, development of track devices, reconstruction of rolling stock and traction). Therefore, with a sharp increase in traffic, when capacity is limited, the sites need to take the necessary measures to comprehensively organize the operation of railway transport on the basis of energy-efficient schedules and train formation.

The energy-optimal train schedule is a schedule that provides for the transportation of scheduled passenger volumes and cargoes with minimal electricity losses associated with the costs of traction for locomotives and unconditional safety of transportation [5]. With energy-optimal train schedules, we can also avoid reducing rolling stock downtime, reducing the amount of shunting work, increasing the speed of delivery of goods and passengers, and so on. The implementation of energy-optimal traffic schedules for passenger trains shows the possibility of reducing electricity costs for traction by 5-6%. Currently, energy-optimized traffic schedules are introduced into the traffic schedule for freight trains [6]. The principle of reducing power losses is formed in the way, when there is a choice of many possible values of the intervals between trains and from them are selected those that correspond to minimal power losses.

First of all, to solve this problem, "hard train-path" are used - the technology of train movement on a strict schedule, which is not subject to change. The use of this technology will reduce the downtime between cars and trains at line and sorting stations by accelerating the turnover of traction rolling stock at technical stations, as well as by stabilizing the work of locomotive crews. This leads to improved use of rolling stock both in terms of power and time. When using "hard" paths, the acceleration of the production cycle is achieved due to following factors:

- reduction of failures in the operation of technical devices, allows up to 10% to increase the available capacity of railway sections;
- shortening of downtime of structures at service stations;
- the use of free path of the schedule to accelerate the movement of trains [7].

When performing transportation by rail on hard paths, it is possible to optimize both the direct transportation process (taking into account information on current speed limits, providing "windows" for repairing the upper structure of the track, information on force majeure) and related operations (supply planning of locomotives for train) [7]. It can be hypothesized that the most perfect will be the schedule of trains with a stable part of the train flow, and free paths can be used to vary its parameters and performance indicators.

To confirm this, we conducted studies on a real electrified section (Fig. 1) with a real trains schedule of (Fig. 2).

The tested section has two tracks, is 128 km long, has 8 section between substations and receives power from 9 traction substations according to the scheme (Fig. 1). The non-load voltages and the internal resistances of the traction substations are determined based on their passport data.

To illustrate the provisions of the proposed hypothesis, consider the movement of the train N7 (Table 1).

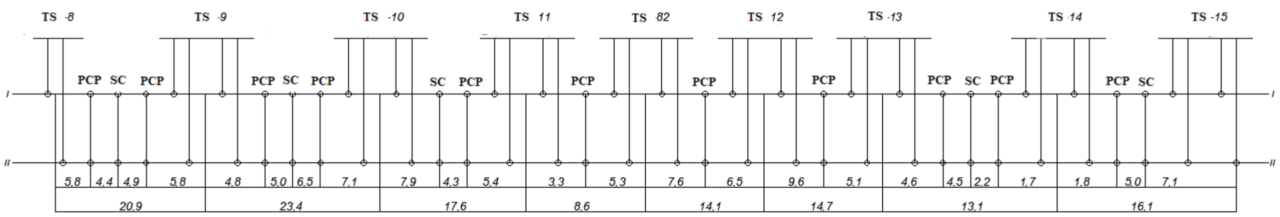

Fig. 1 Power supply of electrified section P – ND

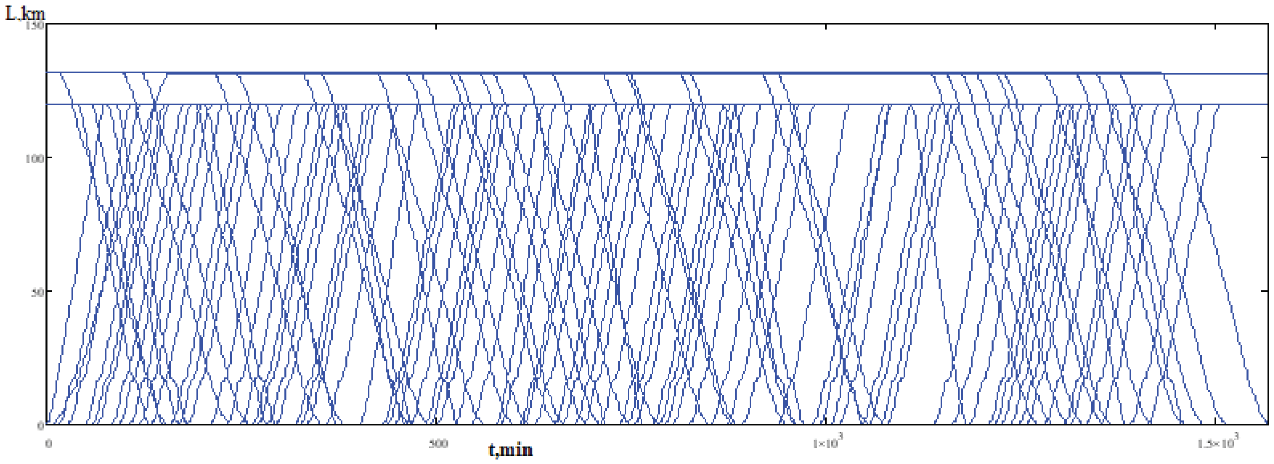

Fig. 2 Train schedule on the section P – ND

Table 1

The movement of the train N7 on the section

No.	Block post	Journey time, min	Distance between stations, km	The distance, km	Note
1	ND	0		0	
2	N	12	4.7	4.7	
3	P	16	3.1	7.7	
4	DN	26	2.3	10	
5	G	33	2.4	12.4	
6	D	42	5.7	18.1	
7	C	55	9.6	27.7	
8	ZK	68	13.7.	41.3	
9	KP	72	3.9	45.2	
10	V	85	12.6	56.7	
11	VD	94	8.2	66.9	
12	RE	109	15	81.9	
13	VG	129	17.3	99.2	
14	E	137	8.9	108.1	Overtaking
	E	152	0	108.1	
15	P	175	17.9	126	
16	PS	188	4.6	130.6	

Calculations of energy parameters were performed using the spatio-temporal representation of the electric traction load. The space-time model of the traction supply system [8] is based on the analytical description of the basic electrical processes by the functions of two variables, the relationship between which is determined by the train schedule, which in turn determines the graphical coordinate of each individual train with the number n in any moment of time t. Using other initial data in the form of electric locomotive power profile, parameters of external and traction power supply system, piecewise-defined functions of two variables are determined, which are the dependences of current distribution and voltage losses in the catenary in time and space.

According to the timetable, the moment of arrival of the first train to the destination is 120 minutes, which also means that there are some trains that have not completed the route. For this purpose, was selected data about voltage and power (Table 2).

Table 2

No. of train	Coordinate, km	Current, A	Voltage,V	Power, kW
N7	100,559	0	3296,1	0
N8	119,207	108,636	3285.1	356,874
N9	89,713	0	3288,1	0
N10	73,931	0	3261.9	0
N11	68,269	0	3267,8	0
N12	39,294	2102,44	2669,1	5611,612
N13	24,339	2477,24	2589.3	6414.324
N14	10,804	2360	2652,3	6259.352
N15	0	736,765	3079,7	2268,99
N16	28,238	1080,08	2563.4	2768,683
N17	12,114	0	2734,5	0
N18	30,835	0	2632,3	0
N19	62.08	0	3262	0
N20	75,295	458,648	3218.1	1475,96
N21	113,962	0	3292.6	0

As can be seen from the results of the analysis, some trains were in traction mode, and some were in idle mode. The maximum current consumption of train N13 is 2477,238 A in the odd direction. The voltage on the pantograph of the rolling stock is outside the permissible values (Fig. 3). If we look to the N17 and N18 passenger trains running in a pairwise direction, one can notice that these two trains are in idle mode, but the voltage on pantograph is beyond the permissible values. This can be caused by the consumption of significant traction current by trains located near these trains N17 and N18. Fig. 4, in turn, shows the power consumption of trains on the tested section.

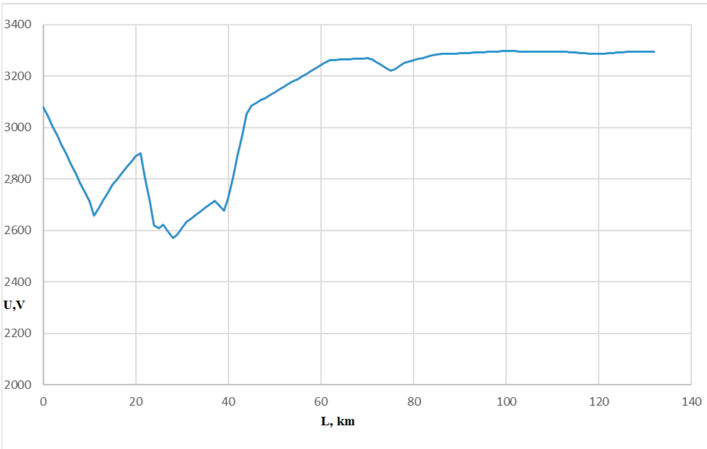

Fig. 3. Voltage distribution on the 1st track

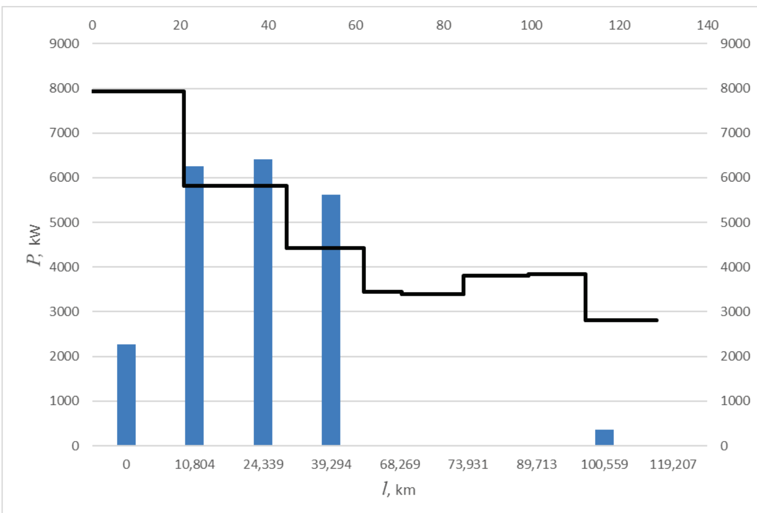

Fig. 4 Power consumption per kilometer while running on the 1st track: solid straight line - specific power of the traction line, columns - power consumed by electric locomotives

The results of the calculation for the maximum mode (in this timetable - 125 minutes) are shown at Fig. 5.

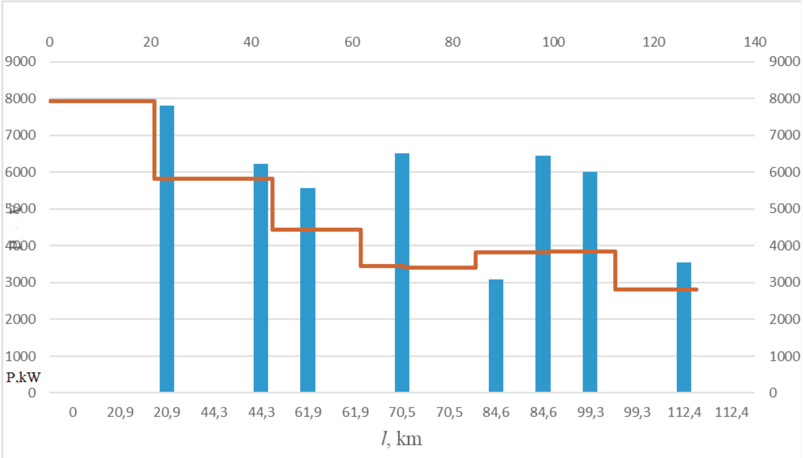

Fig. 5 Power consumption per kilometer during running (maximum number of trains in traction mode)

The analysis of the obtained results shows that in some substation zones the instantaneous power consumed by the traction load exceeds the power generated by the traction substations, which, in turn, decrease the voltage at the rolling stock pantograph below the normative value. Thus, the results of the studies revealed two problems:

- analysis of train timetables shows that in cases of increased power consumption the voltage level decreases;
- in the traction lines there are zones of limited power consumption, ie, zones where the power consumption of the rolling stock exceeds the energy consumption of the traction power supply system, which reduces the speed.

To eliminate these problems, we have changed not only the order of alternation of trains on the section, but also the intervals between these trains. The results of the calculation for the updated train timetable are presented at Fig. 6.

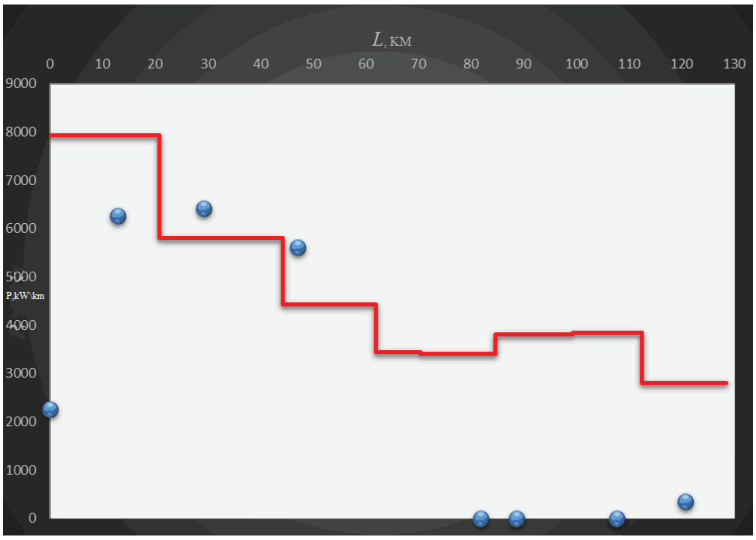

Fig. 6 Power consumption per kilometer while running on the 1st track when the train schedule varies

The analysis of the obtained data shows that the optimization of train timetable can decrease the power consumption of the rolling stock, but in some cases there power supply is limited. For this reason, there is a need for optimization of the traction power supply system. For this purpose it is necessary to install additional generating capacities at points with following coordinates: 40 km and 50 km. Taking into account the current trends in power supply system development, the task of location of additional generators can be performed by using a hybrid, asymmetric traction system [9].

3. Conclusions

To eliminate the limitations in the operation of the electrified section, the approach of optimizing the intervals between trains and reformatting the train timetable was applied in the work. When constructing an optimized train timetable, the train intervals were determined for cases with minimal energy losses in the traction line, taking into account the actual specific power of the traction network while providing the required voltage mode. At the same time, the average voltage level on the limiting sections increases by 7% and the length of the electrified sections limiting in terms of specific power decreases significantly.

At the same time, in order to eliminate the possibility of the emerging of power supply sections limiting the required train flow and to ensure the necessary stability in terms of voltage and specific power, it is necessary to optimize the power supply circuits of the traction line. It can be performed using a new power supply circuitry of electric rolling stock with the use of active means of strengthening the traction line with electricity generators and their asymmetric location in places of localization of voltage instability during the intensification of trains.

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The Impact of Temperature and Wear on Li-Po Accumulators Discharge Characteristics

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Abstract

The goal of our work was to find out the effect of ambient temperature on the discharge characteristics and the useful energy density of lithium polymer accumulators and whether these parameters are affected by age and wear of these accumulators. The knowledge of the Li-Po accumulators limitations allows efficient and safe usage. Low temperatures have a negative impact on the available accumulator capacity, especially of the older accumulator. High temperatures, on the other hand, increased the capacity of accumulators. The new accumulator was less affected than the older one.
KEY WORDS: *Lithium-Polymer, accumulator, battery, energy density, capacity, temperature, vehicles, UAV*

1. Introduction

Unmanned aerial vehicles (UAV) are experiencing significant growth around the world. With the technology development process, these machines have become very quickly available and suitable. The use of industrial applications is particularly attractive due to the reduced costs compared to other solutions. To use UAV effectively, we need to know the limitations of energy sources.

This paper is focused on the influence of temperature environment, age and wear of Li-Po accumulator discharge characteristics. Li-Po accumulators are currently the most applied energy source in electromotor driven UAV. Especially because this type of propulsion and power source combination is very user-friendly. A comparison between Li-Po accumulators and other electrical energy sources for electric motors is in Table 1.

Table 1

Energy density and specific energy of electromotor energy sources [1-5]

Energy source	Energy density [MJ/m^3]	Specific energy [MJ/kg]
Li-Po accumulator	1 440 – 2 628	0.54 – 0.936
NiMH accumulator	720	0.216 – 0.432
Pb accumulator	100 – 900	0.04 – 0.140
Supercapacitor	50 – 60	0.01 – 0.036

Table 1 shows the advantage of a lithium-based accumulator. Nickel metal hydride (NiMH) accumulators are an alternative if a price is more important than energy density. On the other hands, lead (Pb) accumulators are not suitable due to weight and dimension. Super-capacitors have a high energy density, but we cannot compare it with Li-Po or NiMH accumulators. Super-capacitors were mainly developed for combined systems as energy storage with the capability to discharge large currents rapidly.

Energy density and specific energy are not the only parameters that make Li-Po accumulators the most used energy source for UAV. Li-Po accumulators have a relatively high nominal cell voltage 3.7 V, no memory effect, low self-discharge and easy state of charge. Moreover, accumulators are the environment friendly [3]. There is a wide variety of Li-Po accumulator types, each with specific advantages and disadvantages [1].

It is important to remark the differences between Li-Ion and Li-Po accumulators. The main distinction is that Li-Ion accumulator uses liquid electrolyte and the Li-Po accumulator uses polymer electrolyte. Furthermore, Li-Po accumulators are more expensive, however, they are lighter and do not need a hard case. It is important to know the limits of technology because we can make the correct decision of application.

The objectives of practical measurements can be summarized as follows:

- How does the ambient temperature affect discharge characteristics and energy density?
- Does age and wear of the accumulator affect these characteristics?

2. Materials and Methods

For the measurements were used accumulators PECKA-POWER LiPo – 3S 2200 mAh 11.1 V 3S1P 35 C. Thus,

these accumulators have 3 cells connected in series with a nominal voltage of 11.1 V and the indicated capacity of 2200 mAh which is 24.42 Wh (as indicated on the packaging).

$$I[A] = Cr \cdot C\ [Ah]. \tag{1}$$

“I” is current in Amperes, Cr is the given value C of accumulator and C is electric charge of the accumulator in Ampere hours. The accumulator manufacturer specifies a maximum continuous discharge current of 35 C and a maximum peak current of 50 C. This corresponds to a current of 77 A and 110 A respectively for peak load according to (1). The maximum charge current is listed as 1 C, i.e. 2.2 A. The accumulator dimensions are 105 × 35 × 23 mm and weight is 190.6 g. However, the weight and size thus given complicates the calculation of energy density and specific energy which values are then lower.

$$E[J] = 3600 \cdot E\ [Wh]. \tag{2}$$

“E” is the energy in Joules and Watt hours. The stated energy of the 24.42 Wh can be converted using equation (2) to 87 912 J. This value can be converted to 0.087912 MJ. Using this value, weight and dimensions of accumulator, we obtain a specific energy of 0.46124 MJ/kg and an energy density of 1040.07 MJ/m3. These values are considerably lower than those indicated in Table 1. This may be due to the packaging of the particular manufacturer and to the aforementioned cables. Balance cables allow protection against discharge below recommended voltage and to charge to higher than recommended voltage. However, this depends on the settings of the charger or appliance. Balance cables will only get information about voltage of each individual cell to the charger or appliance. Manufacturer of our accumulator does not know and does not mention the sub-type of Li-Po accumulator.

Two accumulators were used. One brand new and one few years old and worn. The old accumulator has already suffered from inflation, which indicates considerable degradation. This wear condition also indicates that the accumulator was not ideally handled. Such considerably different accumulators allowed us to compare well observed characteristics.

For charging and discharging was used Robbe Power Peak I4 EQ-BID 8507. Charger is able to charge 1 to 12 Li-Po cells with current from 0.1 to 10 A (maximum 210 W) and discharge them from 0.1 to 5 A (maximum 50 W). It also has the option of connecting a battery balancer, ensuring even charge of individual cells. During charging and discharging it can discontinue when pre-set voltage limit is reached by any of the cells. Charging of Li-Po cells works automatically on the principle of constant current – constant voltage method (CC-CV). Using this method, the accumulator is first charged with a constant maximum possible current (CC), which is adjustable (determined by the C parameter of the accumulator). At the same time voltage increases. When the voltage reaches the maximum cell voltage, which is pre-set for Li-Po cells to 4.2 V/cell and is also generally accepted voltage as maximum possible, charging switches to constant voltage mode (CV). In this mode, the charger outputs this maximum voltage and gradually decreases the current. As soon as any cell reaches 4.2 V, the charger discharges this cell by several hundredths of V using balancing cables and then continues charging the entire battery. This process may take a long time (a maximum current of 300 mA is used during balancing), especially for older and worn accumulators, which have a significant cell voltage difference. Once the voltage of all cells is within range, charging is terminated [7]. The charger and accumulator connection have been accomplished with appropriate connectors of sufficient length to allow for safe placement of the charger. The temperature measurement function with an external sensor connected to the charger was not used due to the low temperature range it can sense.

The charger was connected to a personal computer via a USB port. The installed Logview software enabled monitoring of existing accumulator and exported them to .csv format.

The charger required an input voltage if 11 to 15 V DC. For this purpose was used a switched power supply Power X-40 supplying 13.8 V and a maximum of 40 A (approximately 550 W).

Initially, a series of charging and discharging cycles with both old and new accumulators was conducted. These test measurements were used to gain experience and resolve any process deficiencies.

During the measurement, the main observed parameters were total voltage, cell voltage and transferred energy converted to the capacity given in mAh. The accumulators were left for a few hours at rest, room temperature and charged before each experiment. The first step in the measurement was to ensure that the accumulator was fully charged (4.2 V/cell) by plugging it into charge and turning on the charging process. Once the charging process was complete, the accumulator was left for 10 minutes. This is due to the internal temperature of the accumulator, which may increase during charging. This time was chosen because during the last charging phase, the temperature in the accumulator is basically not rising, due to the very small charging currents. After this, the charger was set to start the discharging program with setting to discharge at 48 to 50 W and a maximum of 5 A. Thus, only with a C value of about 2.27, which is safely below the maximum value of the accumulator. Discharging was automatically stopped as soon as any cell of the accumulator reached 3 V. After 5 minutes, charging to a maximum cell voltage of 4.2 V was initiated. Measurements were conducted in following temperatures 50°C, 22°C (room temperature), -5°C, -18°C.

3. The Result of the Measurement

Table 2

Capacity of accumulators during individual measurements

	Capacity [mAh]	
Measurement	**Old**	**New**
50°C	1516	2257
room temperature second time	1479	2249
room temperature after 50°C	1378	2245
room temperature 22 °C	1599	2236
room temperature after 5°C	1556	2230
room temperature after -18°C for 25 minutes	1291	2223
room temperature after -18°C	1230	2223
room temperature after -18°C for 20 minutes	1368	2222
5°C	1465	2172

	Capacity [mAh]	
Measurement	**Old**	**New**
-18°C	963	2134
-18°C for 10 minutes	1134	2126
-18°C for 25 minutes	17	2111
-18°C for 25 minutes second time	802	2106
-18°C for 20 minutes	974	2103
-18°C second time	950	-
-18°C for 30 minutes	3	-
room temperature after -18°C for 10 minutes	1420	-
room temperature after -18°C for 30 minutes	1309	-

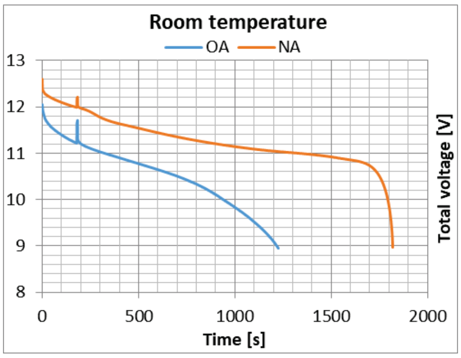

Fig. 1 Voltage drop over time at room temperature

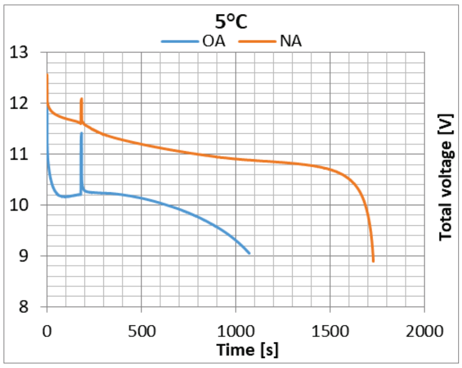

Fig. 2 Voltage drop over time at 5°C

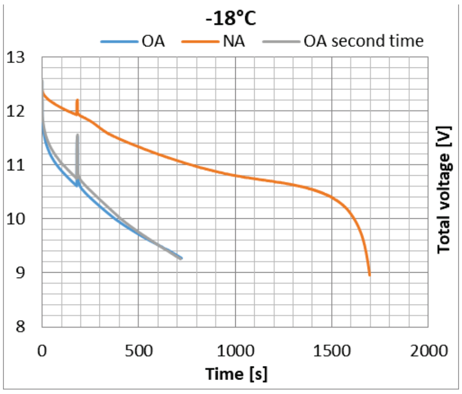

Fig. 3 Voltage drop over time at -18°C

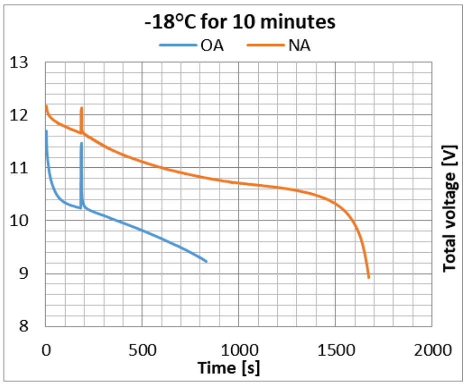

Fig. 4 Voltage drop over time at -18°C (inserted 10 minutes before discharge)

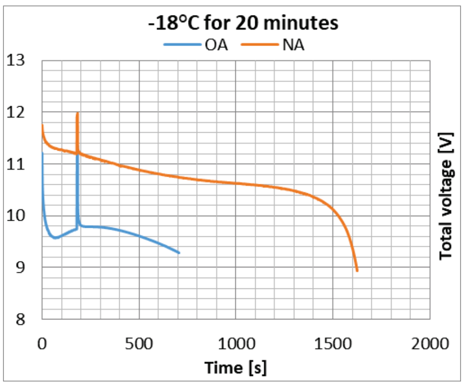

Fig. 5 Voltage drop over time at -18°C (inserted 20 minutes before discharge)

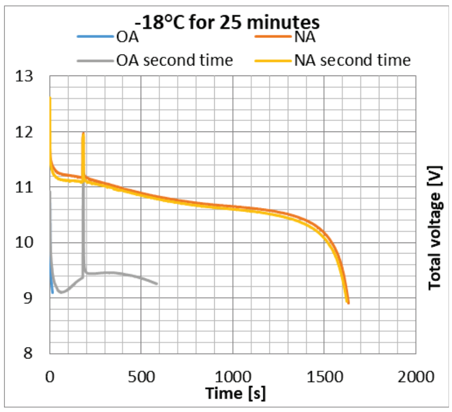

Fig. 6 voltage drop over time at -18°C (inserted 25 minutes before discharge)

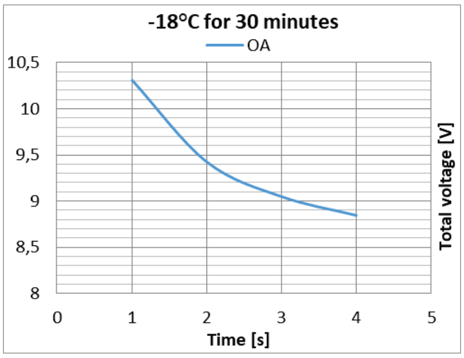

Fig. 7 Voltage drop over time at -18°C (inserted 30 minutes before discharge)

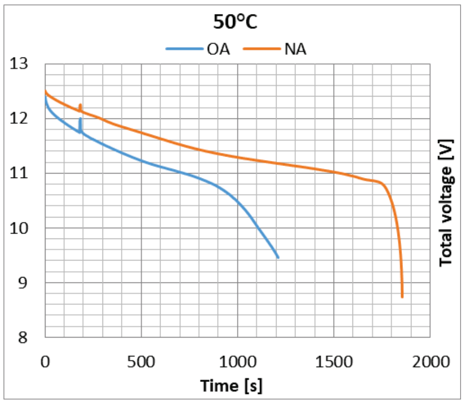

Fig. 8 Voltage drop over time at 50°C

4. Description

For the measurements were used accumulators PECKA-POWER LiPo – 3S 2200 mAh 11.1 V 3S1P 35 C. Thus, these accumulators have 3 cells connected in series with a nominal voltage of 11.1 V and the indicated capacity of 2200 mAh which is 24.42 Wh (as indicated on the packaging).

The difference between accumulators is obvious from Table 2. The capacity of the new one is almost its declared capacity of 2 200 mAh. While the worn accumulator has a capacity of about 1 500 mAh during the first measurements, which is only about 68% of the declared capacity.

The capacity of the old accumulator decreased as during measurements. On the other hand, the new accumulator retained its declared capacity at room temperature even after extreme temperatures. These results indicate that the age and wear of the accumulator has a significant impact on its ability to withstand extreme environments without consequences. Conversely, a new accumulator will survive a limited number of cycles in these environments without further consequences.

The discharge characteristics are shown in Fig. 1. The new one has a nearly linear drop in voltage over time to the point where the voltage starts to drop steeply. Therefore, for a longer accumulator life, it is preferable to set a higher discharge cell voltage limit than 3 V used in the experiments. With such a steep drop in voltage at the end of the curve, there is a risk of exceeding the 3 V threshold and degrading the cells. If we would end the discharge at the beginning of this severe voltage drop, at about 10.7 V and thus about 3.56 V/cell, the capacity used would be 2088 mAh at that time. This capacity is equal to 94.9% of the declared 2200 mAh capacity and 93.4% of the actual 2236 mAh capacity obtained in this experiment. For only 5.1 to 6.6% capacity, such a low threshold does not pay off and at least 3.5 V limit for normal use can be recommended. This will reduce wear on the accumulator, which is prone to undercharge and thus the service life increases. It should be remembered, that this limit varies according to the type of Li-Po accumulator. However, this applies only to the new accumulator. As we see on the second curve of Fig. 1 belonging to the old accumulator, 10.7 V is achieved very quickly. The accumulator has no significant drop at the end of the curve, but we see a steeper almost linear decline. For older and worn accumulators, it is worth setting a lower cell voltage limit when discharging. Apart from the obvious reason for the very low capacity at the higher limit, also for economic reasons. The accumulator should be replaced in the foreseeable future. Lower capacity may prevent use for the purpose for which it was originally intended. The lower limit will, therefore, help us to use it a little longer for this purpose. As the accumulator capacity begins to drop significantly, it is advisable to gradually reduce the cell voltage limit for discharge. This general rule can work well with any Li-Po accumulator type.

Measuring at 5°C a result with a slightly lower available capacity was expected. Fig. 2 and Table 2 show that this decrease is in units of percentage. Approximately 1.3% for the new accumulator compared to the declared capacity and 2.8% when compared to measured actual capacity (for further will be used as reference). At room temperature. 8.4% is then the capacity drop of old accumulator compared to measured capacity at room temperature. By comparing Fig. 1 and Fig. 2 we can observe a fundamental difference at the beginning of the curves. Here for the new accumulator, the voltage quickly dropped to 11.8 V compared to 12.2 V at room temperature after the start of the discharge process. The old accumulator drop is even more pronounced, reaching down to 10.2 V opposed to 11.5 V at room temperature. This decline can be expected to be much more distinct at lower temperatures (as will be seen in discussion later). Interestingly, the capacity difference is no more than 8.4% for the old accumulator despite a significant initial voltage drop. The explanation can be found in the next section of the curve. This decrease is followed by a slight increase in voltage despite the continuous discharge. The increase in voltage is caused by the heat generation inside the accumulators due to internal resistance. This internal resistance is a generally undesirable phenomenon that manufacturers are trying to minimize because it reduces the efficiency of accumulator energy transfer. But here it helps to warm up the accumulator and thus increase its usable capacity. If the effect did not exist, we could expect a similar or steeper curve than at room temperature measurement. Here we can see a significant difference between the new and old accumulators in the ability to withstand lower temperatures. The temperature increase inside the new accumulator cannot be detected on the curve. Thus, the internal heating provided us with similar curve as in the room temperature

measurement case. The capacity reduction can be seen on the curve in the initial voltage drop. After discharging was complete, the accumulators were subjectively warm (as well as after room temperature measurements). It can therefore be said that this heating alone reduces the effect of an ambient temperature of 5°C.

When evaluating Fig. 3, which depicts the measurement at -18°C, it is necessary to emphasize the difference from the measurement at 5°C. Into -18°C (Fig. 3), the accumulators were inserted, and the discharge program was initiated immediately. In contrast, accumulators were put into 5°C temperature for several hours to allow them to reach this temperature fully. We can see a further decrease in available capacities. It is only 4.6% for the new accumulator, but 35.8% for the old accumulator from the room temperature reference measurements. This result again demonstrates the new accumulator’s high ability to withstand adverse temperature conditions. The worn accumulator had a very significant drop in accumulator in capacity. On the curve of the new accumulator we can see a steeper course than on the Fig. 1. However, the shape of the curve remains similar. We may also notice, that there has not been a sharp initial drop in voltage. Thus, if there is no hypothermia of the accumulator and the discharge process starts immediately after the transition to low temperatures, we can expect such good results. There were two measurements with the old accumulator in this experiment. There is no significant initial drop in in voltage as in Fig. 2, but it is nevertheless larger than at room temperature (Fig. 1). Of course, there is a noticeable steep decrease in voltage across the curve. The curve misses the characteristic arc seen in the previous figures. The measurement of the old accumulator was conducted as the 14th and 16th respectively and is affected by the degradation of the accumulator (as stated in the beginning of the paper).

Fig. 4 shows the measurement when the accumulators were inserted into -18°C for 10 minutes before discharging. New accumulator has registered a 5% drop in capacity and the old 25% drop of reference value. The capacity drop for the new accumulator was not significant compared to the Fig. 3. We can see a rapid initial voltage drop to approximately 11.9 V. However, the next progression of curve is very similar to the 5°C measurement apart from its steeper profile resulting in a shorter discharge time and lower capacity. The old accumulator also experienced a rapid initial voltage drop to 10.4 V. The initial voltage drop of both the old and the new accumulators compared to a drop of 5°C suggests that the accumulators did not cool down sufficiently in these 10 minutes at -18°C. However, it is clear from the further comparison of the curves, why the total capacity is lower. The reason for this is the inability of the heat generated by the internal resistance to compensate for the continuous residence at lower temperature. The curves are therefore steeper, and the capacity is lower. Especially in the case of the old accumulator curve we can observe the absence of voltage increase during the discharge (after initial drop), which is present in the Fig. 2. In Fig. 4, the curve after the initial decrease is rather linear.

Fig. 5 shows measurement at -18°C with the accumulators inserted 20 minutes before the start of discharge. We can see a further reduction in capacity of both accumulators in Table 2. 6% for the new and 35% drop (from the reference values) for the old accumulator. Again, a significant initial voltage drop can be observed. For new accumulator to 11.3 V and for the old even to 9.6 V. After this drop, the new accumulator’s curve is similar to other measurements at -18°C. The old accumulator has a significant increase in voltage after approximately 0.2 V and the curve is like that in Fig. 2 (5°C). Here again, the contribution of internal resistance can be emphasized. 20 minutes was enough time to cool the accumulators to display a significant drop in voltage. Thus, caution is needed when using older accumulators at high currents, which could drop voltage below set limit.

Fig. 6 depicts the discharge of the accumulators kept at -18°C for 25 minutes before initiation. In this case, both accumulators were measured twice. For the new one, there was a decrease from the reference capacity of 5.6 and 5.8%. For the old then 98.9 and 46.5%. It is again confirmed, that the new accumulator is well resistant to low temperatures. 5 minutes more than the previous attempt, it did not reduce its useful capacity. We can observe the standard curve we expect here at -18°C. An initial voltage drop of approximately 11.2 V was expected. The old one had even worse results with these additional 5 minutes in the freezing environment. In one of these two measurements, the old accumulator’s voltage dropped below the set limit and had essentially zero capacity. The drop in the second measurement was to about 9.1 V. Which is similar to one, where cell voltage limit was reached. However, none of the cells crossed the limit value here, but one went down to 3.002 V. Only another 2 mV away from reaching the limit before the voltage began to rise. In both experiments, the voltage is so close to this limit that it would be enough to increase the current draw and the cell voltage limit would surely be exceeded. The second attempt with the old accumulator is again marked by a significant increase in voltage after the initial drop, caused by internal resistance and heat generation. This time it the increase is by about 0.4 V. It is interesting to observe that the total voltage in time of end of discharge (when some cell drops below limit) is higher than during the initial drop.

Table 3

Voltage limit values of old accumulator during -18°C for 25 minutes discharge measurement

	Total voltage [V]	Cell 1 voltage [V]	Cell 2 voltage [V]	Cell 3 voltage [V]
Initial drop	9,116	3,009	3,21	3,002
Discharge end	9,258	3	3,357	3,007

As we can see in Table 3, this phenomenon is due to the higher voltage of cell 2. This cell is in better condition than the other two and has better performance at this temperature. However, this is irrelevant for the total accumulator capacity. The whole accumulator depends on the properties of the worst (or weakest) cell. It can be assumed that cell 2

is in the center of the accumulator between cells 1 and 3. Thus, it is much more heated during discharge. We can mark this length of stay at -18°C as the limit for the older accumulator and it cannot be recommended for real environment usage at all. Higher temperature or shorter time should reduce the effect. But any temperature below 0°C should be treated with respect. Especially for the effect of initial voltage drop. If we do not draw sufficient current from the beginning of use, the accumulator will not heat up, and this will virtually prolong time spent in the freezing environment. Conversely, if we take too much current, there is an immediate drop below the set limit. It is therefore necessary to find a compromise and start discharging as soon as possible, but gradually. This will reduce accumulator wear and increase usable capacity. The older the accumulator is, more worn it is or more "inflated" it is, the more it will be prone to the phenomena described.

Fig. 7 displays a measurement with an old accumulator at -18°C stored there for 30 minutes before beginning of discharge. For the reasons described in the previous chapter, only the old accumulator has been tested. As we can see, the voltage dropped immediately below the limit value and discharge was terminated.

In Fig. 8 we can observe the curves for measurement at 50°C. Capacity increases were expected from measurements at higher temperatures. The new accumulator showed an increase of 0.94% from the reference value and 2.6% from declared value. The old accumulator then had increased capacity by 1%. From the reference value. However, it is important to note that this measurement of the old accumulator was done when some degradation was already noted. If we take, as a reference for the older accumulator, the value of the last measurement at room temperature, then the increase is 10.8%. The first thing that can catch our attention on the curves is their greater similarity to room temperature ones. The curve of the new accumulator is steeper at the end and therefore hold the voltage at the nominal level longer. The old accumulator has a more pronounced drop in voltage at the end of the curve and is more alike new accumulator curve. Of course, as we can see, the accumulator did not maintain the voltage as long as the new one. But it can be seen that, the higher temperature was positive for the discharge process. The initial voltage drop we observed in previous measurements Is also present, but its effect is considerably smaller. Even smaller than at room temperature. For the new accumulator drop is to only 12.4 V and for the old one to 12.15 V. So, there is no risk of crossing the limit value for end of discharge even for older accumulator and with strong initial load.

5. Conclusion

In conclusion, higher temperatures improve accumulator chemical reactions. It is particular to help older accumulators to increase their exploitable capacity. However, the temperature does not have a cardinal effect on the new accumulator. Nevertheless, periodically exposing Li-Po accumulators to the high temperatures reduces their lifetime. Even at 45°C there is a reduction of cycles by up to 50% compared to usage at 20°C [5].

Conversely, low temperatures slow down chemical reactions inside the accumulators and increase internal resistance. Increased internal resistance reduces energy transfer efficiency, what's more, also causes significant heat the cells up. Similarity, the cell voltage increases and discharging was initiating. The effect of heating reduces the internal resistance, on the other hand, it increases the efficiency of the energy transfer. The accumulators suffered a rapid voltage drop at the beginning of the discharge, which was pronounced for the older accumulator during a lingering at low temperatures.

The measurements, where we kept accumulators in a cold environment for a long period shown older accumulator as unfit, due to the voltage immediately dropped below the preset limit when the discharge was initiated.

This document presents the overview of environment temperature effects on Li-Po accumulators. Furthermore, there is proves a temperature influence on accumulator depend on lifetime.

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Future Stations Solutions within IN2STEMPO Project of Shift2Rail

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Abstract

One of an important element of the railway system are stations. They are addressed in the project "Innovative Solutions in Future Stations, Energy Metering and Power Supply" called IN2STEMPO within Shift2Rail Joint Undertaking of Horizon 2020. The IN2STEMPO Future Stations project's actions lead to improve the quality of customer service and safety at stations, thus providing better experience for passengers using the railway. Research is focused on improved station concepts and responds to evolving passenger needs in terms of information, technologies, punctuality, crowd management, accessibility including persons with reduced mobility, to transit busy stations and to switch modes.
KEY WORDS: *Future Stations, Shift2Rail, Rail Transport, Research and Innovation, Horizon 2020*

1. Shift2Rail Joint Undertaking

The 'railway of the future' must meet the predicted increase in customer's demand in relation to provided services, meet the environmental challenges of the 21st century, and achieve the European Union's policy objectives. The European research and innovation program for rail is currently the Shift2Rail Joint Undertaking (Shift2Rail), which is a separated initiative established under Horizon 2020 dedicated entirely to rail transport [9]. The Shift2Rail is a new public-private partnership launched for the period 2014-2024 to coordinate research activities and provide innovations through a comprehensive approach focusing on the needs of the rail sector [3, 6]. Shift2Rail as a platform for conducting scientific research has an overreaching goal to integrate research and innovation results in relation to passenger rolling stock, freight transport, traffic management systems and infrastructure from the concept stage to market launch. The core objectives of setting the Shift2Rail are following [11]:

- support the creation of a Single European Railway Area (SERA) leading to achieve seamless rail transport across the Europe. This should be done by removing technical barriers hindering the railway sector in the field of interoperability ensuring that technical solutions work properly together;
- radical strengthening of the competitiveness and attractiveness of the European railway industry, which is facing the growing competitiveness of producers from the United States and Asia;
- maintaining and strengthening the leading position on the global market in relation to rail products and services through R&I activities that will provide competitive solutions and by stimulating and accelerating the introduction of innovative solutions to the market.

The objectives of Shift2Rail are to be achieved by supporting research and innovation (R&I) related activities with public and private sector funding. The Initiative is partly financed from the budget of the eighth framework program Horizon 2020 from European Union funds, and partly from funds from private entities.

In addition to the European Union, which is a Founding Member of the Initiative, Shift2Rail has eight other Founding Members and nineteen Associate Members, selected through a two-stage competition announced in 2014, who declared a significant financial contribution towards the implementation of Shift2Rail's long-term goals as laid down in the Master Plan [7, 8]. The Founding Members include key producers: Alstom Transport, Ansaldo STS, Bombardier Transportation, Construcciones y Auxiliar de Ferrocarriles (CAF), Siemens AG, Thales as well as infrastructure managers: Trafikverket and Network Rail. The following entities have obtained the status of an Associated Member: the AERFITEC consortium, Amadeus IT Group SA, AZD Praha sro, the CFW consortium, Deutsche Bahn AG, DIGINEXT, the EUROC consortium, Faiveley Transport, HaCon Ingenieurgesellschaft mbH, Indra Sistemas SA, Kapsch CarrierCom, Knorr-Bremer MER MEC SpA, Patentes Talgo SL, consortium Railenium Swi'TRACK'EN, consortium Smart DeMain, consortium SmartRaCon, SNCF, consortium Virtual Vehicle Austria. Participation in Shift2Rail is also possible for stakeholders who are not direct members of the initiative, through open calls for submitting project applications as part of open competitions announced by Shift2Rail.

According to the EC decision, the estimated total budget of Shift2Rail is EUR 920 million [7]. The EC's contribution to the initiative is EUR 450 million and comes from Horizon 2020. Compared to the previous seventh framework program (2007-2013), the EC's financial support for research activities in the railway sector has increased more than tripled. The remaining financial contribution to Shift2Rail is 470 million euros and comes from the Founding Members (270 million euros) and Associate Members (200 million euros).

The activities of the Shift2Rail are identified in a common, forward-looking strategic Master Plan and are organised around five key "Innovation Programmes" [5, 8]:

IP 1: cost-efficient and reliable trains, including High-Speed and high-capacity trains;
IP 2: advanced traffic management & control systems;

IP 3: cost-efficient and reliable high capacity infrastructure;
IP 4: IT Solutions for Attractive Railway Services;
IP 5: Technologies for Sustainable & Attractive European Freight.

Each of the IP identifies the challenges, objectives and research activities to be implemented through the research and innovation projects.

2. IN2STEMPO Project

The IN2STEMPO project addresses the topic of "Smart system energy management solutions and future station solutions" of the 2017 Horizon 2020 Shift2Rail Call for proposals for the Joint Undertaking Members (S2R-CFM-IP3-01-2017) [10]. The IN2STEMPO is related to the IP3 (Fig. 1).

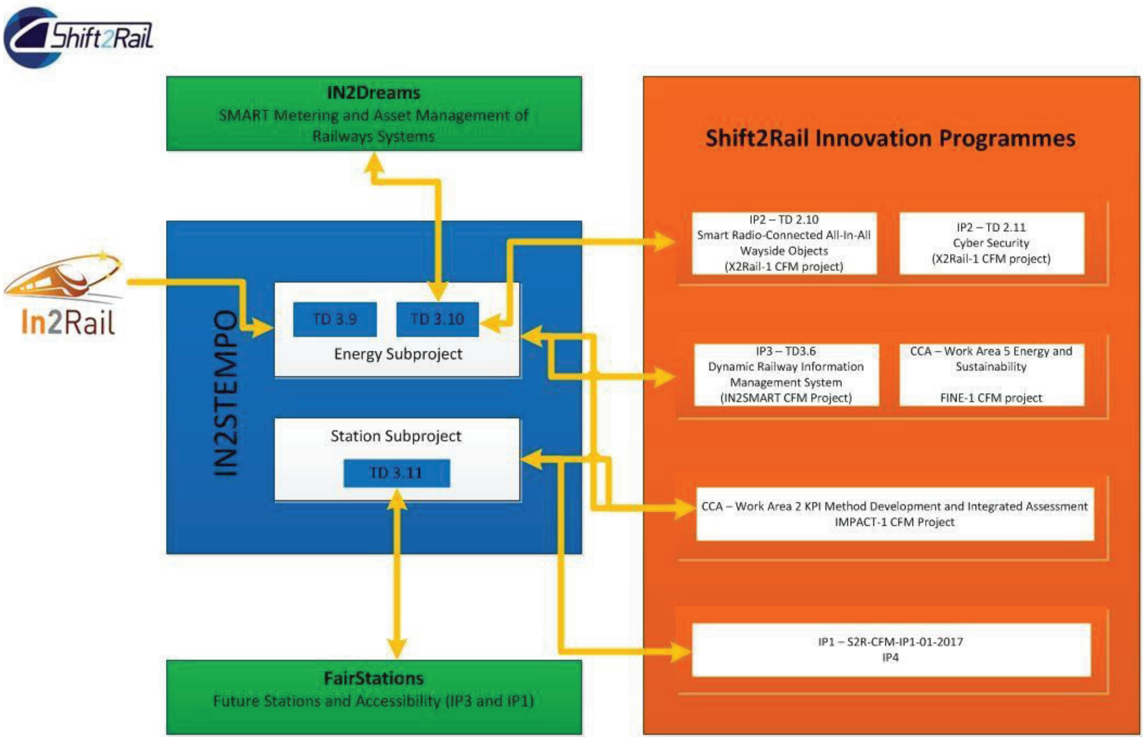

Fig. 1 Relation of the IN2STEMPO project with Shift2Rail Innovation Programmes [2]

The project started on 1st September 2017 and will continue until 31st August 2022 under the coordination of Network Rail. The consortium consists of nineteen participants and eight Linked Third Parties (LTP) (Fig. 2). IK Railway Research Institute is a linked third party of Polskie Koleje Państwowe (PKP). The total budget of the project yields of 13.6 M€ with max. EU contribution of nearly 6 M€.

The ambitions of Shift2Rail which are inherited by IN2STEMPO project require substantial ground-breaking improvements in the energy technology area and station area addressed by the project. All of the individual Work Package task activities have been developed with respect to the technical progress beyond the current "State of the Art".

The railway stretches across most of Europe and impacts millions of lives. It contributes to economic and social development, bringing jobs, transport links and other benefits to local communities. It is also increasingly a relatively clean form of transport that is a contributor towards reducing global CO_2 emissions, improving air quality and proactively manage biodiversity. These are collectively termed as the 'three pillars of sustainability':

1. People (Social Impact) – the railway has a long history of improving the quality of life for people who are able to use it. This includes local job creation and increasing incomes, increase in local businesses and recreational facilities, reduction in social deprivation and provision of local, regional and long-distance transport.
2. Planet (Environmental Impact) – the railway provides a means of low-carbon transport for both passengers and freight and is a key part of reducing carbon emissions and tackling future climate change. It can also significantly improve air quality in major cities and contribute towards improving biodiversity and the local ecology.
3. Profit (Economic Impact) – improving rail infrastructure has a positive impact on local businesses and national GDP. Improving the connectivity of national cities as well as European countries will also increase tourism and other commercial activities (retail, leisure etc) [6].

The IN2STEMPO research contributes towards these three pillars of sustainability and will further enhance and expand on the benefits experienced by local communities and wider European society.

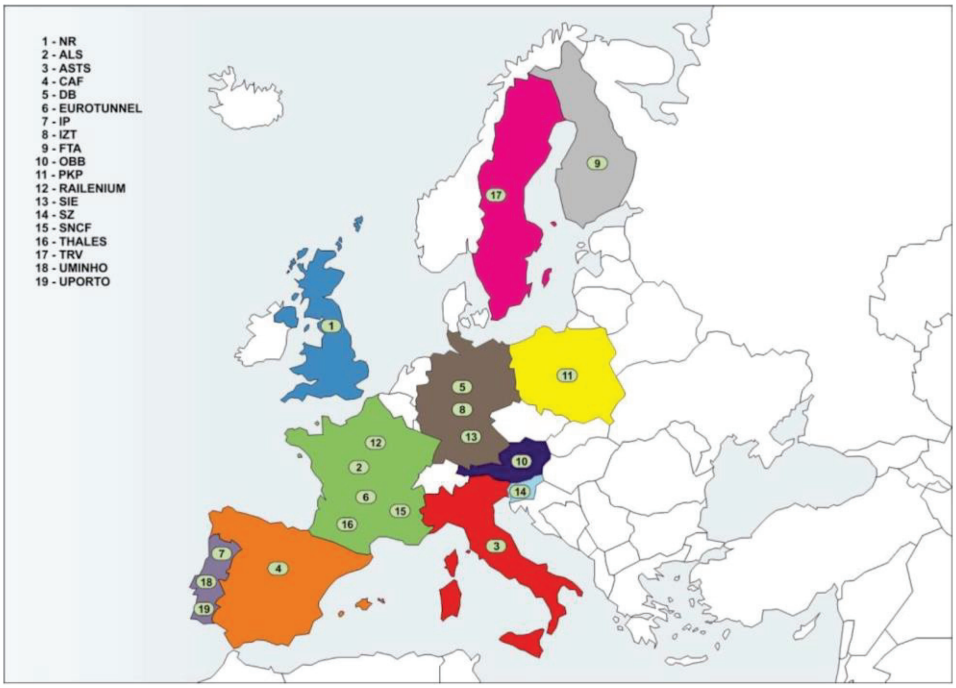

Fig. 2 IN2STEMPO project partners

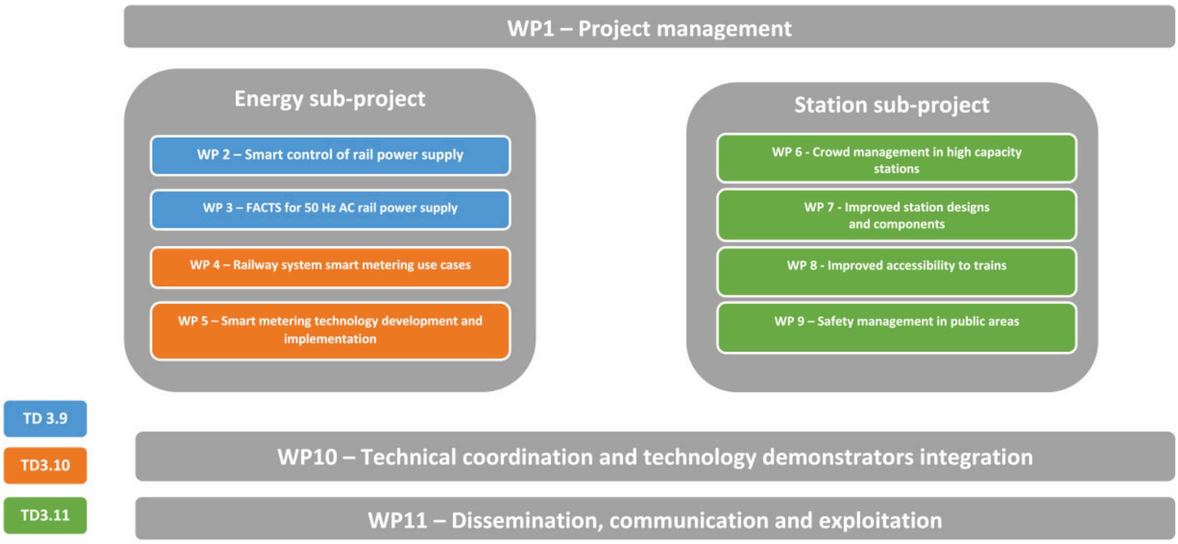

Fig. 3 Work packages of the IN2STEMPO project

IN2STEMPO fulfills the Shift2Rail objectives and aims to develop criteria for intelligent, economical and user-friendly high-capacity stations, taking into account functional aspects for all categories of passengers (elderly, blind, with limited mobility), safety standards, solutions for multimodality and interoperability, reduction of energy consumption, systems passenger information and small stations and their importance for the European rail network. The IN2STEMPO is divided into two sub-projects: energy and stations (Fig. 3).

Smart Power Supply means combining energy resources into one network, forming a system of interconnected vessels. Such a network will enable the integration of smart metering data collection systems, innovative power electronic devices, energy management systems and energy storage systems. This will improve train operations, reduce electricity costs and increase the security of energy supply for rail infrastructure. The system will be useful not only at the operation and maintenance stage, but also at the investment stage.

Intelligent metering systems consist in creating a network of intelligent metering sensors in the railway system. Within the system, it will be possible to aggregate and analyse data. Applications used in the system will allow for energy analysis, which will be used to improve decision-making on the energy used. Within the system it will be possible to create preventive maintenance plans, improve the process of asset management, as well as life cycle cost management.

The IN2STEMPO Future Stations objective is to improve customer experience and security in large and high capacity stations during standard operations and emergency cases. Research is focused on improving passenger flows management in high capacity stations, station design and components, accessibility to trains for all user groups and new

ticketing technologies, leading to increase capacity, enhancing interoperability and providing better experience for passengers using the railway.

3. Future Stations Concept

The IN2STEMPO Future Stations project is a challenge to develop a station design method using cost-effective solutions and technologies that will have a positive impact on station management. A railway station is a showcase for rail transport, so customer growth can be achieved by improving passenger service and experience at the stations.

The subproject "Future stations" focuses on four work packages:

- Crowd management in high-capacity stations: a tool for crowd management, especially in emergency situations, will be developed in order to ensure a smooth journey from start to finish as well as to support operational strategies (WP6);
- Better station designs and elements: typical small station designs will be developed to allow low energy consumption and the use of modern materials to meet passengers' needs (WP7);
- improving train availability - platform-train interface: proven methods will be provided to ensure safe crossing of the space between platform edge and train floor edge (WP8);
- safety management in public areas: improve security within the station and in the public areas immediately surrounding the station including specification development of resistant materials (including glass) – WP9.

The following partners participate in the WP6÷WP9 packages:

- Network Rail Infrastructure Limited (NR);
- Ansaldo STS S.p.A. (ASTS);
- CAF Turnkey & Engineering Sociedad Limitada (CAF);
- Infraestruturas DE Portugal SA (IP);
- Liikennevirasto (FTA);
- OBB-Infrastruktur AG (OBB);
- Polskie Koleje Państwowe Spółka Akcyjna (PKP);
- Slovenske Zeleznice DOO (SZ);
- Thales Services SAS (THA).

The following linked third parties are involved in these packages:

- Construcciones y auxiliar de Ferrocarriles Investigación y Desarrollo, S.L. (CAF I+D), affiliated or linked to CAF;
- IP Patrimonio - Administracao E Gestao ImobiliariA, SA (IP Patrimonio), affiliated or linked to IP;
- Hameen Ammattikorkeakoulu OY (HAMK), affiliated or linked to FTA;
- Instytut Kolejnictwa (IK), affiliated or linked to PKP;
- Promeni Institut Ljubljana DOO (PI), affiliated or linked to SZ;
- Slovenske Zeleznice-Potniski Prometdruzba ZA Opravljanje Prevoza Potnikov V Notranjem In Mednarodnem Zelezniskem Prometu DOO (SZ-PP), affiliated or linked to SZ.

4. Role of IK in the Project

IK conducts the research in the following work packages of IN2STEMPO:

- WP06 - Crowd Management in High Capacity Stations;
- WP07 - Improved Station Designs and Components;
- WP08 - Improved Accessibility to Trains - Platform Train Interface;
- WP10 - Technical Co-ordination and Technology Demonstrators Integration;
- WP11 - Dissemination, Communication and Exploitatio.n

Work Package 6 aims to improve the safety of large stations both in normal operation and in emergency situations, which will have a positive impact on passenger experience. The task uses a 3D simulation system, implemented on the basis of the existing station, which will allow to provide a solution in the TRL6 phase. IK participates in behaviour models definition and integration of data sources, models and crowd simulation.

In work package 7, the work focuses on improving the design of small stations. This will enable reduction of construction and maintenance costs of such facilities.

Work Package 8, which is coordinated by IK, includes the following tasks:

- improving safety in the Platform Train Interface (PTI), thereby increasing the accessibility of trains for all groups of passengers;
- indication of methods to allow safe access to trains with different floor heights while maintaining a short period of platform occupancy by the train;
- analysis of parameters related to PTI (different floor heights in trains, platforms in the curve) in the context of the impact on accessibility;
- Presentation of new PTI solutions to improve train availability conditions at existing stations.

Work Package 10 aims to ensure the coherence of the project with other IN2STEMPO activities. The

coordination will benefit from the integration of the work package leaders' activities and streamline organisational work in the project.

The tasks in work package 11 are to disseminate the results and outcomes of the project, especially to target groups (e.g. railway operators). Thanks to the creation of effective communication tools, the conclusions of the project can be used by a wide audience.

5. Progress of Work in the Project

The first phase of the project consisted mainly of verifying the state of the art on the issues under consideration and creating assumptions for planned analyzes. A great added value in the project is the presence of representatives of countries where there is a railway network with different technical parameters - several nominal track widths, as well as various gauges that are related thereto. Team members include representatives of infrastructure managers of individual countries, which is helpful in analyses carried out in the project due to the easy availability of valuable data. Communication between team members takes place through face-to-face joint meetings several times a year, periodic teleconferences, as well as by phone and e-mail.

The WP6 package has started substantial analytical work on crowd management at large stations. The analyses are conducted on the basis of the existing station with high passenger traffic.

A technical demonstrator was designed in the WP7 package in the form of a station object with low traffic load. It plans to use innovative materials and technologies.

The WP8 package analysed the problems associated with the platform-train interface that occur in various European countries [1]. Work on creating assumptions for the technical demonstrator has begun.

6. Conclusions

Railway stations in large agglomerations have become large centers of commercial, service and social activities. As a result, there are problems related to congestion, lack of comfort for passengers and the need to ensure safety in crisis situations.

The objective of the Future Stations is to optimise station management by creating cost effective solutions and developing technologies. It also aims at improving the customer experience at stations and delivering better services, ultimately, resulting in an increased number of railway customers.

Improving the offer of rail services requires a focus on customers' needs, including passengers with reduced mobility. This goal can be achieved, among others, through extensive use of universal design, which not only passengers with reduced mobility, but also other groups of passengers will positively feel [2, 4].

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Strategy of Selected Cities of the Czech Republic in the Field of Transport from the Perspective of City Logistics: Qualitative Comparative Analysis

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Abstract

The issue of city logistics is very current topic not only from the point of view of city dwellers, but also from the perspective of state administration and self-government and other stakeholders. Transport and transport management are the key pillars of the city logistics system. Cities regularly develop strategies and strategic documents in the field of transport. The Czech Republic is administratively divided into fourteen regions with twelve regional capitals and the capital city Prague. Each city develops transport strategies and related strategic documents. The aim of the article is to analyse strategies of these cities of the Czech Republic in the field of transport from the perspective of city logistics. The method of content analysis was used to analyse strategic documents of selected cities and the method of qualitative comparative analysis was used to analyse and compare the strategic documents of selected cities.
KEY WORDS: *transport management, city logistics, strategic documents*

1. Introduction

The modern logistics industry has become an increasingly important part of the modern economy, which is flourishing worldwide with the rapid development of the world economy and the development of technology and science [1-3]. The logistics industry is the leading sector in the development of the national and international economy. The challenges of coordinated development of the city economy and logistics have attracted great attention [4].

Due to the increasing volume of traffic and the limited capacity of the road network, congestion in urban areas has become an everyday phenomenon. Congestion creates a significant change in vehicle speed on city roads, especially during peak hours of the morning and evening. In real life, traffic conditions change throughout the day, so the routes of vehicles in the transport network have different levels of congestion depending on the time of the day [5-6].

Daytime congestion in urban areas has significantly increased fuel consumption and carbon emissions from vehicles, resulting in poor air quality, late arrivals and additional rental costs for vehicle drivers. According to the International Energy Agency, the transport sector was the second largest contributor to CO_2 emissions in 2015 [6-7].

Congestion and pollution problems caused by the increasing demand for city freight transport have led researchers and public authorities to involve their efforts in city logistics initiatives in recent years [8]. City logistics supports the development of integrated logistics systems, where all stakeholders are coordinated to reduce the negative impact of city transport distribution on citizens [9-10]. Local authorities seek to reduce pollution and congestion by implementing public policies that reduce the number of vehicles traveling inside the city centre, such as low-emission zones [11] or delivery windows [12]. Freight carriers play an important role in fulfilling the main tasks of the city logistics process and their daily activities can be largely influenced by city logistics initiatives aimed at reducing the negative impact of the city logistics operations [12-14].

The aim of this paper is to analyse strategies of these cities of the Czech Republic in the field of transport from the perspective of city logistics.

2. Theoretical Background

City logistics introduces a new concept that integrates urban planning and management of city logistics flows to address the cause of cargo transportation problems by acting on factors that characterize each context, such as: organization, planning, land use, vehicle routing, number of trips and vehicle carrying capacity [15-16]. Stakeholders are entities that are involved or interested in the results of city logistics initiatives and city logistics too. This share is based on a variety of stakeholders' motives that could influence decision-making when implementing city logistics solutions [17, 18].

City logistics is one of the most serious problems in most cities around the world in terms of recent phenomena such as urbanization or increasing the expected level of well-being of citizens [19-20]. City logistics is described as: “The process of optimizing the logistics and transport activities performed by private companies in urban areas, taking into account the traffic situation, congestion and energy consumption in a market economy” [21]. The basic philosophy of city logistics is to propose the right planning of goods distribution in the city [22]. It aims to optimally plan and manage freight movements within the logistics network in the metropolitan area with a view to integration and coordination between stakeholders [23].

The negative shown externalities are some of the most disturbing effects of the flow of goods in the city logistics. In response to these problems, city logistics is emerging to improve logistics systems in the urban area by monitoring costs and benefits and how to plan, organize, coordinate and manage physical flows and information aimed at protecting the environment [24-26]. Despite efforts to reduce congestion associated with the transport of people or materials and emissions of gases less harmful to the environment and social and economic activities in cities, it is still a challenging issue [27]. City logistics is a complex area characterized by many actors and stakeholders, and therefore many interests are at the stake [28]. Efficient and environmentally friendly logistics systems contribute to the competitiveness of businesses in terms of economic development. Due to the expansion of urban areas and the relative growth of economic activities, the logistics facility finds space and location in areas immediately outside the city centre and on the periphery [29-30]. The problems of transport and logistics have existed for a long time. The history of transport and logistics and shows that transport science, which has changed since the 1960s, has experienced a huge change with the development of information and communication technologies. Today, many scientists are discussing this and innovating from a variety of perspectives, such as studying different auction mechanisms, considering time-effect transport, and analysing the impact of reducing transportation costs or environmental pollution through collaboration. All these researches help to improve the efficiency of logistics operations in the reality [31, 32].

3. Methods and Data

The method of content analysis and qualitative comparative analysis were used in this paper. The analysis processing procedure is shown in Fig. 1. Firstly, relevant strategic documents of selected cities (twelve regional capitals: Brno, České Budějovice, Hradec Králové, Jihlava, Karlovy Vary, Liberec, Olomouc, Ostrava, Pardubice, Plzeň, Ústí nad Labem, Zlín and the capital city Prague) were identified from publicly available databases. Subsequently, the method of content analysis was used to identify relevant documents in the field of transport. The method of content analysis is a research technique for making replicable and valid inferences from texts or other meaningful matter to the context of their use [33]. Furthermore, the method of qualitative comparative analysis of these documents was used to analyse and compare strategies of selected cities in the field of transport from the perspective of city logistics. The method of qualitative comparative analysis is a non-statistical research data analysis technique for determining which logical conclusions a data set supports [34].

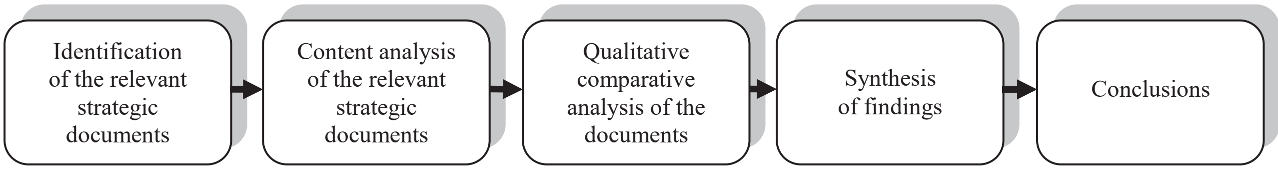

Fig. 1 Analysis processing procedure [authors]

A total of 22 relevant strategic documents were identified, there were: Sustainable City Mobility Plan of the City of Brno 2017, Tourism Development Program of the City of Brno 2016-2020, Strategic Plan of the City of České Budějovice 2017-2027, Strategic Development Plan of the City of Hradec Králové until 2030, Strategic Development Plan of the City of Jihlava until 2020, Strategic Plan for Sustainable Development of the City of Karlovy Vary 2014-2020, Update of the Strategy of Development of the City of Liberec 2014-2020, Strategic Development Plan of the City of Olomouc 2017-2023, Strategy of the Administrative District of Olomouc 2015-2024, Strategic Development Plan of the City of Pardubice 2014-2025, Strategic Development Plan for the Prague 7 District 2016-2022, Strategy of Public Space in Prague 10 District, Strategic Plan for Sustainable Development of Prague 12 District 2013-2020, Strategic Plan of Prague 13 District 2018-2024, Strategic Development Plan of Prague 14 District 2015-2025, Strategic Development Plan of Prague 20 District 2013-2020, Concept of Cycling Transport of Prague 20 District, Strategic Development Plan of Prague 21 District 2012-2022, Strategic Development Plan of Prague-Libuš District, Strategic Development Plan of Prague-Slivenec District, Strategy of Development of the City of Ústí nad Labem 2015-2020 and Strategy of Development of the City of Zlín until 2020 – “ZLÍN 2020” [35].

A total of eight areas were identified using content analysis of the relevant strategic documents in the relation to the field of transport and city logistics by three independent researchers, there were:

- Transport planning including mobility planning, transport services planning, city logistics planning, traffic system planning;
- Transport infrastructure including roads, railways, airports, ports;;

- Pedestrian transport including sidewalks, barrier-free measures;
- Public transport including urban public transport, passenger rail transport, regular passenger services;
- Sustainability including environmental issues, greenhouse gas emissions, noise, vibration;
- Cycle transport including bicycle paths;
- Traffic safety including traffic accidents, protection of traffic participants;
- Static transport including parking, parking spaces.

4. Results and Discussion

Based on the synthesis of data obtained by the method of content analysis and qualitative comparative analysis by three independent researchers, the following conclusions can be presented. The analysed cities have a total of 126 strategic measures in the relation to the field of transport and city logistics in their strategic documents, but some of these strategic measures may span more than one of the identified thematic areas; as a result Table contains a total of 221 strategic measures of the cities analysed.

The capital city Prague and its related districts have the largest number of measures in its documents (120 measures in total, which is 54.30% of all measures). This is understandable and predictable, because it is the capital city and also the most important centre of the Czech Republic in terms of tourism and economy with more than 1.3 million inhabitants. The second largest city in the Czech Republic and the most important centre of the Moravia region Brno has 26 strategic measures (11.76% of all measures) in the relation to the field of transport and city logistics in its strategic documents. It is remarkable that in some areas (pedestrian transport, cycle transport and transport infrastructure) Brno has only one measure compared to Prague.

The other analysed cities have between 2 and 14 strategic measures in their strategic documents except for the city of Ostrava, which has no strategy in the relation to the field of transport and city logistics (included in descriptor "transport").

Table

The overview of the number of strategic measures of the individual cities and thematic areas

City / Area	Traffic safety	Static transport	Pedestrian transport	Cycle transport	Transport infrastruct.	Public transport	Sustaina-bility	Transport planning	Total
Prague	11	5	22	10	31	11	10	20	120
Brno	2	2	1	1	1	5	5	9	26
Olomouc	1	1	2	2	2	1	2	3	14
Pardubice	1	1	1	---	1	2	1	5	12
Liberec	1	---	2	1	2	---	1	5	12
Hradec Králové	---	1	1	1	---	2	---	3	8
Karlovy Vary	---	1	1	1	2	1	---	1	7
Ústí nad Labem	---	---	---	---	---	2	1	3	6
Plzeň	---	---	1	1	---	---	1	2	5
České Budějovice	---	---	---	---	---	1	---	4	5
Zlín	---	---	---	---	---	1	1	2	4
Jihlava	---	---	---	---	---	---	1	1	2
Ostrava	---	---	---	---	---	---	---	---	---
Total	16	11	31	17	39	26	23	58	221

Only three cities have prepared strategic measures for all identified areas, it is the capital city Prague, Brno and Olomouc. The capital city Prague has the most strategic measures in the area of transport infrastructure (31 measures), pedestrian transport (22 measures) and transport planning (20 measures). On the contrary, the least strategic measures were identified in relation to the static transport (only 5 measures). In other thematic areas (traffic safety, cycle transport, public transport, sustainability), the capital city adequately has the same number of defined measures (between 10 and 11 strategic measures).

Brno, the second largest city in the Czech Republic, focuses on transport planning area in terms of strategic measures (a total of 9 measures); it also deals with sustainability and public transport (both equally 5 measures). In other thematic areas, Brno has one or two measures. The last city for which measures have been identified in all the examined thematic areas is the city of Olomouc, which has prepared one to three strategic measures in all thematic areas. The city of Pardubice does not have prepared strategic measures in only one area, which is the area of cycle transport, which is understandable, because this city has a sufficient and densest network of cycle paths from all cities of the Czech Republic. In other areas, the city already has defined strategic measures, with most in the area of transport planning.

The analysis of strategic documents for the remaining cities revealed that these cities (Liberec, Hradec Králové, Karlovy Vary, Ústí nad Labem, Plzeň, České Budějovice, Zlín, Jihlava and Ostrava) do not have any strategic measures in at least two or more thematic areas. The city of Liberec has not prepared any strategic measures in the thematic area of static transport and public transport. The city of Karlovy Vary does not focus on the thematic areas: traffic safety,

sustainability. The city of Hradec Králové is in a similar position to the city Karlovy Vary, but in addition to those already mentioned it has no transport infrastructure strategic measures.

Cities Ústí nad Labem, Plzeň, České Budějovice, Zlín and Jihlava have developed strategic measures in only one to four thematic areas. Most often it is the area of transport planning (all cities), sustainability (four cities) and public transport (three cities). As already mentioned, the city of Ostrava has not processed the strategy in the relation to the field of transport and city logistics.

The division of the 126 identified strategic measures in the relation to the passenger and freight transport measures is presented in Fig. 2. It is clear that cities have defined more strategic measures in the relation to the passenger transport (a total of 96 measures, 76% of all measures). The remaining 30 measures (24% of all measures) are linked to the freight transport. All analysed cities have defined strategic measures in the relation to the passenger and freight transport. The division of the strategic measures to the identified thematic areas is presented in Fig. 3.

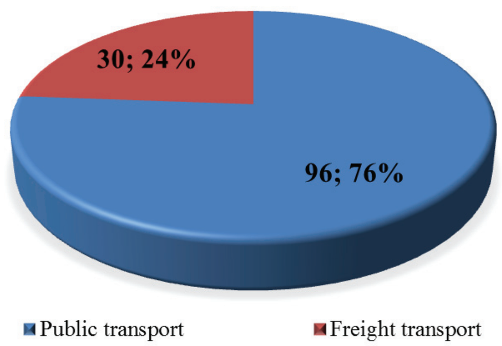

Fig. 2 The division of the strategic measures in the relation to the passenger and freight transport measures

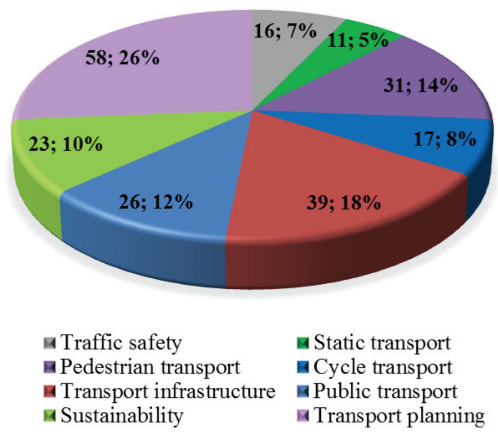

Fig. 3 The division of the strategic measures to the identified thematic areas

It is evident that the most strategic measures have been identified in the relation to the transport planning thematic area (a total of 58 measures, 26% of all measures). Furthermore, it is necessary to state that the thematic area of transport planning is the only thematic area where each of the analysed cities (except the city of Ostrava) have defined strategic measures. Subsequently, the cities in their strategic documents focus mainly on the area of transport infrastructure (a total of 39 measures, 18% of all measures), pedestrian transport (a total of 31 measures, 14% of all measures), public transport (a total of 26 measures, 12% of all measures) and sustainability (a total of 23 measures, 10% of all measures). Other thematic areas (cycle transport, traffic safety and static transport) individually account for less than 10% of the total. The analysed cities are least concerned with the strategic measures in the field of traffic safety (only five cities have defined some measures), static transport and transport infrastructure (only six cities have defined some measures).

Based on the presented results it is possible to reach the following findings. It was to be expected that, in the strategic documents of the analysed cities. Cities would mainly address thematic areas where they had shortcomings and space for improvement. Furthermore, it was possible to assume that the capital city Prague will have the most strategic documents and strategic measures, which was also confirmed. In terms of number of the strategic documents and the strategic measures, the capital city Prague was followed by the second largest city in the Czech Republic, Brno which is not surprising. However, much more interesting results have been identified in other regional cities of the Czech Republic.

The most shocking fact is that the city of Ostrava has any strategic documents with a descriptor "transport". Given the fact that Ostrava is the centre of the Silesian region, it is burdened with the poor state of the environment, it is connected to two highways (D1 and D56) and to one of the main railway corridors of the Czech Republic, so it should have developed some strategic documents with strategic measures in the relation to the field of transport and city logistics.

The fact that most of the cities (except Prague, Karlovy Vary and Ostrava) are dominated by the strategic measures in the field of transport planning is understandable, because the importance of this area is indisputable. The transport planning area including mobility planning, transport services planning, city logistics planning and traffic system planning uses many optimization tools to achieve a sustainable transport system for all stakeholders nowadays. It is also understandable that the city of Pardubice does not have prepared strategic measures in only one area, which is the area of cycle transport, because this city has a sufficient and densest network of cycle paths.

Given the problems of most cities in the static transport area should all cities to establish strategic measures for this area, because only six analysed cities have defined measures in their strategic documents. Furthermore, cities should more focus on the traffic safety area and prepare a series of strategic measures, because the number of traffic

accidents is increasing. The last area that should be given more attention in the strategic documents is the area of the transport infrastructure, especially the planning of new transport infrastructure and modernization of existing transport infrastructure.

Not surprisingly, more measures have been identified in the relation to the passenger transport than freight transport. Given the fact that individual strategic documents are prepared by cities and their representatives, who are elected by citizens, it is understandable that more measures will be linked to the passenger transport.

5. Conclusion

Transport and hence city logistics is one of the key pillars of every country's economy. Creating, setting up, optimizing and maintaining of the transport system is today crucial not only from the perspective of the state, but also from the perspective of individual regions, agglomerations, cities, municipalities and their citizens. Many stakeholders are dependent on a functioning transport system that is why strategic documents and strategic measures in this area are also important. These documents can affect the design of the transport system and city logistics for a very long period. These are strategic decisions in the areas of investment, transport infrastructure, transport planning, modal split etc.

The aim of the article was to analyse strategies of the twelve regional capitals and the capital city Prague in the field of transport from the perspective of city logistics with the use of the method of content analysis and the method of qualitative comparative analysis. The analysis showed which thematic areas each city is paying more attention and less attention too. Furthermore, the results of individual cities were compared with each other.

The results of the analysis and key findings can serve as an inspiration for cities in developing further strategic documents and strategic measures in this area, with the aim of improving the existing transport system. Most cities should consider whether they should also address thematic areas where no strategic measures are currently defined. The city of Ostrava should prepare a strategic document in the relation to the field of transport and city logistics.

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Monitoring of Service Management of Transport Enterprises of Urban Agglomerations

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Abstract

The authors have developed a model of organization of provision of passenger transportation services in urban agglomerations by including transport enterprises of various forms of ownership in a single corporate structure. Thus, efforts of all parties aimed at the improvement of transportation service quality can be combined. It was scientifically substantiated that the corporate structure can ensure the coordinated development of the passenger transport system of urban agglomerations in the region, as well as the consolidation of the interests of the supplier and consumer in the passenger transportation services market. According to the authors, the development of transport infrastructure and the increased pace of life call for the creation of passenger conveyance and logistics centres to provide the fastest transfer from one line to another, from one mode of transport to another, i.e. as much co-ordinated interaction as possible, and a user-friendly interface for consumers of passenger transportation services, regardless of the distance of the trip. The feasibility of applying the integrated quality assessment indicator of passenger transportation services in Kharkiv was substantiated from the scientific point of view. The integrated service quality assessment indicator makes it possible to assume the existence of significant potential in improving the quality of passenger service and requires the development of appropriate measures to improve the individual quality parameters of passenger transportation services in urban agglomerations.
KEY WORDS: *monitoring, services, management, transport enterprise, urban agglomeration*

1. Introduction

Increasing socio-economic efficiency and improving the quality of freight and passenger services are impossible without organizing a scientifically substantiated monitoring system for services management of transport enterprises. The expedient and strategically sound management of freight and passenger services is based on goal setting for the development of transportation services and of strategic directions for their achievement by such optimality criteria as reducing the cost of transportation of goods and passengers; increasing the quality of provided services; improving the environmental friendliness, and safety of transport. In this regard, the development of the theory and methodology of strategic management of road transport organizations, the application of economic and mathematical methods and models of managerial decision-making in the freight and passenger transportation, the development of methods for determining the socio-economic efficiency of investments in the development of services provided by transport enterprises of urban agglomerations are relevant.

The transport system in the agglomerative places of settlement is controlled by various local administrative units, which in modern conditions hinders its coordinated interaction and sustainable development of the region. Thus, the development of new conceptual approaches to monitoring the service management of transport enterprises becomes particularly important, and searching for specific methods, models and forms of transport services for the population to provide high-quality passenger transportation services is necessary. All of the above predetermined the relevance of our study.

2. Expediency of the Integrated Quality Assessment Indicator for Passenger Transportation Services of Urban Agglomerations Used in the Monitoring

The main features of the development of the service economy are the exponential growth in the value added of the service sector and the qualitative change in the proportions of gross domestic product (GDP) production in different economic sectors and by different economic activities. However, these regularities can be detected over a quite long period of time.

The principal modern trends of the economic development in Ukraine include the growth of the service sector of the national economy; the maximum growth in this sector is recorded in the social services, which solve important constitutional problems of ensuring equal social rights of citizens, compensation of losses caused by imperfection of the market, growth of the general welfare of the Ukrainian population; the volume of transportation services in social

services is growing rapidly. However, despite the positive dynamics of freight and passenger transportation services, there are several factors worth mentioning that have a negative impact on their development, such as poor quality of services in terms of speed, reliability and safety of transportation; insufficient development of freight and passenger transport infrastructure; environmental pollution of urban agglomerations; aging of fixed assets of transport organizations, number of decommissioned fixed assets exceeding that of the commissioned new transport; low rates of development of public transport compared to the increase in the number of privately-owned cars; uneven distribution of freight and passenger transportation across Ukraine and in its regions; significant gap in the level of transportation services and their quality in different urban agglomerations.

Passenger transportation services and the underlying public conveyance services provide conditions for the development and maintenance of human capital. The economic importance of this type of service is determined by a number of circumstances, such as saving time in the cycle of reproduction of human capital, i.e., the increase in the useful functioning time associated with the growth of health, education and cultural capital; secondly, by increasing its mobility, i.e., the speed and good timing of implementation of the ways and directions of its development [1, p. 789].

The management sub-system for passenger transport of urban agglomerations must include elements related to the strategic (goals and strategies, functions and methods of strategic management) and the operational levels (functions of analysis, planning, organization, operational regulation, managerial decision-making methods and management technologies). The managed subsystem includes such activities as passenger conveyance, environmental protection of urban agglomerations, road facilities, service and social relations.

We have conducted a study of the urban transportation services management system, strategic planning functions, including goal setting and development strategies to achieve them. State-of-the-art ideas about the role and importance of strategic management in the activities of economic actors, including road transport companies providing transportation services suggest that there is an urgent need to use it to overcome the economic recession, to improve the competitiveness of domestic enterprises by modernization and achieving new quality of economic growth [2].

In the course of the study, we have developed a model for organizing the provision of passenger transportation services in urban agglomerations which provides for including transport enterprises of different ownership in the corporate structure, which will allow combining efforts of all parties aimed at improving the quality of transportation service.

The advantage of the proposed transportation service model for urban agglomerations is the unification of the economic interests of the interacting parties to achieve the common goal of providing high-quality passenger transportation services to the population without prejudice to the economic interests of the party providing these services.

To implement the transportation service model for urban agglomerations it is necessary:

1. to determine the total amount of resources necessary to create a unified transport system of urban agglomerations of the region;
2. to conduct monitoring and use it as a basis to evaluate the existing quality of transport services for the population;
3. to monitor the mobility of the population of urban agglomerations;
4. to consolidate the interests of the transport enterprises of the region and to formulate uniform requirements for the quality of service and the rolling stock.

In our opinion, the corporate structure can ensure the coordinated development of the passenger transportation system of urban agglomerations in the region and the consolidation of the interests of the supplier and consumer in the passenger transportation services market.

The authorities act as the customer, perform the function of service quality monitoring and develop standards [3, p. 806].

A transport corporation is a passenger conveyance service provider; it consolidates the efforts of transport enterprises of various forms of ownership to provide services to the population in a certain territory and safeguards their economic interests. As a result, a multimodal public transport operator is established, which is responsible for the development of the passenger transport system and transport policy. One of the steps is the creation of a unified informational, organizational and economic space that allows efficient use of the full potential of the passenger transportation system of urban agglomerations of the region. Thus, a single brand of the passenger transportation services provider is formed for the consumer.

Consumers of passenger transportation services in urban agglomerations include not only permanent population, but also visitors, including tourists.

Implementation of our transport service model will favour coordinated operation of passenger transport, creating a multimodal passenger transportation system, improving the quality of services provided to the population, implementing a modern information system at the passenger transport, and attracting additional investments of private business in the urban passenger transport.

The development of transport infrastructure and the increased pace of life call for the creation of passenger transport and logistics centres to provide the fastest transfer from one line to another, from one type of transport to another, i.e. as much co-ordinated interaction as possible, a user-friendly interface for consumers of passenger transport services, regardless of the distance of the trip.

Passenger transportation is often performed consequently by different modes of transport of urban agglomerations of the region, but not infrequently this process is neither planned nor coordinated as a complete

technological chain. It is assumed that in the agglomerative places settlement, different types of passenger transport should complement each other effectively without competing with each other. In order to achieve the greatest benefits and advantages, the main goal is to create legislative and regulatory frameworks that would facilitate the establishment of a single domain of passenger transport services.

A passenger transport logistics centre is an organization that is intended to solve management and control problems of multimodal passenger transportation, one of the most important functions of which is the implementation of a consistent technology of interconnection of passenger transportation with minimal loss of time for passengers, service organizations and increased utilization efficiency of transport.

The formation of a passenger transport and logistics centre requires:

1. Interaction of the rail transport system and elements of the road transport (buses, street cars).
2. Creating a regional interface between long-distance and short-distance transport.
3. Cooperation between companies providing passenger transportation services in different modes of transport.

Creation of a passenger transport and logistics centre requires the formation of a multifunctional system, the basic element of which is rail transport conducting transportation within the agglomeration and suburban commuting.

Advantages of the passenger transport and logistics centre include:

- direct access to the road network;
- cooperation between businesses, different modes of transport and logistics;
- a wide range of services provided on the territory of the centre;
- effective use of the territory due to the implementation of logistic systems with regional transport communication;
- increase of efficiency of commercial activity in providing passenger transport services;
- implementation of modern technological solutions in the passenger transport system of urban agglomerations in the region.

Target activity of the passenger transport and logistics centre is carried out together with simultaneous solving of tasks as follows:

- coordination of urban and regional transport policy;
- development of passenger transport and the transport infrastructure;
- optimization of the transport connections system;
- informatization of transport activity;
- provision of integrated environmental safety.

If a passenger transport and logistics centre is built and included into the urban environment, thus urban, transport and social problems will be solved on the basis of a combination of transport and commercial functions. The effect of creating such centres is the sum of 4 types of effects: 1) the effect obtained from improving the quality of transportation services; 2) the effect from the rational use of territories; 3) commercial effect resulting from the development of the service sector; 4) synergetic effect which is a consequence of the emergence of an organizational and economic system that leads to an increase in the quality of services and life of the population.

The passenger transport and logistics centre is built and included in the urban environment taking into account the results of preliminary monitoring.

Monitoring that underlies the strategic planning of passenger transportation services is one of the basic functions of strategic management of this type of economic activity and is considered in strategic management and systems theory [4, p. 197]. In the scientific literature, the basic principles of goal setting and the development of management strategies have been quite adequately studied. Using the systems theory in goal-setting allows conducting systematic study of the field of passenger transportation, determining the relationship between goals and the behaviour of the elements of its structure, establishing regularities of interaction with the environment [5].

In the modern scientific literature, the theoretical development of strategies for achieving the goals for different types of economic activity, complexes and organizations has not been adequately described yet. This can be explained by the complexity of strategic planning for the development of hierarchical, poorly determined economic systems with unlike interests of their entities that have different goals, as well as ideas about how to achieve them [6, p. 118].

An analysis of the development strategies for the passenger transport formulated in the policy documents suggests a conclusion that they have not been systematized sufficiently and that they are consistent with the goals set for the development of passenger transport services, and that a scientifically based strategy roadmap lacks.

The conducted analysis of the scientific literature and a poll taken among the employees of road transport companies showed that planning at motor transport enterprises in urban agglomerations generally has three levels of strategic decisions: the level of an enterprise, the level of strategic economic zones (SEZ), and the level of a structural unit.

The strategic development plan of any organization is based on a corporate strategy, the development of which is the main responsibility of its top managers. The system of strategies at all levels of the organization forms the basis of its portfolio strategy.

The corporate strategy of the entity determines its long-term goals, development direction, allocation of its resources and investments, as well as strategic directions of its production, commercial and service activities, and the appropriate reorganization of the management system.

There are a few options for the most common corporate strategies, the variety of which for the road transport organization is reduced to four main types: growth strategies, limited growth strategies, combination strategies, and

reduction strategies [7, p. 39].

Growth strategies include the following alternatives:

- unlimited growth strategy is optimal when the company has a significant increase in the volume of provided motor transport services as compared to the previous period of time;
- concentrated growth strategy is justified in cases when the company has potential for the provision of existing services in the already tapped markets. There are a few types of concentrated growth strategies, namely:
  1) position strengthening strategy, which consists in finding by the enterprise ways to increase sales of existing services in the tapped markets, for example, by strengthening a marketing or logistics strategy;
  2) market expanding strategy, which is associated with the introduction in new markets of the services that the urban agglomeration already provides in order to increase their sales;
  3) service improving strategy, which consists in increasing sales by creating new or improving existing services in already tapped markets;
- integrated growth strategy is used in cases when the urban agglomeration enterprise has a very strong market position or seeks to earn additional income by advancing, moving backward or horizontally within a certain type of economic activity. There are a few types of integrated growth strategies:
  1) regressive integration which provides for the company's attempts to get new suppliers or tighten control over the existing ones;
  2) progressive integration, which means the company's conquest of a whole services distribution system;
  3) horizontal integration strategy, consisting in the attempts of the enterprise to acquire or tighten control over individual competing enterprises.
- diversified growth strategies are justified in cases where the current type of activity of the enterprise does not have the potential for further growth or when another type of activity becomes more attractive.

The following types of diversification strategies are distinguished her:

- concentrated diversification strategy which means supplementing the existing range of services with new services of a similar type;
- horizontal diversification strategy, which means replenishing the existing range of services with completely new ones that are not related to previously provided ones and that may interest the existing consumers;
- conglomerate diversification strategy, which consists in replenishing its offer with services based on the latest technologies.

Limited growth strategy. The stabilization or limited growth strategy is implemented if the growth of the enterprise does not meet its goals. This strategy is optimal in sustainable areas and conditions of the enterprise. It is also used in case of limitation of the flow of resources from the external environment or when the internal production potential of the enterprise is insufficient for its further development.

Combination strategy. It means combination of individual strategies that can be applied to different fields of activity. The combination strategy is carried out by reducing unprofitable activities of the enterprise or their reorienting to more promising areas that can bring profit to the enterprise.

Reduction strategy. It is used when the financial performance of the company tends to decrease or in order to prevent the bankruptcy of the company. This strategy can be implemented by such methods as reorientation, cutting off excess, liquidation:

1) reorientation strategy is used when the organization has not yet reached its critical point, but its activity is ineffective;
2) strategy of cutting off excess involves the development of effective measures to reduce costs. For example, the reduction of certain low-income activities or the partial sale of existing business;
3) business liquidation strategy is implemented when there is a bankruptcy threat, sale of its assets or the liquidation of the enterprise.

At the SEZ or business unit level, a business strategy is developed which provides long-term competitive positions in a specific area of economic activity. This strategy underlies the business plans and reveals the competitive advantages of the urban agglomeration enterprise in the market of services provided, and also determines the ways to successful competition. Therefore, such a strategy is also called a competition strategy. For urban agglomeration enterprises with a single type of activity, the corporate strategy coincides with the business strategy.

Functional strategies are defined for individual functional areas and units of the enterprise; they describe the strategic orientation of each function. They are developed by departments and offices of the enterprise based on corporate and business strategies. These are innovation, investment, logistics, marketing, finance, production strategies, etc. A functional strategy provides the practical implementation of the general strategy of the enterprise.

The service quality monitoring of passenger vehicles and their specifications was based on the method of assessment of the result of the service provision taking into account the following properties.

1. Complexity. The contractor must ensure the fulfilment of all components of the technological content of the service, and provide related services, the specification and requirements of which are established in the transportation agreement.
2. Safety. By providing a service, the contractor must ensure compliance with the life, health and environment safety requirements of urban agglomerations.
3. Good timing and speed. The contractor must fulfil the transportation of passengers in accordance with the established schedule, other requirements for the time and speed of movement of vehicles, provided for by the

conveyance agreement for the urban agglomerations.

4. Comfort, ethics and aesthetics. The contractor must ensure compliance with the requirements for the service conditions for passengers in a vehicle, as well as at the initial, intermediate and final points of travel.

5. Informational content and reliability. The contractor must make available for passengers necessary and reliable information about the departure (arrival) of vehicles, the rules of travel and baggage transportation, the route, the location of the fire extinguisher and the first-aid kit, the location of emergency exits and how to open them, and how to contact the Contractor.

6. Availability. The carrier must provide various groups of consumers (passengers) access to the services in accordance with its purpose by providing appropriate social, economic and technical characteristics of the service.

7. Baggage safety. When providing the service, the carrier must ensure the delivery of baggage on time to the destination without loss or damage.

We have chosen the calculation method based on the criterion of the minimum variance of the generalized indicator as the main method for determining the generalized quality indicator for passenger transport services, taking into account the weight coefficients of the particular indicators in the integral. Weight coefficients were obtained on the basis of the results of the study, the following values of average scores for assessing the quality of services, their variances (Table 1).

Table 1

Calculation of the integral quality indicator for passenger transport services in Kharkiv

Quality parameter	Total score	Average score	Variances	Weight coefficient	Weighted quality assessment
1 Complexity	406	6.340	1.5460	0.1793	1.1369
2 Safety	482	7.539	1.3050	0.2830	2.1335
3 Good timing and speed	399	6.228	1.3277	0.1676	1.0436
4 Comfort, ethics and aesthetics	325	5.080	1.4399	0.0425	0.2157
5 Informational content and reliability	356	5.558	1.4544	0.0410	0.2276
6 Availability	327	5.110	1.3308	0.1661	0.8488
7 Baggage safety	533	8.321	1.5471	0.1206	1.0035
Total amount of products (average)	2827	6.311	-	1.0000	6.6096

The integral quality indicator for passenger transportation services is the sum of the products of average scores given by passengers for each individual quality indicator and the corresponding weight coefficients. Monitoring of the service management of Kharkiv transport enterprises showed that the integral quality indicator is 6.61 (maximum 10.0), which suggests the existence of significant potential in improving the quality of passenger service and requires the development of appropriate measures to improve individual indicators of the service quality of Kharkiv passenger transport.

3. Conclusions

1. In the course of the study, a model for organization of provision of passenger transport services in urban areas was developed. The model provides for the inclusion of transport enterprises of various forms of ownership in a single corporate structure. Thus, the efforts of all parties aimed at improving the quality of transport services will be combined.

2. It was scientifically substantiated that a corporate structure can ensure the coordinated development of the passenger transport system of urban agglomerations in the region, as well as the consolidation of the interests of the supplier and consumer in the passenger transport services market.

3. The development of transport infrastructure and the increased pace of life call for the creation of passenger transport and logistics centres to ensure the fastest transfer from one line to another, from one mode of transport to another, i.e. as much co-ordinated interaction as possible, and a user-friendly interface for consumers of passenger transport services, regardless of the distance of the trip. The feasibility of applying the integrated quality assessment indicator for passenger transport services of urban agglomerations was substantiated from the scientific point of view. The integrated service quality assessment indicator makes it possible to assume the existence of significant potential in improving the quality of passenger service and requires the development of appropriate measures to improve the individual quality parameters of passenger transportation services in urban agglomerations.

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Enhancement of the Technology for the Distribution of Gondola Railcars for Loading in a Competitive Environment

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Abstract

In the modern context, the efficiency of the railway transportation process depends on many factors, one of which is the high-quality organization of empty railcar traffic at branchy railway operating domains. The aim of the paper is the formation of an effective technology for organizing and controlling the movement of freight trains, which will help to eliminate delays in the transportation process. The key problems of railway logistics are the shortage of railcars to fulfill customer requests and the suboptimal distribution of empty railcars for loading. In order to meet customer needs and reduce light running, the management systems are improved and optimal logistic schemes are implemented. The use of information systems can significantly expand management capabilities. Due to them, it is possible to achieve timely quality information, increase the reliability of forecasting planning and organize continuous monitoring of technological operations in local operation using the dynamic database of the automated system for managing freight traffic of the Ukrainian Railway.

KEY WORDS: *empty railcars distribution, freight transportation, freight front, automated control systems*

1. Introduction

The today's market for rail freight transportation requires enhancing the efficiency of traffic management, increasing flexibility and speed of decision-making, improving labour productivity. Compliance with the terms of cargo delivery and improvement of the railcar circulation, transition from regional principles for the management of the transportation process in organizing the movement of trains at large operating domains is provided for in the Strategy [1-4]. In conditions of the creating a competitive environment in rail transport, an intensive search for effective technologies for organizing the transportation process and methods for their implementation should be provided (Fig. 1). Those conditions create a need to timely meet the needs of shippers in the transportation of goods and the rational use of rolling stock when organizing transportation, considering the specifics of the competitive environment when fulfilling the planned volumes of cargo transportation on the entire railway network of Ukraine. Consequently, the pressing task is the formation of an automated technology for managing railcar traffic in the main tracks, which would eliminate delays in transportation with minimal operating costs.

2. Relevance and Scientific Novelty

The aim of the paper is the formation of an effective technology for organizing and controlling the movement of freight trains, which will help to eliminate delays in the transportation process.

A lot of scientific works have been devoted to the issue of efficient organization and quality management of transport services, among which of special attention are papers [1, 5-9].

Scientific research [6, 10-16] is aimed at improving a certain link in the transportation process. Also, the full cycle of railcar traffic movement is not well understood [7, 11, 14, 17-19]. Therefore, it is advisable to consider the process of bringing empty railcar traffic to the consignor, railcar loading, cargo transporting, unloading and returning empty rolling stock to the station [5, 13, 18].

It takes into account delays that may occur when moving railcars in the direction of the port or border transshipment station and idle railcars in the absence of traction rolling stock. The paper [20] investigates technological parameters affecting the process of cargo delivery.

It has been revealed that in the case of a busy traffic direction, both the number of delayed trains and the delay time caused by the downtime of trains at the final stage of transportation significantly increase.

In the paper [21] as a result of scientific research, a mathematical model has been constructed to optimize the regulation of empty railcars and determine their reserve at loading stations of a railway domain.

3. Formulation of the Problem

Rail freight management no longer exists without automated systems [22, 23]. The issue of development and implementation of automated control systems (ACS) has been given great attention not only in Ukraine, but throughout the world. Recently, automation in railway transport and logistics in empty railcar distribution for loading has been very relevant [24, 25]. This is done not only by railways, but also by private railway operators and railcar owners. One such example is Swiss Federal Railway (SBB), which, in order to improve the manual method for empty railcar distribution, has developed a mathematical model aimed at maximizing the level of satisfaction of demand and minimizing shunting and empty railcars. As far as can be determined, this is one of the few, if not the only completely mathematical solution designed to optimize the problem of freight railcar distribution. Another distribution principle is an automated system which has been implemented and stably operates in Russia and is called AS DRPV (Automated system for dynamic empty railcar distribution). This system is used not only by Russian Railways, but also by private operators, among which is Freight One.

4. Statement of Basic Materials

A significant part of the business processes on the railways of Ukraine uses automated control systems. At the same time, at the Ukrainian Railways domain, the system for the operational empty gondola railcar distribution is not sufficiently automated and contains the lion's share of the human factor. In order to arrange and make railcar transfer after unloading for a subsequent loading, a person considers a significant number of factors that must be taken into account, such as (Fig. 1):

- electronic loading requests;
- availability of empty railcars at the stations;
- information on carriage operations;
- information on the existence of restrictions (conventional, traffic restrictions).

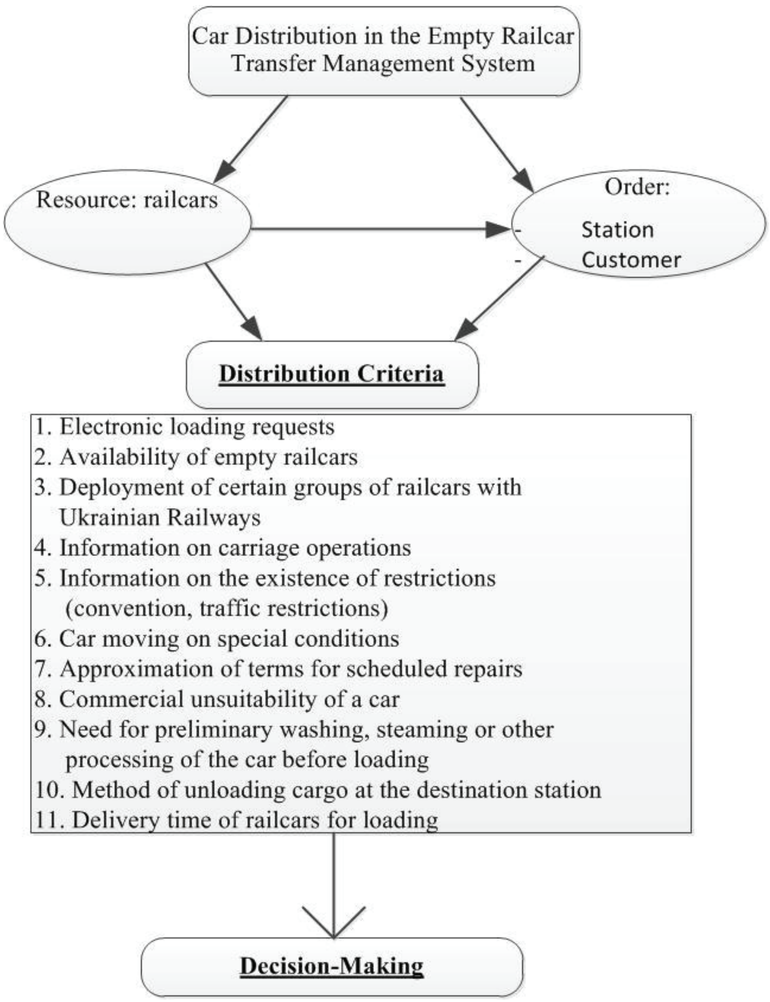

Fig. 1 The principle of empty railcar distribution

Analysing the current technology, one could argue that it is outdated and requires significant improvement using automated technologies. JSC Ukrainian Railways already has a similar experience with the distribution of empty railcars of other types of rolling stock, namely: covered railcars, hopper grain carriers and hopper cement trucks, which were called AS “Empty Railcar Management”. The purpose of its creation is the adoption of an effective solution for the moving of traffic flows, a significant reduction in light running and downtime of railcars, minimizing oncoming light running, reducing the impact of the human factor. It is worth noting that the algorithm of the automated system also takes into account the following technical characteristics and commercial criteria of wagons, which must be taken into account when delivering railcars to shippers for loading, specifically:

1) Conventional restrictions;
2) Railcar moving on special conditions;
3) Approximation of terms for scheduled repairs;
4) Commercial unsuitability of a railcar;
5) Need for preliminary washing, steaming or other processing of the railcar before loading;
6) Method of unloading cargo at the destination station;
7) Delivery time of railcars for loading.

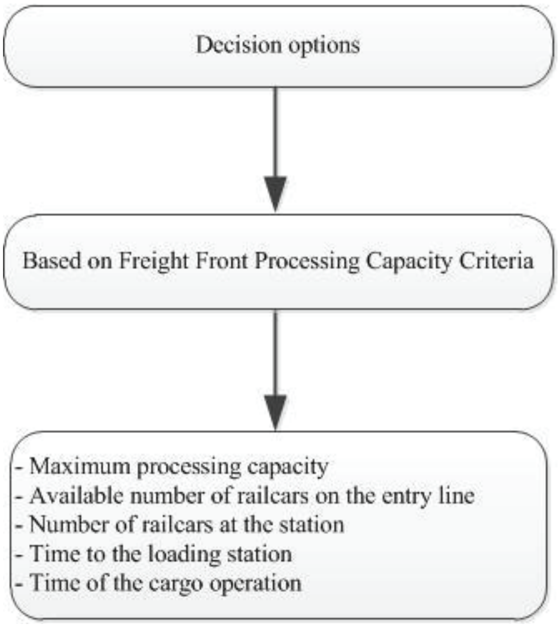

Fig. 2 Components of the freight front processing capacity criterion

Practices on working with this system (Fig. 2) and the analysis of the criteria taken into account in the algorithm, have shown so far that it is also necessary to take into account the downtime of railcars at the destination station in anticipation of delivery for cargo operations [26, 27]. But the “decision” on the railcar distribution generated by ACS PPV in accordance with the above criteria does not take into account the employment of freight fronts of the entry line. Therefore, as a result, railcars upon arrival at the destination station may be delayed before being served for loading, including due to the employment of the freight front.

In order to take into account the downtime of railcars at the destination station, pending delivery for cargo operations, the customer is invited to introduce an additional criterion, namely, “freight front processing capacity”. This criterion will make it possible to consider the processing ability of entry lines and ensure uniform delivery of empty railcars to the consignor. If the freight front is busy at the time of arrival of the railcars at the station, the system algorithm selects other options for sending empty railcars.

The technology takes into account the processing ability of the freight front, the downtime of railcars at the station in anticipation of cargo operations, because the freight front processing capacity criterion provides for the calculation of the following specifications of the technological interaction of the entry line and the road, specifically:

- maximum freight front processing capacity according to the data of the system of certification of entry lines;
- presence of railcars on entry lines and the time they were under cargo operations in accordance with the freight front processing capacity;
- time the railcars travel to the destination station;
- downtime at destination station pending loading.

These specifications are contained in the terms of the contract concluded between the enterprise and the railway. The time spent by the railcars in anticipation of the cargo operation depends on the following parameters:

- time of the cargo operation at the front, t_f;
- number of wagons processed simultaneously at the front, n_{fp};
- number of railcars in the push group, n_i;

- railcar re-push times, $t_{r.f}$;
- number of railcars arriving at the enterprise, N;
- railcar group processing time, t_i ;
- balance of pushed railcars (N - n_i) = Δn.

When pushing the train of N railcars to the entry line, to calculate the time of employment of the freight front is determined:

- how many groups of n_{fp} railcar is contained in N;
- for a railcar batch (N:n_{fp}), the time spent by the railcars in anticipation of a cargo operation is equal to the time of delivery of the previous group plus simultaneous processing on the freight front, $t_{p.p.}$.

The specifications of the processing ability of the front are indicated in the Passportization System, which is an integral part of the ASKVP (Automated enforcement system) UZ-E. The formalized description of the freight fronts of an enterprise, for example, CJSC Complex Agromars, has the following form, see Table. So far, this data is used in the current system. Taking into account the processing ability as a criterion for the automated distribution of railcars for loading will significantly increase the efficiency of the solution.

Table

Operating process chart of freight fronts of CJSC Complex Agromars

Loading Location	Ff Capacity	Operation	Cargo	Number Of Railcars Processed Simultaneously	Number Of Railcars In A Push	Duration Of Cargo Operations	Estimated Daily Railcar Flow	Utilization Factor Of The Freight Front	Type Of Handling Operation
CJSC Complex Agromars	5	Unloading	Oil	1	5	2.0			Pump
	5	Unloading	Corn	2	5	0.64	0.22	0.04	Feed hopper
	1	Unloading	Lime	1	1	4.1	0.04	0.008	Non-mechanized
	3	Loading	Flour	3	3	2.25	0.22	0.04	Non-mechanized
	4	Loading	Compound feed	2	4	1.33	0.4	0.1	Chain conveyor

5. Conclusion

It can be argued that the automation of the empty railcar traffic distribution has assumed greater urgency, given the significant shortage of rolling stock and the human factor, prone to ineffective decisions. The automated distribution technologies will help to increase the volume of cargo transportation by reducing the downtime of railcars waiting to be pushed for loading, reducing the turnover of railcars and improving the organization of forwarding empty railcar traffic for loading. The use of information systems can significantly expand management capabilities. Due to them, it is possible to achieve timely quality information, increase the reliability of forecasting planning and organize continuous monitoring of technological operations in local operation using the dynamic database of the automated system for managing freight traffic of the Ukrainian Railway.

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Development of a Complex for Laboratory and Practical Works Based on a Solar Charging Station for Electric Vehicles

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Abstract

The development and implementation of green technologies is not only relevant, but also a very cost-effective scientific and engineering task. Therefore, training of specialists in the latest green energy-saving and energy-efficient technologies is also an urgent task for the modern educational process. The aim of current article is to develop a circuit solution for a laboratory and practical training based on a solar charging station for electric vehicles. A review of the most common methods of converting solar energy into electrical energy is carried out, and the main types of solar power plants are investigated. Silicon photovoltaic modules currently occupy about 90% of the market for photovoltaic converters. Given their prevalence and a good indicator in terms of price-quality, solar panels based on silicon photovoltaic modules are selected. A schematic solution of the complex for laboratory and practical exercises based on a solar charging station for electric vehicles is proposed. The main element of the proposed solar charging power plant is a hybrid grid solar AC power station, which has the ability to operate both from a centralized power supply network and autonomously. The technical characteristics of the developed complex are given. Since solar panels are the main element of the complex, the main dependencies for calculating their parameters are given. A scheme is proposed for conducting experimental studies with solar panels of the complex. A list of laboratory and practical exercises that can be carried out at the developed complex is proposed. The specific tasks that must be completed during the laboratory work at the developed complex are described.
KEY WORDS: *solar charging power station, green energy, green tariff, solar energy, solar power station, electric car, energy-efficient technologies, solar panels.*

1. Introduction and State-of-the-Art

The European network for argumentation and public policy analysis (APPLY) improves the way European citizens understand, evaluate and contribute to public decision-making on such matters of common concern as climate change or energy policies [25].

In other hand, decision-making, problem of climate change and energy policies are significant topics also in education and science. Transport give a significant impact to ecology and climate change. So, is significant to use nature-friendly "green" transport and to perform this task, it is needed to educate more students, who understand challenges of climate change, energy policies of the World and "green" transport technologies. Providing and criticizing reasons is indispensable to achieve sound level of sustainability of education and science (especially in such actual directions as climate change, energy policies and transport) that commands the support of teachers, researchers, scientists, other stuff of universities, as well as, students, government, citizens and stakeholders. So, the argumentation to perform current research is serious. To address this need from a multidisciplinary perspective, the development of a complex for laboratory and practical works based on a solar charging station for electric cars has been performed.

Recently, renewable energy not only remains in trend, but also is gaining more and more popularity every year [26]. And a rather significant role is played by solar energy [1]. However, in Ukraine, solar energy, in comparison with other countries, is just beginning to develop, and therefore the state is introducing various measures to stimulate it. For example, targeted subsidies, the abolition or easing of the tax burden, subsidies, etc. [2, 3].

In accordance with the law of Ukraine on electric power industry No. 575/97-BP dated 10.16.1997, the “green” tariff is the tariff at which the wholesale electricity market of Ukraine is obliged to purchase electric energy produced at electric power facilities from alternative sources energy. So, the “green” tariff is a mechanism designed to push the population to generate electricity using alternative energy sources [4]. In accordance with the above law, electricity generated by solar power plants, wind power plants and hydro power plants - is accepted by the general grid and paid

for by the wholesale electricity market at the “green” tariff.

It should be noted that the green tariff indicator changes every year. So, for example, in the case of the production of electric energy from solar energy for private households, depending on the date of signing of the contract, the “green” tariff is: 20 eurocents / kWh (upon signing of the contract from July 1, 2015); 19 eurocents / kWh (upon signing of the contract from January 1, 2016); 18 eurocents / kWh (upon signing of the contract from January 1, 2017); 16.3 euro cent / kWh (upon signing of the contract from January 1, 2020); 14.5 euro cent / kWh (upon signing of the contract from January 1, 2025).

Accordingly, the development and implementation of "green" technologies is not only relevant, but also cost-effective scientific and engineering task. Therefore, the release of specialists in innovative “green” energy-saving and energy-efficient technologies is also an urgent task for the modern educational process [5]. The market for solar panels consists of several different types, which differ both in the manufacturing technology and in the materials from which they are made [6-8]. The most popular and common are silicon-based solar panels. This is due to the fairly wide distribution of silicon in nature, its relative cheapness and high performance indicator, in comparison with other types of photovoltaic cells. The vast majority of cells of modern solar panels are made of single-crystal (C-Si) or polycrystalline (MS-Si) silicon. Currently, these silicon photovoltaic modules occupy about 90% of the market for photovoltaic converters [9-11]. Therefore, for a solar charging power plant, as the main element of the complex on the basis of which it is planned to conduct a number of laboratory and practical exercises, silicon solar panels have been selected. These solar panels have the best price-quality ratio compared to other types [9]. Details on the main kinds and types of solar power plants (SPP) are given in [12-15]. After comparing of all the advantages and disadvantages of the SPP circuit solutions, it is proposed to take a hybrid AC solar power grid as a basis. Consequently, a complex for laboratory and practical training will be developed on the basis of the SPP network, which is the main element in the structure of the solar charging station for electric vehicles. In [16], the authors analyzed the operation of a solar charging station for electric vehicles in an electric power distribution system. Based on the research results, they gave recommendations on the minimum acceptable characteristics of a solar charging station for electric vehicles. Compliance with these characteristics will allow you to balance the load on the electrical network from electric vehicles while they are charging. In [17], a new architecture of a solar canopy for cars is proposed. This canopy contains solar panels, which are the energy sources of the charging station for electric vehicles. In the proposed design of the charging station, a direct DC / DC interface is made, which increases the overall efficiency of the station. The authors of [18] explore the possibility of charging electric vehicles at workplace in Netherlands using solar energy. A priority mechanism is proposed to facilitate charging several EVs from a single charger. The possibility of integrating energy storage systems into a charger to make it independent of the network is assessed. The optimal size of energy storage systems for electric vehicle charging stations is also evaluated. The purpose of the article [19] is to reduce the number of DC-DC converters in an AC charging station. For this, the authors of the article suggest the design of a charging station using PSIM software. In [20], it is proposed to use “ultra-capacitors electro busses” for urban transport with their recharging from special chargers. Such devices, as charging stations at public transport stops are proposed in [17] and can be successfully used. The canopy itself, which contains solar panels, is well suited for equipping public transport stops.

The purpose of current article: development of a circuit solution of the complex for laboratory and practical exercises on the basis of a solar charging station for electric vehicles.

To achieve this goal it is necessary to solve the following tasks: to conduct an analytical review of the most common methods of converting solar energy into electrical energy and to explore the main kinds and types of solar power plants. To propose a schematic solution of the complex for laboratory and practical exercises on the basis of a solar charging station for electric vehicles. Provide a list of the main elements and equipment of the proposed complex. To propose a list of laboratory and practical classes at the developed complex.

The article considers, investigates and analyzes the circuit solutions of solar charging stations for electric vehicles. Various modes of operation of a solar charging station are investigated; the operation of its individual components in various operating conditions are researched. These studies are designed as a series of laboratory and practical exercises. After going through the entire spectrum of the proposed studies, knowledge, understanding and practical skills are acquired in the field of building infrastructure for electric vehicles, and in particular in the field of charging stations for them. The student not only begins to understand the structure of the charging station, but also gains practical experience in setting it up and bringing it to the optimal operating mode, depending on the prevailing conditions. As a result, we have a specialist who is able to effectively establish the work and functioning of the main infrastructure elements for electric vehicles - their charging stations, which, among other things, operate on the basis of renewable energy sources (solar energy).

2. The Complex for Laboratory and Practical Classes

From based on the analysis of the types and designs of solar power plants [13-21] and in accordance with the task, a hybrid network SPP of alternating current was chosen as the basis for the complex of laboratory and practical exercises, Fig. 1. Through the control panel shown in Fig. 1, measurements of signals and diagrams of current, volt-age, power versus time are carried out on key constituent elements of this complex. Namely: signals from solar panels (SP). Signals from the battery (charge / discharge). Signals from a centralized power supply network (reception and return). Signals presented to consumers (e.g. electric vehicle charge).

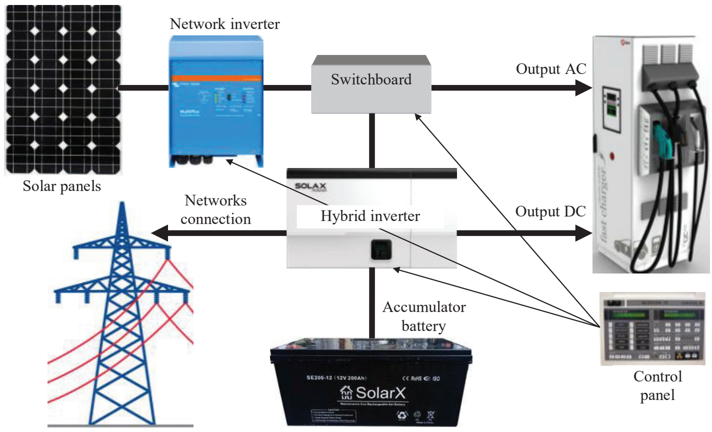

Fig. 1 Scheme of the complex for laboratory and practical exercises on the basis of the solar charging station

In this complex SP are connected to the mains solar inverter (DC / AC). The AC mains is connected to the input of the hybrid inverter (DC / AC). Batteries are also connected to the hybrid inverter. The output of the mains solar inverter and the hybrid inverter are connected through a switchboard and provide power to AC consumers. The output of the hybrid inverter is connected to the charging stations of electric vehicles. The use of a hybrid inverter with a charger provides a number of advantages, for example, SES works even in the absence of voltage in the AC network, as well as in an unstable network.

As energy storage devices in the proposed charging station, authors offer to use batteries from electric vehicles or helium batteries intended for use in solar power plants. Their total power should provide 200 kWh. This is approximately 8 to 10 lithium-ion batteries from the Nissan Leaf electric car).

In accordance with the research conducted at the Vehicle Electronics Department of Kharkiv National Automobile and Highway University (KhNAHU), an experimental version of a solar charging power plant for electric vehicles has been developed as a complex for laboratory and practical classes. According to the curriculum for specialty 141 "Electric power, electrical engineering and electro-mechanics", students of KhNAHU, studying in the program "Electric cars and energy-saving technologies" can work out practical names on the developed complex, covering disciplines: "Energy-saving and electric car technologies" on transport; "Electrical systems of environmentally friendly ATC"; "Intelligent information technologies and systems"; "Methods of planning research in ATC". In addition, at the developed complex, students have the opportunity to undergo research and do research on diploma design. The general view of the complex for laboratory and practical classes on the basis of a solar charging station is presented in Fig. 2.

a b

Fig. 2 A complex for laboratory and practical training: a - battery with a hybrid / autonomous inverter; b - solar panels

The composition of the equipment of the complex is presented in more detail in Table 1.

Table 1

Equipment of the complex

№	Name of equipment	Quantity, pcs
1.	Solar panel EnerGenie EG-SP-M300W-33V9A	4
2.	Hybrid / autonomous inverter Voltronic Axpert VM3000-24(MPPT)	1
3.	Accumulator battery KSTAR Solar Series 12V 100Ah (6-FM-100T)	4
4.	Automatic switch Schneider Domae BA63 1P+n 16A C 11213	3
5.	Power cable Brille ШВВП 3x1,5 (106658), m	30
6.	Mounting box Schneider IMT35092	2
7.	Switchboard MasterTool OB-4 (94-0234)	3

One of the main elements of the complex that converts the energy of solar radiation into electricity is SP. In accordance with the technical characteristics of solar panels, you can determine their internal resistance [9]:

$$R_{in} = \frac{U_{oc}}{I_{sc}}. \tag{1}$$

where R_{in} – internal resistance SP, Ohm; U_{oc} – voltage at open circuit SP, V; I_{sc} – hort-circuit current SP, A.

Another important parameter of SP that needs to be determined is the fill factor FF. This parameter in combination with the short-circuit current (I_{sc}) and the voltage at the open circuit SP (U_{oc}) determines the maximum power at the output of the solar panel. FF is defined as the ratio of the rated power SP to the product U_{oc}) on I_{sc} and is equal to the maximum area of the rectangle that can be inscribed in the volt-ampere curve SP [22]:

$$FF = \frac{I_{nom} \cdot U_{nom}}{I_{sc} \cdot U_{oc}}. \tag{2}$$

Another important SP parameters that can be both calculated and measured are: volt-ampere characteristic; load characteristics (dependence of the power of the solar panel on the load current). Manufacturers must determine these characteristics in accordance with approved methods, which are given in [23, 24]. The calculation of the volt-ampere characteristic can be performed by the formula:

$$I = I_f - I_0 \left(\exp\left[\frac{q}{AkT} \left(U + IR_l \right) \right] - 1 \right), \tag{3}$$

where I_f – photocurrent, A; I_0 – saturation current, A; q – charge, C; A – the coefficient obtained by comparing the theoretical and experimental characteristics, takes values from 1 to 5; k – the Boltzmann constant; T – absolute temperature, K; I – current in SP, A; U – voltage, V; R_l – successive resistance of SP, Ohm.

The scheme for conducting experimental studies of the SP complex is presented in Fig. 3, where A is an ammeter, V is a voltmeter; W - wattmeter.

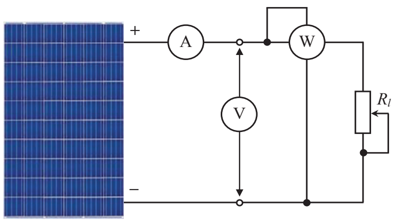

Fig. 3 The scheme for measurements on SP [12]

According to the presented scheme, SP can be loaded with active resistance and carry out measurements with construction of graphs. A sample of graphs obtained during experimental studies is shown in Fig. 4.

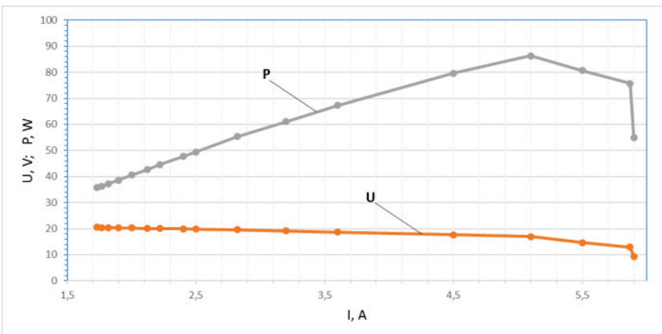

Fig. 4 Sample graph of experimental measurements on SP

A hybrid / stand-alone inverter type Voltronic Axpert VM3000-24 (MPPT) is used for measurements. It allows you to measure electrical signals from both the SP unit and from the battery and external network. This model of the inverter forms graphs of load of SPP and the schedule of the generated electric power. The output of data from the inverter to the computer allows you to quickly and efficiently analyze them, and thus effectively program the mode of operation of the SPP as part of the complex for laboratory and practical classes. Based on the results obtained, using the presented complex, it is proposed to carry out the following laboratory and practical work listed below.

3. The List of Laboratory Works that Can be Carried out at the Developed Complex

Laboratory work № 1. “Research SPP in the mode of autonomous work” - 4 hours.

Tasks:

1.1. Investigate the graphs of current, voltage and power in the generation of electricity SP depending on their angle of inclination.

1.2. Investigate what proportion of energy will be consumed by the SPP from the network, when: fully horizontal position SP; at an angle of inclination SP 150; at an angle of inclination of SP 300; at an angle of inclination SP 450.

1.3. Investigate under what conditions under constant load, SP will generate exactly 50% of electricity.

Laboratory work № 2. “Research SPP in the mode of mixed power supply” - 4 hours.

Tasks:

2.1. Investigate the operation of the SPP when discharging its battery by 20% and connecting the power supply. Measure the current, voltage and power supplied from the SP and the battery: when operating SPP without connected electricity consumers; during operation of SPP in the mode of charge of the electric car.

2.2. Investigate the operation of the SPP when discharging its battery by 50% and connecting the power supply. Measure the current, voltage and power supplied from the SP and the battery: when operating SPP without connected electricity consumers; during operation of SPP in the mode of charge of the electric car.

Laboratory work № 3. “Research SPP in the mode of reserve power supply” - 4 hours.

Task:

3.1. Determine the load conditions of SPP and measure the graphs of voltage, current and power over time, at which: 20% of the generated electricity goes to the grid at a "green" tariff; 50% of the generated electricity goes to the network at a "green" tariff; 70% of the generated electricity goes to the network at a "green" tariff; 100% of the generated electricity goes to the grid at a "green" tariff.

4. The List of Practical Exercises that Can be Carried out at the Developed Complex

1. Setting up a hybrid inverter of a solar power plant for different operating modes.
2. Measurement of volt-ampere characteristic SP with gradual increase and decrease of load resistance.
3. Determining the optimal load SP with different schemes of their connection.
4. Measurement of the power function SP depending on its load: at an angle of inclination SP 150; at an angle of inclination of SP 300; at an angle of inclination SP 450; at an angle of inclination SP 600; at an angle of inclination SP 750.
5. Measurement of the function of current, voltage and power from time to time during the discharge of the battery of a solar power plant during operation at rated load.
6. Determining the efficiency of SP depending on its heating.
7. Determining the efficiency of SP when it is partially and completely dimmed.
8. Plotting the load schedule of a solar power plant when connecting a time-varying load.
9. Calculation of a solar charging power plant to charge an electric car.
10. Calculation of a solar power plant to operate at a green rate for one household.
11. Calculation of a solar autonomous power plant to provide electricity to one household.

5. Conclusions

In the current research, a review of the most common methods of converting solar energy into electrical energy was conducted, and the main kinds and types of solar power plants were investigated. Silicon photovoltaic modules currently occupy about 90% of the market for photovoltaic converters. Therefore, taking into account their prevalence, a wide range of products and a good indicator in terms of price and quality, solar panels based on silicon photovoltaic modules were selected. Based on the conducted studies, a circuit solution of the complex for laboratory and practical exercises based on a solar charging station for electric vehicles is proposed. The main element of the proposed solar charging power plant is a hybrid grid solar AC power station, which has the ability to operate both from a centralized power supply network and autonomously.

The technical characteristics of the developed complex are given, its main components are indicated and a list of its equipment is presented.

Since solar panels are the main element of the complex, which converts the energy of solar radiation into electrical energy, the main dependencies for calculating their parameters are given. A scheme is proposed for conducting experimental studies with solar panels of the complex.

A list of laboratory and practical exercises that can be carried out at the developed complex is proposed. The specific tasks that must be completed during the laboratory work are described in detail.

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Economic Impact and Current Position of Žilina Airport Within its Catchment Area

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Abstract

The catchment area of regional international Airport Žilina – Dolný Hričov consists of three separate NUTS3 regions – Žilina region, Trenčín region and Banská Bystrica region. Those regions are important economic centers of the Slovak Republic. Currently, Žilina International Airport does not have any regular flights. For this reason, its current impact on the development of the region is negligible. This paper examines various forms of the impact of regional airports to their catchment areas. Also, analysis based on Žilina Airport movement statistics (from 2000 to 2017) and their possible impact on gross national product of the catchment area is conducted to establish a link between economical performance of region and presence of regional airport.
KEY WORDS: *Žilina, regional airport, impact*

1. Introduction

Air transport is generally beneficial for the economic development of the region in which the airport is located. In the past decades, air transport was not available for the general public because of the high price of air tickets. Today, mainly due to pressure from low-cost airlines, air transport is considered to be normal, reasonable and affordable for travel [1]. In particular, smaller international regional airports are benefiting from the expansion of the network of routes of low-cost airlines and various regional carriers [2].

Three NUTS3 regions of Slovak Republic can be considered as the catchment area of Žilina Airport - Žilina region, Trenčín region and Banská Bystrica region. All regions within the catchment area are currently developing economically steadily ahead. Since 2000, all three regions have achieved a combined average of 5.88% increase in regional GDP per capita in the region (Fig. 1). One of the main reasons is the arrival of foreign investors such as KIA Motors, Schaeffler or Mobis, which operate within the ever-growing automotive industry.

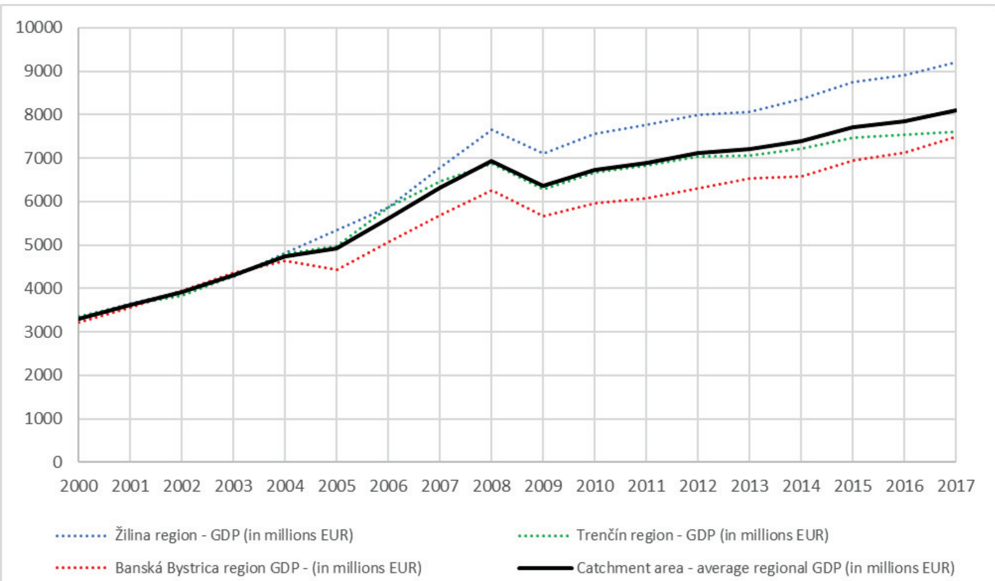

Fig. 1 GDP statistics of Žilina Airport's catchment area

In order to accelerate or at least maintain positive economic development[1] and maintain the attractiveness of the region for investors, it is necessary to constantly improve the accessibility of the region in terms of transport infrastructure [3]. Air transport is one of the most important determinants dictating the overall development of a given

[1] On the other hand, various forms of transport and its infrastructure have possible negative impact on region in terms of environment [4].

area. However, Žilina Airport does not currently provide this function. The main reason is the absence of a regular air connection caused by the insufficient length of the runway[2].

Investments in the expansion of the Žilina airport have great potential to help the local economy in the form of increasing the accessibility of the region not only from the point of view of trade, but also from tourism. Due to the size of the catchment area and its economic performance, Žilina Airport has the potential to become the third important international airport after Bratislava and Košice airports with regular flights to Western Europe. The most suitable candidate for a regular air connection is the connection with Václav Havel Airport in Prague, which, due to the Žilina airport, can function as a hub for the whole of Europe and other world destinations. There are several examples from various authors supporting the significance of regional airports for its catchment area.

2. Literature Overview

The influence of the presence of regional airports on the development of the region was addressed by a relatively large number of authors. According to Glaser, Kolka and Saiz [5], the development of the local economy can be positively influenced by the presence of an international airport by making the region more attractive from the point of view of investors. Giroud [6] argues that airports can help reduce corporate costs and make it easier for companies to run. An example is a mechanism where air transport in the region makes it easier for the company's management to oversee the proper functioning of remote branches. According to Blonigen and Crist [7] the presence of a regional airport also has a positive socio-economic impact. According to the authors, the airport can improve access to markets and thus mediate the personal contact of people living far apart, thus increasing their productivity.

According to Halpern and Brathen [8], the airport's effects on regional development can be divided into four groups. The first group is the direct effects given by the operation of the airport. The second group is the indirect effects associated with the business of suppliers in the area. Third, they are impacts caused by activities generated by direct or indirect action. The fourth group is the catalytic effects associated with the wider role of the airport in regional development. Empirical impact studies (Bandstein et al. [9]; Percoco [10]; Kufper & Lagneaux [11]; Cooper and Smith, [12]) show that airports have two main catalytic effects. The first is the impact on regional economic competitiveness as a result of the airport's ability to increase export activities (including tourism). The second effect is the positive effects associated with the accessibility of the region and its social development given the airport's ability to connect the region and facilitate travel for its residents.

Hakfoort et al. [13] conducted an impact study at Amsterdam Schiphol Airport and concluded that one job at the airport generates approximately one additional job in activities indirectly dependent on the airport's functions. Vijver, Derudder & Witlox [14] used data from European regions according to NUTS2 between 2002 and 2011. The main variable examined was employment in these regions, as it is a relatively robust and well-measurable indicator of regional development. The results of the study showed bilateral causality: Higher employment led to more people transported and higher numbers of people transported led to higher employment. The Intervistas study [15], commissioned by ACI, states that for every 100,000 passengers handled each year, it creates approximately 120 jobs at the regional level and more than 600 new induced jobs.

Novák Sedláčková and Švecová [16, 17] even made several studies focused on regional airports within Slovak Republic. They identified several reasons for the implementation of state aid funding for small regional airports within Slovakia due their the importance for their catchment areas not only in terms of economic performance, but also for their sociological factors.

3. The Current Position of Žilina Airport within the Impact Area

Žilina Airport serves the needs of the area of northwestern Slovakia (which includes three NUTS3 self-governing regions). This area has an approximate population of about 1.2 million people and is thus an important socio-economic center of Slovakia. Žilina Airport among 6 public international airports that can operate commercial air transport. However, the short runway length does not allow the airport to operate virtually any type of larger, more economically advantageous aircraft types (charter, low-cost, cargo, etc.). For this reason, it is not possible to directly compare Žilina Airport with others. At present, the airport is eligible for the following operations:

a) Scheduled public air transport for aircraft types with a capacity of approximately 50-60 passengers (e.g. ATR 42/72);
b) Irregular domestic and international transport flights of Slovak and foreign airlines and corporate private planes;
c) Flight training (currently mainly for the needs of the University of Žilina);
d) Sport flying;
e) Sanitary flights and special aerial work;
f) Airborne, transport, and training flights of police and military forces of Slovak Republic.

Fig. 2 shows the basic operating statistics of Žilina Airport in the years 2000 to 2017. As can be seen from Fig. 2 at present, the number of transported passengers is practically negligible in terms of commercial operation.

[2] TORA (Take off Run Available) of the runway of Žilina Airport is 1150 m (AIP SR, March 2020). For example, most common aircraft types used for regional and short-haul flights like Boeing 737-800 or Airbus A321 need approximately 2100 m for takeoff at 60% payload.

The significant increase in the number of transported passengers in the years 2004 to 2012 was caused by the existence of a regular air connection Žilina - Prague, operated by Czech Airlines. The number of movements is always higher that number of transported passengers. This situation is caused by the fact, that Žilina Airport servers as the main training base for The Training and education center of the University of Žilina.

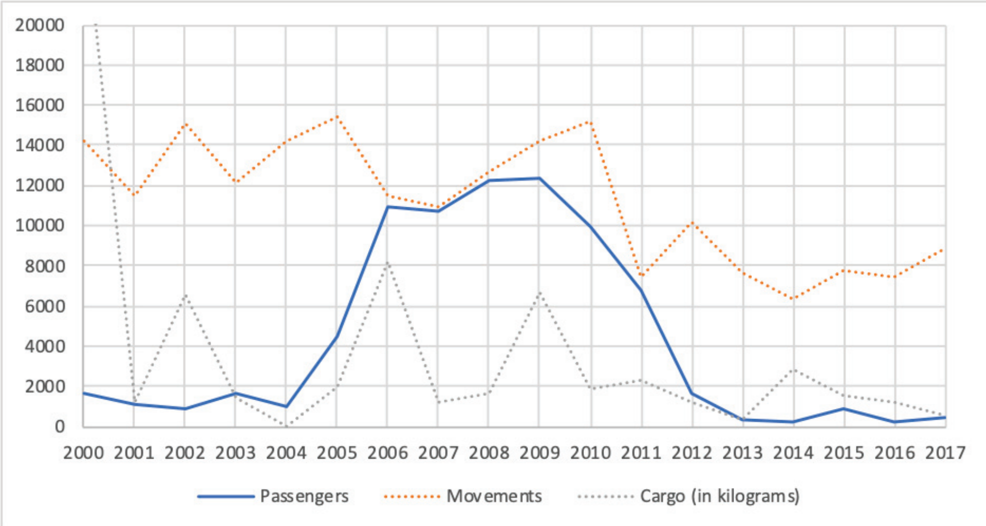

Fig. 2 Žilina Airport operational statistics

Žilina Airport has a convenient geographical location, located in the middle of its catchment area and at the crossroads of traffic routes from east to west and from north to south. At the same time, it leads to near the highway. At present, the main importance of Žilina Airport can be perceived as facilitating the access of foreign clients and foreign investments in the Žilina region. From this point of view, the regular line Prague - Žilina - Prague played an important role, which enabled business clients to get to the Žilina region with the help of Prague's Václav Havel Airport, both directly for Czech business partners, and especially for foreigners who used Prague airport as a transfer point to Žilina. Currently, there is no permanent connection between Žilina Airport and European airports, thus preventing the influx of foreign entrepreneurs who would make priority use of this route. Entrepreneurs traveling to the Žilina region (and surrounding regions) must use Bratislava, Košice, Poprad, Brno or Ostrava airports. Due to the limited number of international connections, especially permanent routes with European capitals, Vienna Airport is also considered.

4. Economical Impact of Žilina Airport to the Catchment Area

Based on estimates of Intervistas study [15] the current number of passengers brings into the local economy, a negligible 147-168,000 EUR. These numbers are not favorable from the point of view of the importance of the international airport Žilina. The region does not directly benefit economically from the existence of this airport. It is possible to re-use Intervistas methodology to estimate the direct positive financial effects on the region where the international airport is located, the local economy will benefit from increased revenues of 52.5 up to 60 million EUR with 150,000 visitors. However, this estimate needs to be taken with caution, as there will be a relatively large number of charter flights that business travelers will not bring to the region. Nevertheless, the overall socio-economic benefits of expanding the airport may be greater, thanks to increased activity from foreign investors and easier access for local companies to foreign markets. However, the importance of the Žilina airport cannot be seen solely in the inflow of capital, but also in the increase of tourism.

Also, it is possible to establish a link between the number of passengers at Žilina airport and gross domestic product (GDP) of the whole catchment area based on data from a period when there was a regular connection between Prague and Žilina. Fig. 3 visualizes relevant statistical data from the year 2000 to 2017. Annual passenger statistics at Žilina airport are portrayed as a blue surface graph. GDP values of individual NUTS3 regions are displayed by color curves. The black curve represents the cumulative GDP value of the whole catchment area. Green bars reflect annual GDP change of the whole catchment area compared to the previous year.

It is clear from Fig. 3, that after the initial period ČSA’s line establishment in 2004 and 2005, GDP of the whole region had started to grow more rapidly in comparison with previous years. Years 2006 – 2008 were showing one of the highest annual GDP growth for the whole catchment area in years which was followed by one of the highest passenger numbers at Žilina airport. Unfortunately, a massive GDP drop appeared in 2009 due to the financial crisis. It seems that catchment’s area GDP recovered quickly in 2009, when the number of passengers was still relatively high. Since 2009 passenger numbers at Žilina airport have started to decrease as well as relative annual GDP change of the whole region started to be much lower. In 2012 ČSA canceled its scheduled connection to Prague. Since then, the rate of annual GDP growth of the whole region has never reached numbers before the financial crisis and before the cancellation of only Žilina airport’s regular commercial flight. It seems that regular connection to Prague with approximately 12,500

passengers per year during the peak of the line's existence in 2006 – 2010 greatly helped with the economic performance of the whole catchment area.

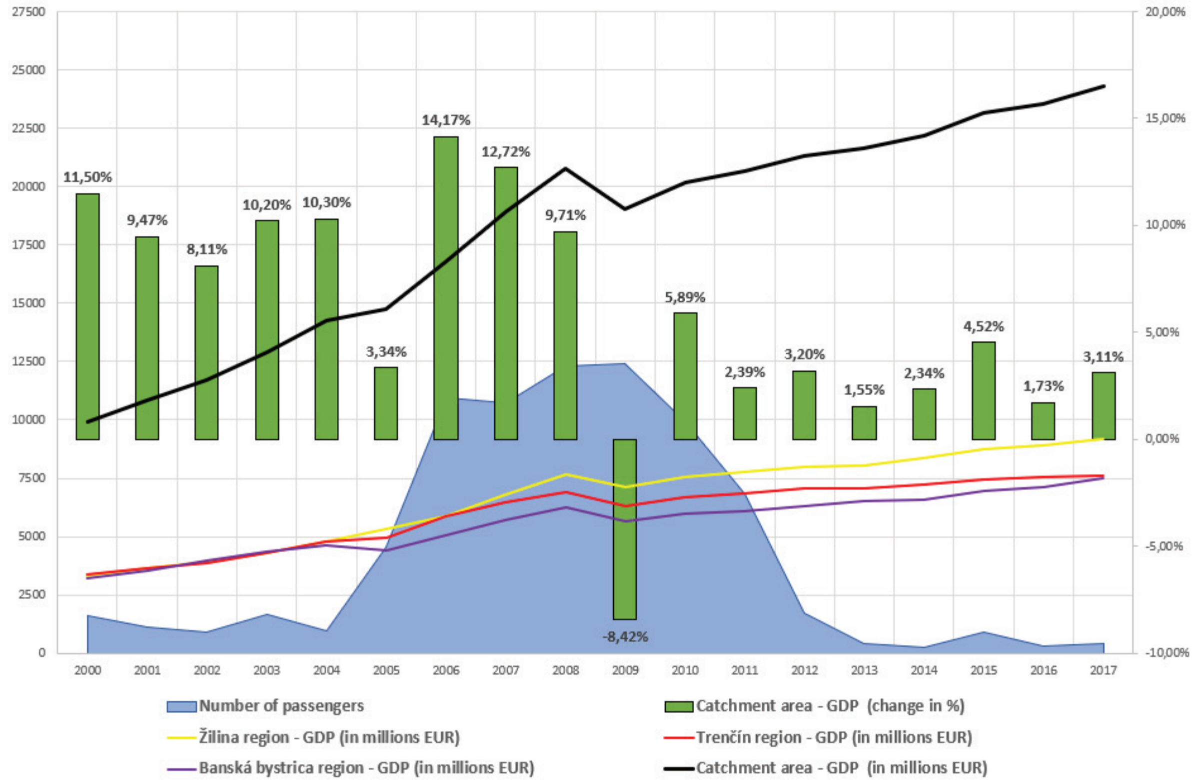

Fig. 3 Žilina Airport passenger statistics compared to GDP of individual NUTS3 regions and whole catchment area

5. Conclusion

Development of Žilina Airport depends primarily on the extension of the runway, which must be extended so that even larger aircraft of low-cost airlines and charter flights can land on it. Due to the catchment area, which has a population of 1.2 million people, the potential for checked-in passengers is in the hundreds of thousands. The largest airport in Slovakia is the M. R. Štefánik Bratislava International Airport, which served 2.3 million passengers in 2018, the second largest in Košice served 540,000 passengers. With sufficient investments the Žilina Airport can possibly approach the regional importance of the Pardubice International Airport, which handles approx. 150,000 passengers. In the longer term, and with the positive development of air transport, it could be closer in importance to the Leoš Janáček International Airport in Ostrava, which handled 370,000 people in 2018 and is thus the third busiest airport in the Czech Republic.

However, simply extending the runway and improving the infrastructure will not be enough to increase passenger numbers. It is necessary to attract air carriers to favorable conditions [18, 19]. It is especially important to attract at least one carrier that will provide a permanent line between Žilina and one of the European capitals, the connection with Prague's Václav Havel Airport, which has year-round connections with a number of European capitals and can therefore serve as a hub, seems ideal. Other possibilities are connections to Vienna, Frankfurt, or Paris, which are natural HUBs that can possibly ensure connection of Žilina with virtually whole world.

The importance of regional airports for their catchment areas has been proved by many authors. There is strong evidence from the past that the presence of regular air connections at Žilina airport had a positive impact on GDP of the whole catchment area. But strong financial state aid will be needed to make Žilina airport attractive for air carries [20]. This financial support can make the airport more attractive not only for passenger transport, but for various other multimodally transported commodities [21, 22]. The airport itself, as a state-owned entity at the regional level would greatly benefit from more traffic due to income from airport charges [23]. It is highly probable that the whole region would greatly benefit from a healthy and live regional airport as Žilina – Dolný Hričov has the potential to become in the future.

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Properties Changes Evaluation of Engine Oils Modified by E-beam

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Abstract

The paper focuses on e-beam combustion engine oils modification. The article compares the properties of conventional and irradiated engine oils by high energy electrons. Researched oil properties were physical and physicochemical, mainly kinematic viscosity, viscosity index, hydrocarbons, total base number, etc. Amounts of hydrogen and carbon were monitored to determine the maximum radiation dose depended on the used of various plastic storage materials. The article introduces new selected approaches to improve overall quality, chemical and thermal stability, solving reliability issues and reduce wear.
KEY WORDS: *engine oil*, *e-beam, electron accelerator, irradiation*

1. Introduction

Hi-tech of accelerators represent modern technologies for various applications in science and industry. Among the most widely used are electron accelerators, which are around 2000 in the world. The accelerated electron application has recently seen a dynamic increase in the protection of historical artefacts. An essential issue in this process is the homogeneous irradiation of matter [1].

Nowadays combustion engines continually push the boundaries of technology and engineering. They are smaller and ultra-efficient, with as low as possible sacrificing performance. Advanced 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 the engine warms up. Serious interest in properties of combustion engine oils are 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 the higher viscosity index, so the engine oil kinematic viscosity should be independent on 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 to engine oils. It has already been proven, that electron radiation can change the kinematic viscosity of combustion engine oils and base oils [2, 3]. Therefore research continues to explore other physical and physicochemical properties of engine oils. The accelerated electron applications have no significant role in the automotive industry. Mentioned technology is used for modification of colors and plastic materials properties of car parts. An essential issue in the implementation of electron irradiation processes into mass production is not well known outcomes in practice.

For submitted work was used linear electron accelerator UELR-5-1S, which is designed to perform various radiation technological processes, research and radiation sterilization, utilizing a beam of accelerated electrons spread out to form the band. The accelerator is working on the electro - magnetic standing wave structure. This structure provides a high rate of acceleration, allowing it to shorten its length and overall radiator length. The working resonance frequency of the structure is 3000 ± 3 MHz. The electro- magnetic standing wave structure is a chain of accelerating resonators and transfer resonators located on the axis of the structure. The accelerator works in a vertical position. The high- frequency power is led through a Y wave - mode transformer located in the last acceleration chamber. Electron clusters move after acceleration to a sensing device where it expands to a band of ≤ 500 mm, depending on irradiation settings. The banding takes form in a trapezoidal vacuum chamber by a sensing electromagnet in which the field varies according to the saw tooth law at 0.25 - 5 Hz. On the chamber outlet is placed 50 µm thick titanium foil to release electrons into the atmosphere [4, 5].

2. Materials and Methods

The presented study was realized on Castrol EDGE 5W40 with the specification of ACEA C3, API SP and VW 505.01. Product data is presented in Table 1 [6]. The main reason for choosing engine oil was the impossibility of

purchase any type of base oil. Base oils are the raw material from which engine, transmission and hydraulic oils are produced by adding additives. Mentioned engine oil was chosen for primary research done [3] on the similar products of this manufacturer, for the possibility of research continue on the old combustion engine with “PD” injection and for its affordability.

Table 1

Castrol EDGE 5W40 C3 Characteristics [3]

Name	Method	Units	Value
Density @ 15°C, Relative	ASTM D4052	gml^{-1}	0.8508
Kinematic viscosity 100°C	ASTM D445	mm^2s^{-1}	13.2
Viscosity, CCS -30°C (5W)	ASTM D5293	mPas	5934
Kinematic viscosity 40°C	ASTM D445	mm^2s^{-1}	77
Viscosity index	ASTM D2270	-	176
Pour point	ASTM D97	°C	-39
Flash point, PMCC	ASTM D93	°C	196.5
Ash, sulphated	ASTM D874	% wt	0.69

For primary research it was done irradiating of 7 samples, each at the same irradiating parameters and volume on the different pad, packaging and height. Every sample consists of 70 ml of mentioned engine oil, except of sample 4FeP50ml. Every Petri dish and container was purified by N-heptane 96% before applying oil sample. To assess the irrelevance of pad, there are results 1DD which describe the first run of irradiation with wood pad and 2FeP relates to the second run in a steel container. Both two samples were 40 mm higher from the conveyor, because of wood dimensions. The other two samples 3FePP and 3FePK have equal numbers considering one irradiation process. Samples set is shown in Fig. 1. The last letter “P” refers to “Petri dishes”. The plastic container was high-density poly-ethylene. The steel container had 1 mm thick walls and 100 mm walls height.

For detecting radiation dose was used radio chromic B3 films. At all positions were two pairs of detectors. Each pair of detectors were both sides coated by duct tape to ensure oil proof and to prevent depreciation. Detectors were fixed at the bottom and at the top-level they float. The radiation dose of tested samples was calculated as the arithmetic means of bottom and top level detectors. The radiation dose of each sample is shown in Table 2. Irradiation parameters were set to the energy of 5 MeV, clusters frequency of 120 Hz, scanning frequency 1 Hz by 40 cm, conveyor speeds were 1.2 mms^{-1} and beam current were 58 ± 2 μA at the whole experiment. Different was only the last samples labelled “4” where conveyor speed was 0.1 $mm.s^{-1}$.

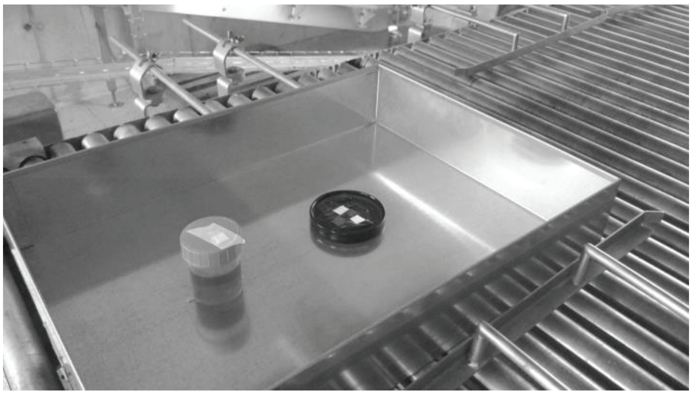

Fig. 1 “3FePP” and “3FePK” samples set for irradiation

Table 2

Radiation dose of tested samples

Container marking [-]	1DD	2FeP	3FePP	3FePK	4FeP
Radiation dose [kGy]	12.58	12.19	20.76	20.76	52.94

Samples marked 3FePP and 3FePK has the same value of irradiation dose. This dose is not equal in real, it's only approximate arithmetic mean value for estimating results for the closed container by the lid. The exact dose of 3FePK could not be measured. The mentioned sample had oil level at 37 mm, which is too high for 5MeV electron accelerator to penetrate through. This information led us to realize the depth profile of used engine oil.

3. Depth Profile

For depth profile of engine oil was used plastic containers due to the possibility of pouring different sample

volumes. Exact volume does not matter in this case. Number of samples was 7 with an oil level step of 5 mm (Fig. 2). Therefore, the first sample had oil level at 5 mm and the last sample had oil level at 35 mm. Depending on information from the previous chapter and penetration curve of electron beam [6] it is estimated, that the last sample would be approaching zero irradiation value. Irradiation parameters were set to the energy of 5 MeV, clusters frequency of 120 Hz, scanning frequency 1 Hz by 40 cm, conveyor speed 0.7 mms^{-1} and beam current 56 ± 1 μA. The radiation detecting principle was the same as described upper. Depth profile results are shown in Table 3.

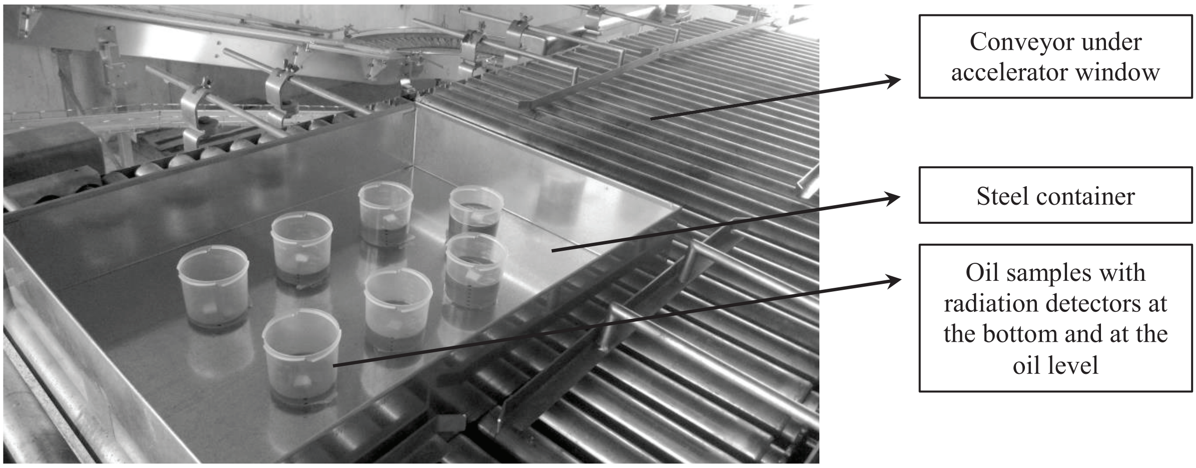

Fig. 2 Samples set for depth profile irradiation

Table 3

E-beam radiation depth profile of engine oil Castrol EDGE 5w40

Oil level [mm]	5	10	15	20	25	30	35
Radiation dose [kGy]	22.24	25.08	23.42	24.51	17.49	15.02	8.33

4. Results and Discussion

It is relevant to determine hydrogen and carbon amounts. For this purpose was used atomic emission spectroscopy method by the optical - emission spectrometer with a rotary disc electrode [7] which fulfills the requirements of ASTM D6595. By this instrument it is possible to measure 24 different chemical elements. These elements represent hydrocarbons as the main component of base oils, undesirable impurities, added additives and oil contaminants with abrasive metals in used oil expertise. For the purpose of researching unused engine oils it is necessary to study hydrogen and carbon. In the irradiation process at higher radiation doses is the potential of cross-linking and implementing engine oil hydrocarbons to or from a plastic containers. In Fig. 3 is shown hydrogen and carbon amounts in each sample. It could be seen that at first two samples with radiation dose 12 kGy there is in order of magnitude larger amount of hydrocarbons as in samples irradiated by 20 or 50 kGy. It can be caused by the upper mentioned idea. It is necessary to make other experiments at much more radiation doses to confirm the theory of cross linking or elements implementation in chemical chains or grid in plastics.

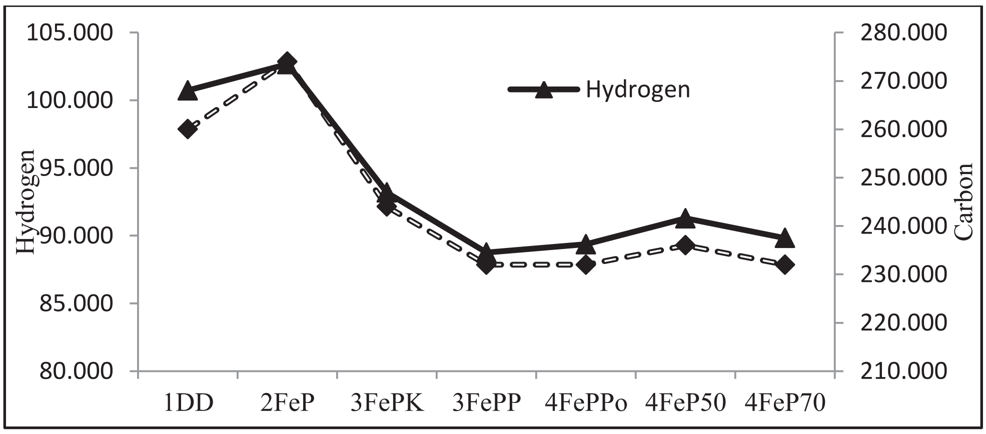

Fig. 3 Influence of container on hydrogen and carbon amounts

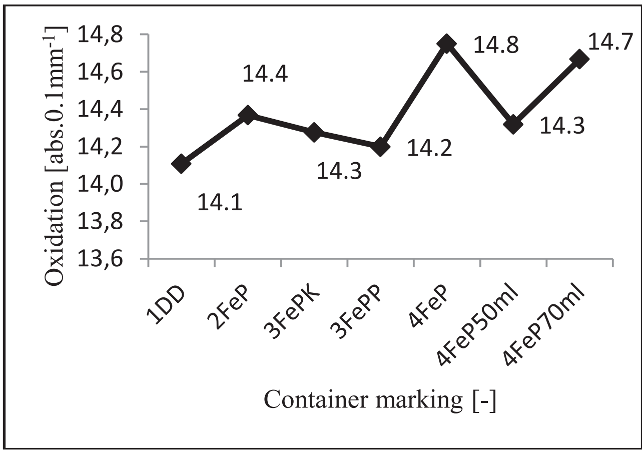

Fig. 4 Change of oxidation value depending on the container

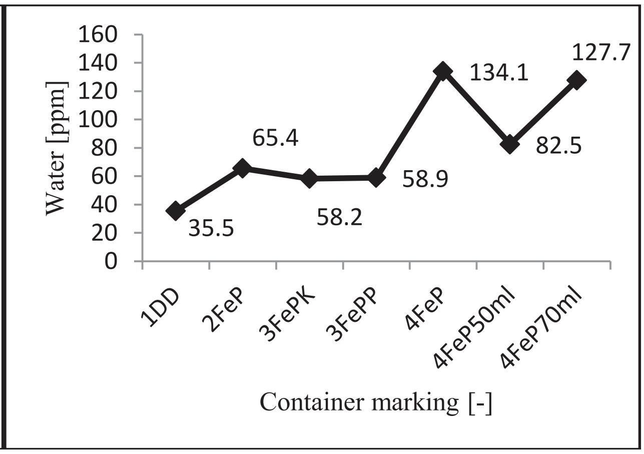

Fig. 5 Changes in water content

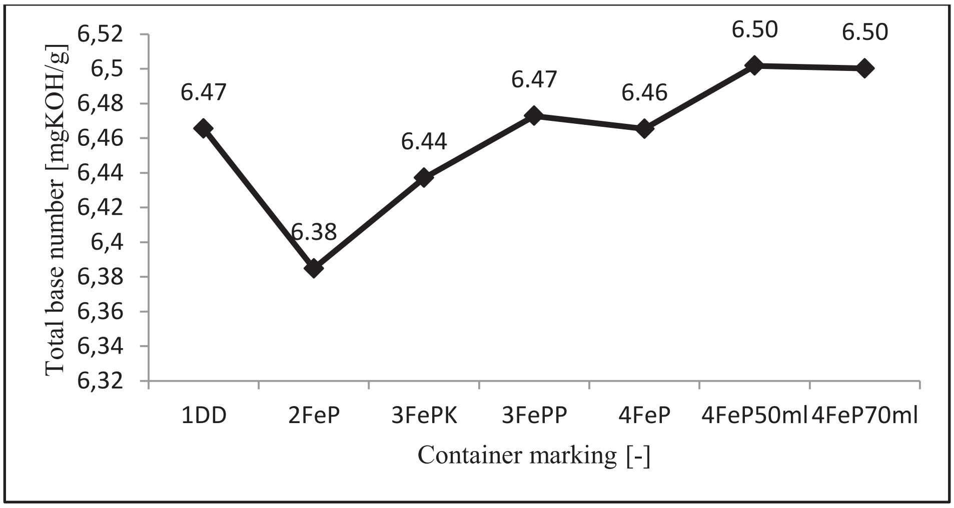

Fig. 6 Total base number

Fig. 4 represents oxidation in researched engine oil. Oil oxidation is the reaction between air oxygen and molecules of oil. Its change could be triggered by oxygen and ozone which is formulated by the irradiation process. A variety of values is accompanied by a variety of radiation doses and used containers- petri dishes, plastic containers and closed plastic containers with lid (Fe3PK). For deceleration of engine oil oxidation are used antioxidants like phenols, amines or at high temperatures are effective zinc dialkyldithiophosphate. The content of dithiophosphates is limited by the maximum permitted concentration of phosphorus in the oil. Recently this limit is consistently reducing. Fig. 5 is an informative graph which points on water content- depending on hydrogen and oxygen. Water and oil are two incompatible substances. Water dissolves in oil only in negligible amounts. When the amount of water exceeds this very low concentration, water falls out in the form of smaller or larger drops and settles down. Water can cause precipitation of some additives in the form of deposits or sludge or the hydrolysis and degradation of other additives (typical for detergents). After evaporation of the water, the precipitated ingredients may dissolve in the oil again. We can see different curves between water content and the total amount of hydrogen. It is caused by the fact, that at these low doses and energies radiation cannot tear the molecules of water but the energy and oxygen supplied to the system can form other molecules of water as we can see on samples at the fourth run of irradiation.

Total base number or alkalinity reserve changes are shown in Fig. 6. 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 some additives (antioxidants or lubricants) 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 of the oil itself and the acids formed by the reaction of sulfur with moisture so we can predict a little decrease of TBN with higher radiation dose and higher amount of residual sulfur from base oil production. Oxidation, water content and the total base number were measured by quantitative and qualitative IR analysis, which complies ASTM E1655. With the reproducibility and repeatability of ASTM E2412, the TBN measurement accuracy is consistent with ASTM D4739 and ASTM D664.

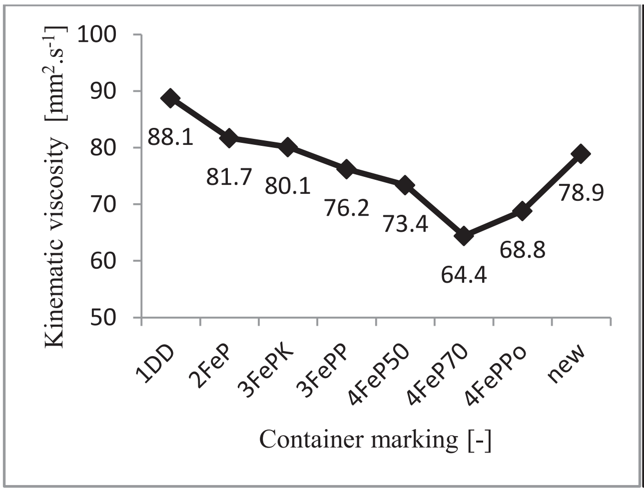

Fig. 7 Kinematic viscosity at 40°C

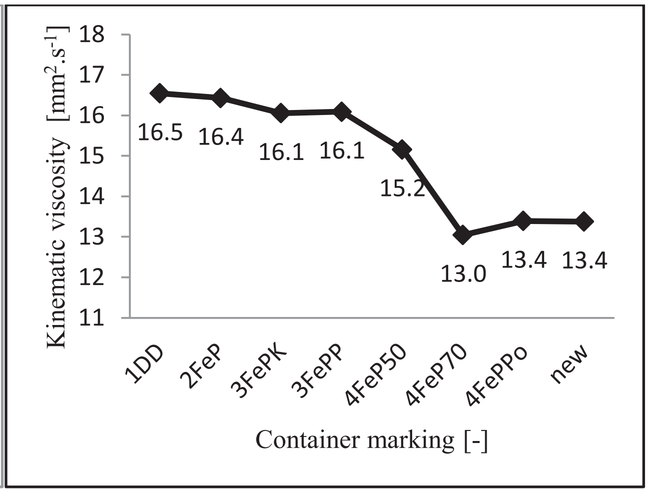

Fig. 8 Kinematic viscosity at 100°C

Viscosity is very important for motor oils. Viscosity is a measure of the fluidity of liquids. During engine oil operation can occur large changes in engine viscosity. The increase in oil viscosity during operation is mainly due to the thermal and oxidative degradation of the oil and in the case of diesel engines in addition to the amount of soot in the oil. Conversely, a decrease in viscosity causes an excessive fuel content in the oil. Another reason for the decrease in viscosity is the shear stability of viscosity modifiers. These are polymeric substances that adjust the viscosity of engine oils and increase their viscosity index.

The viscosity value changes very quickly according to the current oil temperature (Figs. 7-8). The dependence of viscosity on temperature is expressed by the value of the viscosity index. The less the viscosity changes with temperature, the higher the viscosity index (Fig. 9). Viscosity index was evaluated from kinematic viscosities by ISO norm [8]. Kinematic viscosity was measured by automatic viscometer corresponding requirements of ASTM D445, D446, D7279, and ISO 3104.

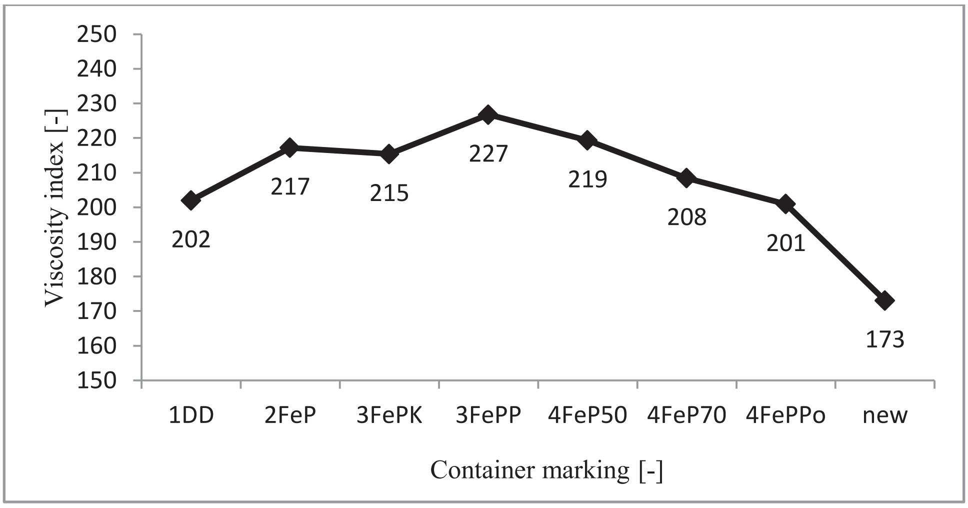

Fig. 9 Viscosity index

5. Conclusion

The e-beam accelerator can be used for 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. A significant step was reached in modifying viscosity and viscosity index. After extended research it is possible to add another method into manufacturing engine oils. By incorporating e-beam irradiation into the engine oil production process by pre-additivation of the base oil, the adverse effect of potentially increasing oxidation and water concentration can be eliminated. 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 engine oils.

Results of the investigation can be used for subsequent experiments in which is admissible to examine tests in the same container, at the same settings and irradiation parameters with vary irradiation dose.

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 arise. High probability is expecting in modifying kinematic viscosity, viscosity index and basicity reserve.

Acknowledgement

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Cargo Throughput of Spanish Maritime Ports

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Abstract

The economic goal of the work of maritime or inland ports is to fulfil their financial budget. The individual items of the budget have a direct or an indirect bond to operation activity indicators. One of these indicators is the throughput of the port that can be defined as the capability of transshipment berths of the port to process the volume of cargo in tones in the specific required structure and variants of work for the monitoring period. Spain belongs to the countries of the European Union (EU) where maritime transport plays a relevant role in the transport system of the state in cargo transport. Spanish maritime ports have the second largest share of cargo throughput after the Dutch ports which are the European busiest ports. Forty-six Spanish ports are owned by the state, and may be divided into two groups (according to the coastline where they are situated). The basic goal of the article is to focus on structural analysis of cargo throughput in Spanish Ports including their container terminals and to predict their development with using the least squares method.
KEY WORDS: *maritime transport, maritime ports, cargo throughput, containers*

1. Introduction

Maritime ports are the hubs located on the coast of oceans or seas where different logistics operations and services are carried out, such as transshipment, storage, transport of cargo by different means of transport between ports and hinterland. Generally, ports consist of water area and land area. In land area there are located different transshipment terminals where cargoes are loaded or unloaded by various handling equipment among maritime transport and other modes of transport [1-2].

Spain is one of the countries of the European Union where maritime transport plays an irreplaceable role in the transport system of the state in transport of bulk, general, liquid cargo, including intermodal transport units. Spain is the country with the longest coastline in the European Union with the length of 8,000 kilometers.

Due to its geographical location, Spain is a leader in cargo throughput of maritime ports not only within the Iberian Peninsula but also in Southern Europe. Spain lies on the main cargo routes between Asia and Europe, Europe and North Africa, Europe and the whole of America, particularly after the Panama Canal was modernized a few years ago [4].

The basic goal of the article is the analysis of cargo throughput of Spanish ports including their container terminals, and to predict their development with using the leas square method. At the end of the article the authors focused on automation processes in the container terminals of Spanish ports.

2. Spanish Maritime Ports

In Spain, there are forty-six maritime ports that are state-owned and managed by twenty-eight port authorities. According to the coastline where they are located, they can be divided into two groups, ie. the seaports situated on the coastline of the North Atlantic and the seaports located on the coastline of the Mediterranean [3].

2.1. Cargo Throughput of Spanish Ports

Over the last thirty years, the development of Spanish maritime ports (Fig. 1) has been very uneven as the result of the development of the world economy, particularly in the Far East (China has become a key country in the production and distribution of consumer goods in the world).

In 2018, 550.75 mil. tons of cargo were transferred in the Spanish ports, of which dry bulk cargo was 102.35 mil. tons (18.6%), liquid cargo was 180.91 mil. tons (32.8%), general (non-containerized) cargo was 76.17 mil. tons (13.8%) and general (containerized) cargo was 191.32 mil. tons (34.8%). The ports located on the North Atlantic coast relocated approximately 33.4% of cargo. On the other hand, the ports situated on the Mediterranean coast, which are a natural gateway to cargo transported from Asia, moved 66.6% of cargo. While the ports on the North Atlantic coast recorded only a slight increase (0.6%) compared to 2017, the ports on the Mediterranean coast recorded their increase up to 4.9%.

Fig. 1 Spanish maritime ports

The leader in cargo throughput was the sea port of Algeciras which transferred 107.2 million tons of cargo (an increase of 5.5% compared to 2017). This port is located on the Mediterranean coast near the Strait of Gibraltar. It was followed by two other ports on the Mediterranean coast (Valencia with 76.6 million tons of cargo and Barcelona with 67.9 million tons of cargo). These three ports controlled 67% of the traffic recorded in the Spanish ports located on the coast of the Mediterranean Sea and moved around 45% of cargo in 2018.

The Basque port of Bilbao with 35.7 million tons of cargo (an increase of 4% compared to 2017) was the most important port situated on the North Atlantic coast. It was followed by the ports of Huelva with 33.1 million tons and Las Palmas with 27 million tons of cargo (the port lies on the Canary Islands). These three ports controlled more than 50% of the total traffic recorded in the Spanish ports on the North Atlantic coast and reloaded about 17% of cargo in 2018.

Table 1

Top 30 European ports by total cargo in 2018 [3]

Rk	Port	Country	2018	2017	2008	%18/17	%18/08
1	Rotterdam	Netherlands	469.0	467.40	421.10	+0	+11
2	Antwerp	Belgium	235.2	223.61	189.40	+5	+24
3	Hamburg	Germany	135.10	136.50	140.40	-1	-4
4	**Algeciras**	**Spain**	**107.2**	**101.56**	**74.85**	**+6**	**+43**
5	Amsterdam	Netherlands	101.8	100.80	94.80	+1	+7
6	Ports of Le Havre, Rouen, Paríž	France	94.74	92.88	n/a	+2	-
7	Marseille	France	81.00	80.60	95.90	+0	-16
8	**Valencia**	**Spain**	**76.60**	**73.56**	**57.77**	**+4**	**+33**
9	Bremenhaven	Germany	74.05	74.18	74.70	0	-1
10	Ports of Gante a Zeeland	Belgium	70.30	66.60	n/a	+6	-
11	**Barcelona**	**Spain**	**67.90**	**61.37**	**51.81**	**+11**	**+31**
12	Duisburg	Germany	65.30	68.30	54.50	-4	+20
13	Trieste	Italy	62.70	61.96	48.30	+1	+30
14	Constanta	Rumania	61.30	58.38	61.80	+5	-1
15	Genoa	Italy	55.80	56.08	54.20	0	+3
16	Gr & Immingham	United Kingdom	n/a	54.03	65.30	-	-
17	Dunkirk	France	51.60	50.40	57.70	+2	-11
18	London	United Kingdom	n/a	49.87	53.00	-	-
19	Gdansk	Poland	49.0	40.60	n/a	+21	-
20	Sines	Portugal	47.9	49.91	25.10	-4	+91
21	Klaipeda	Lithuania	46.57	43.17	29.90	+8	+56
22	Gothenburg	Sweden	40.50	40.80	43.30	-1	-6
23	Zeebrugge	Belgium	40.10	37.12	42.80	+8	-6
24	Livorno	Italy	36.50	33.64	34.03	+9	+7
25	Riga	Latvia	36.43	33.67	35.50	+8	+3
26	**Bilbao**	**Spain**	**35.70**	**34.31**	**39.40**	**+4**	**-9**
27	Southampton	United Kingdom	n/a	34.47	40.97	-	-
28	**Cartagena**	**Spain**	**33.80**	**34.69**	**25.75**	**-3**	**+31**
29	**Huelva**	**Spain**	**33.10**	**32.30**	**20.62**	**+2**	**+61**
30	Liverpool	United Kingdom	n/a	32.54	n/a	-	-
	Total Top*	-	1 995.15*	1 954.3*	1 773.63*	+3	+12

Six Spanish ports (Algeciras, Valencia, Barcelona, Bilbao, Cartagena and Huelva) are among the first thirty ports of the European Union in cargo throughput for 2018 (Table 1), of which four ports are situated on the coast of the Mediterranean Sea and two ports are located on the coast of the North Atlantic. These ports moved 16% of the total volume of cargo. The Dutch cargo ports were the leaders in cargo throughput which together transferred about 26% of cargo [3].

The port of Barcelona had the largest increase in cargo throughput (+11%) between 2017 and 2018, it was followed by Algeciras (+6%), Valencia and Bilbao (both ports had about +4%). The ports of Huelva (+61%), Algeciras (+43%) and Valencia (+33%) had the largest cargo increases between 2008 and 2018.

2.1.1. The Prediction of Cargo Throughput

It will be used the least squares method (linear function $y = ax + b$) to predict the future development of cargo throughput in Spanish ports. For the prediction it will be used the available data with cargo throughput in Spanish ports between 2009 and 2018 (Table 2).

Table 2

Cargo throughput in the Spanish ports between 2009 and 2018 (in millions of tons) [3]

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Year of cargo throughput	1	2	3	4	5	6	7	8	9	10
Cargo throughput [in millions of tons]	399	418	443	461	445	468	488	496	532	551

To simplify the calculation procedure, a linear function will be generated with using the Excel program. The function has the form $y = 15.36x + 385.6$ (Fig. 2), where x represents the year of cargo throughput in Spanish ports and y represents the volume of cargo throughput (in millions of tons). Based on this function, it can be calculated (estimated) the amount of cargo that should be transferred in the ports in a near future. In 2020, it should be about 569.92 million tons of cargo.

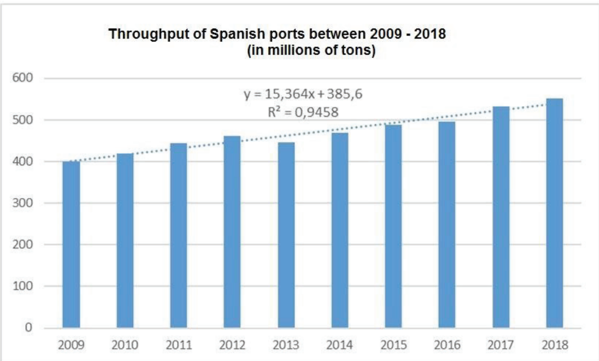

Fig. 2 Gained function for the prediction of the future development of cargo throughput (in millions of tons)

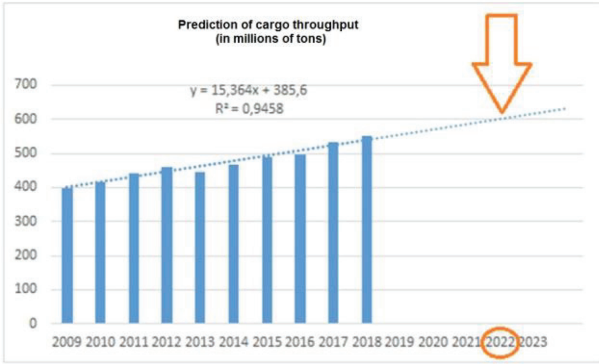

Fig. 3 Prediction of the future development of cargo throughput (in millions of tons)

Then, it will be calculated in which year Spanish ports will transfer more than 600 million tons of cargo. This value is calculated from the equation $600 = 15.36x + 385.6$, where x (the year of cargo throughput) will be 13,96. In 2022, Spanish ports should move more than 600 million tons of cargo (Fig. 3).

3. Throughput of Spanish Container Ports

In 2018, top 30 European container ports transferred about 85.480 million TEUs. The Dutch port of Rotterdam was the busiest European container port with 14.5 million TEUs, it was followed by Antwerp (11.1 million TEUs) and Hamburg (8.7 million TEUs). Spanish ports transfer about 2 thousand of containers per hour.

In 2018, the port of Valencia was the busiest container port in Spain with 5.183 million TEUs (it was the 5th among European container ports). It was followed by the ports of Algeciras with 4.773 million TEUs (7th among European container ports), then Barcelona (10th among European container ports with 3.473 million TEUs) and Las Palmas (twenty-second among European container ports with 1.140 million TEUs) [3].

3.1. Prediction of Container Throughput

Containerized cargo is the most transferred type of cargo in Spanish ports, therefore the prediction of the throughput of container ports will be carried out. It will be also used the same method (least squares method (linear function $y = ax + b$)). It will be used the data related to the throughput of Spanish container ports between 2009 and 2018 (Table 3) for the prediction.

Table 3

Throughput of Spanish container ports between 2009 and 2018 (in millions of TEUs) [3]

Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Year of throughput	1	2	3	4	5	6	7	8	9	10
Throughput of Spanish container ports [in millions of TEUs]	6.367	6.587	7.689	7.689	7.344	7.612	7.427	7.923	8.501	9.287

Using Excel program, a linear function will be generated. The function has the form $y = 0{,}2444x + 6{,}2983$, where x represents the year of throughput of Spanish container ports and y represents the throughput of Spanish container ports (in millions of TEUs) (Fig. 4). Based on this function, it can be estimated the volume of containers that should be transferred in ports in a near future. In 2020 about 9.23 million TEUs should be moved in these ports.

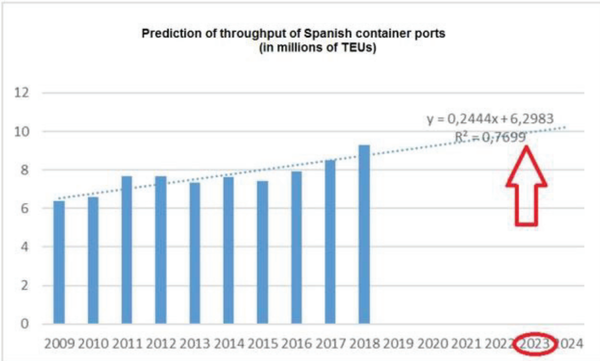

Fig. 4 Prediction of container throughput

At the end it will be predicted in which year the Spanish ports will tranship more than 10 million TEUs. This value is calculated from the equation $10 = 0.2444x + 6.2983$, where x (the year of transhipment of containers) will be 15,15. In 2023, the Spanish ports should tranship more than 10 million TEUs.

3.2. Automated Spanish Container Terminals

Automated container terminals are terminals where some container handling devices operate without direct human interaction. Drivers of the cranes have been physically re-moved, or they have remained in their cabins but they are not needed for the entire duty cycle. These terminals have a higher throughput than standard container terminals that use port workers for handling operations. [5]

In Europe there are 11 automated container terminals. The port of Rotterdam has four terminals; and Hamburg has two terminals. Three ports in the United Kingdom (Liverpool, London and Thamesport) have each one terminal, one terminal is also in the port of Antwerp. Two years ago, the terminal of the Italian port of Vado Ligure was also added to this list [6].

Total Terminal International (TTI) located in in the port of Algeciras was the first automated container terminal in Spain that was put in the operation in 2010. Automated or semi-automated handling devices (semi-automated ship to shore gantry cranes and automated stacking cranes on rails) are located in the sea (water) side transfer area and container yard that is fully automated. Semi-automated ship to shore gantry cranes move containers between container vessels and straddle carriers. Automated stacking cranes on rails handle with containers between straddle carriers located in the sea (water) side transfer area and the blocks of the container yard, within the blocks of the container yard (each block has got two automated stacking cranes), and between the blocks and straddle carriers located in the land side transfer area [7].

The second Spanish automated container terminal is Barcelona Europe South Terminal (BEST) that is situated in the port of Spain. It was opened in 2012. This terminal has a fully automated container yard where automated stacking cranes on rails move containers between straddle carriers located in the sea (water) side transfer area and the blocks of the container yard, within the blocks of the container yard (each block has one automated stacking crane) and the blocks and container trucks located in the land side transfer area.

A new automated container terminal is going to be built in the port of Valencia. The terminal will include area of 1.382.000 m², the quay line of 1,970 m, with the draft of 20 m near the berth as well as in all the basin, and the access channel will be 22.5 m deep [8].

4. Conclusions

Maritime ports are the gateway for all types of cargo transported by seagoing vessels among the continents [3]. Spain is country with the longest coastline among the countries of the European Union. Spanish maritime ports have got the second biggest share in the throughput after the Dutch ports. These ports are located on the coast of the North

Atlantic and the Mediterranean Sea. Two thirds of cargo are transferred by the ports situated on the coast of the Mediterranean Sea.

The basic goal of the article was to analyse and predict the throughput of Spanish maritime ports and their container terminals using the least squares method. In 2022, Spanish ports should transfer more than 600 million tons of cargo. In 2023 Spanish container ports should move than 10 million TEUs.

The port of Algeciras is the busiest Spanish port as the result of its good position close to the Strait of Gibraltar. It also lies on the trade routes between Europe, North America, the Far East and America. On the other hand, the port of Valencia is the busiest Spanish container port. Two of the ports are also equipped by automated container terminals. These terminals do not only increase the throughput of the ports, but also reduce the downtimes that arise during handling operations.

Development of maritime sector is determined by a lot of factors that may stimulate or reduce it. In spite of the fact that there are some methods that can predict the development for a near future, a global crisis, local war conflicts or diseases such as COVID 19 can completely change the prediction.

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Operational Capabilities as a Part of National Defence Potential

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Abstract

The national defence potential is a whole material and moral opportunity of a national that can be used to achieve the objectives of the war. The size of these capabilities during a given period depends on the number and quality of combat measures, the production capacity of the defence industry, the number and quality of trained reserves and the degree of preparation of personnel and their organizers, the skills of senior commanders in the management of the preparation and use of armed forces on a strategic, operational and tactical level. The operational potential influenced by specific defence capabilities. The fulfillment of operational capabilities is possible in many cases. One part of this process is a prioritization of operational capabilities. It gives the opportunity to focus only on those capabilities that are most important to the national military potential. The prioritization is the main process for defining the operational capabilities that are necessary to achieve and maintain. This article shows the selected element of an analysis of the operational capabilities and requirements and assessment and influences the national military potential.
KEY WORDS: *national defence potential, operational capabilities, national safety, national security*

1. Introduction – Threats for Safety & Security

Safety and security is often a subjective feeling that can be felt by anyone in a different way. However, regardless of the way we feel safe or secure, we can consider them in the following five dimensions [19]:

– in the military dimension - related to the offensive and defensive military force of States and the mutual evaluation of intentions by States;

– in the political dimension - related to the institutional stability of States, systems of governance and ideologies that provide them with legitimacy;

– in the economic dimension - functioning around access to resources, financial assets and markets, the access necessary to maintain the expected level of prosperity and power of the State;

– in the social dimension - focused on the stability and development of traditional language and cultural patterns and religious and national identities and practices;

– in the environmental dimension - related to maintaining the local and global dimension of the biosphere as an indispensable base for all human activity.

Nowadays, another health dimension can be added to the above-mentioned dimensions, namely the dimension related to the provision of health protection as an essential condition of human existence.

The reason for the uncertainty in achieving the specified objectives is the threats, the number and scale of which affect the level of safety and security. Security is to achieve a status of certainty and stability and to obtain the minimum level of occurrence of a threat that may affect this status. As you can see, a threat is the opposite of security or security. Therefore, each entity strives to influence its external environment and internal sphere in order to remove, neutralize or at least dismiss threats and eliminate its own fears, concerns, anxieties and uncertainties.

Security can be assumed to be a function of threats, which are always symbolized by uncertainty [2]:

$$B = f(Z) \rightarrow N_p, \tag{1}$$

where B – Security; Z– threats; N_P– uncertainty.

Threat means the subjective (and therefore dependent on the perception by an entity) and/or the objective (real) occurrence of a threat for the essential safety/security values for a given entity. The threat is directed at specific values, which are the object of protection by a given entity [22].

Following the analysis of trends contained in NATO documents such as: The Strategic Foresight Analysis 2013 and the Framework for Future Alliance Operations 2015, one can define ten unstable situations (future events), crises or conflicts that NATO will have to face by 2030. Unstable situations range from large-scale disasters and the destructive effects of migration to warfare between the states. This situation forces the Alliance states to plan defensive scenarios, which become a response to emerging threats. The cited examples are identical in their importance and are not listed in any order of priority [3]:

1. Access and use of global resources.
2. Conflict in the Euro-Atlantic region.
3. Migration.

4. Cyber-threats.
5. Large-scale catastrophes.
6. The overcrowding of cities.
7. Non-state actors as rivals of the State.
8. Disturbances in cosmic space.
9. The conflict between the State and a state.
10. Weapons of mass destruction.

In “The Concept of Defense of the Republic of Poland” the following assumptions, which influence the shape of specific challenges and threats to the safety and security of Poland [7], were adopted:

– the gap in many fields between globalisation and national interests;
– governance based on international law is subject to further upheavals due to the powerful aspirations of individual countries;
– the inevitability of changes as a result of the relative decline in the role of Western countries and the growth of new economic powers;
– Diversification of the non-state sphere of activity (transnational corporations, NGOs, social movements or extremist groups) in terms of motivation and in ways and objectives of actions;
– the need for solidarity in the face of social trends in developing countries, in terms of falling authoritarian regimes;
– the dynamism of technological development may be a source of progress but also of threa.s

It is therefore crucial to have an adequate defence capability to ensure that the required level of state safety and security is maintained.

2. Defense Potential of the State

Potential in common sense is the power, production capacity, capabilities, as well as the efficiency, productivity and possibilities of (someone) the state in some area [16]. In turn the defence potential of a country is “the entirety of material and moral capabilities of the state, which such capabilities can be used to accomplish the goals of a war”. The size of these capabilities over a given period depends on the quantity and quality of the combat assets, the production capabilities of the arms industry, the number and quality of the reserves trained and the degree of preparedness of the personnel and their organisational capabilities, the ability of senior commanders to manage the preparation and use of the armed forces on a strategic, operational and tactical scale. Generally speaking, the state's war potential is divided into moral-political, military and war-economic potential [17].

Among other things, the defence potential is created by the armed forces, which are becoming the most important counterweight to emerging threats. The armed forces are the guarantor of the safety and security of the state, the foundation and the pillar of the state. The armed forces symbolize the state’s institution - its organization, seriousness and efficiency. The armed forces give the society a sense of safety and security, faith in the state, pride and seriousness from their own country, and constitute the organization, through which and in which citizens identify (equate) themselves with the state and feel co-responsible for it [11].

The size of the defence potential affects the national safety and security dimension, which is one of the basic dimensions of the existence and development of the state community. They are defined as the ratio of the size of the defence potential to the scale of threats [21]. We can present them by using the following formula:

$$W_{BN} = \frac{P_{OB}}{P_Z}, \tag{2}$$

where W_{BN} - national safety/security indicator; P_{OB} – the size of the defense potential; P_Z – the level of threats

Defence potential is a function of such components as: territory and geostrategic location of the state (*TiPG*), economic potential (*PG*), military readiness (*GM*), natural resources (*ZN*), quantitative and qualitative state of society (*IJSS*) and quality of power and diplomacy (*JWiD*). We can write this function down as follows:

$$P_{OB} = f\left(TiPG, PG, GM, ZN, IJSS, JWiD\right). \tag{3}$$

The military preparedness of the state can be defined as the suitability of its military and non-military elements to maintain national safety and security and to act effectively in situations of threat, either immediately or at the planned time. Military readiness will be affected by the quantitative and qualitative status of defence products, especially military equipment.

3. Capabilities as the Determinant of the State's Defence Potential

Modern military operations generate new needs for individual and team equipment for the armed forces. These needs vary depending on the scale of the conflict, the place of action on the globe, the climate conditions. A modern

assessment of the safety and security environment should not be based only on threats, but should be largely based on capabilities. They are the expression of the value and usefulness of the armed forces as the tool for achieving the objectives of the national security strategy. The capabilities are intended to enable effective and efficient response to national security challenges that will ensure the success of national or allied defence in the event of armed aggression, as well as in crisis situations. The requirements of the modern safety and security environment, technological development and progressive modernization of the armed forces of the neighbouring countries and member states of the North Atlantic Alliance - are the determinants of the growing challenges to be faced by the Polish Armed Forces. Allied obligations and social expectations force the Polish Armed Forces to take transformational actions aimed at faster development of operational capabilities [18].

Capability is the predisposition to easily master certain skills, acquire knowledge, learn. This is a potential skill, possibility to do something, ability to do something [15]. According to the Military Operations Research Society (MORS), capability is the skill to achieve, under given conditions and given standards, the desired effect through the realization of appointed tasks by means of appropriately selected and collated objectives, assets and resources [5]. The Capability is the asset to obtain operational results necessary for the success of the armed forces mission [9].

The term "operational capability" is used to plan the development of the armed forces. This term is defined as the potential efficiency, the possibility of an entity resulting from its characteristics and properties to take action to achieve the desired results. The functional components of the capabilities are: doctrines, organisation, training, armaments/weapons and military equipment, personnel, leadership, infrastructure and interoperability [12]. The presented definition contains model components of capabilities consistent with NATO standards.

The required level of operational capabilities is most often expressed by the following criteria [10]:

– the verb describing the action - this verb allows to define the purpose of the capability (what it is used for, e.g. to identify, incapacitate). The verb should be strict enough (precise) to enable identification and assessment of the satisfaction of the needs for the development of this capability;

– the purpose (object/receptor of a capability) - the actions on the battlefield must be directed against some objects or entities. Clarifying the purpose, or otherwise - an object/receptor of a capability helps to develop a variety of solution options such as;

– target size - a determination of the size or range of target size is necessary to define the purpose of the capability as well as to guide activities related to the development of specific options for solutions (e.g. to be able to identify small submarines and large surface vessels);

– capability domain (capability environment) - Identifying air targets and identifying ground targets are completely different capabilities. Distinguishing these capabilities by domain is a necessary discriminant of a capability;

– area of operation - the size of the area of operation of a given capability allows to determine the scope of potential solutions.

The operational capabilities are based on the tasks to be performed by the armed forces. The first stage of their identification is the analysis of the safety and security environment and of the level of national ambitions (assessment of the tasks of the national defence subsystem). As a result of the analysis, we obtain a collection of scenarios for the use of armed forces (a collection of threats) possible to occur within the assumed time horizon. In the next stage, on the basis of an ordered collection of scenarios (threats), a collection of tasks is developed, which in turn will result in the capabilities that the armed forces should have to meet the defined options for their use.

The list of capabilities is compared with the potential (possibilities) of the armed forces and the limitations that may affect the achievement of the capabilities. The result of the comparison is a list of capabilities with a detailed description of each of them. It may happen that the potential of the armed forces, even with existing limitations, is able to achieve a defined capability, but it is also assumed that there are capabilities that require additional resources. In the latter case, an operational programme shall be established to meet the requirements necessary to achieve the developed operational capability.

The end result of this stage is the presentation and definition of those capabilities which the armed forces are unable to achieve within the assumed time horizon.

Decisions on which capacities to develop, at what level and over what time horizon, must take into account the satisfaction of current needs, ongoing projects and programmes (e.g. in the field of research and technology) and funding (e.g. ongoing R&D).

The definition of operational capabilities is now the basis for planning and programming the development of the armed forces. The basic document used for programming the development of the Armed Forces is "Methodology for planning and programming the development of the Polish Armed Forces in 2017-2026". This document specifies the normative and legal basis as well as the principles of implementation of the process of planning and programming the development of the Armed Forces, indicates the participants of this process together with the scope of their competences and tasks [19]. One of the most important documents developed as part of the "Methodology..." is the "Catalogue of capabilities of the Polish Armed Forces" [14]. The Catalogue contains all the potential capabilities needed for the missions and tasks that the Polish Armed Forces face - from the main capability area to the smallest single tactical capabilities. On the basis of the Catalogue, it is possible to analyse the tasks of the armed forces from the point of view of their feasibility, taking into account their capabilities and also the needs for maintenance, development and acquisition of new capabilities have been specified [19]. It should be noted that each capability has its own life cycle, the management of which should be important for the planning and programming process for the development of the armed forces. There may be so-called one-off, short-term capabilities and those that need to be maintained and

developed for a long time. Abilities very often permeate each other, i.e. they influence each other and should not be considered on an individual basis. Prioritization is becoming the serious problem. This is the ability to define not only key areas in terms of operational capabilities but also to develop their hierarchy.

As part of the Strategic Defence Review (SDR) factors of importance were identified for the state defense and seven areas of operational capabilities were defined: command, reconnaissance, fire, survival and protection of troops, support of operations, transfer and mobility and the support of the non-military system in situations of non-military threats [4]. The functional systems (structured logical collections of separate and organisationally related subsystems and areas of activity of the Ministry of National Defence) and the functional persons responsible for them were established for capability management and also the main areas of capabilities were pointed. In the Concept of Establishing Organisers of Functional Systems, seven functional systems and their organisers were distinguished [14]. These are the following systems:

- the Command Support System;
- the Reconnaissance System;
- the Striking System;
- the System for Survival and Protection of Troops;
- the Logistics System;
- the Replenishment and Mobilisation System;
- the Training System.

In the adopted solutions, the capability-based planning of development of the Polish Armed Forces includes a collection of conceptual and planning activities undertaken to determine the directions of shaping and modernizing the Polish Armed Forces, the directions identified in terms of achieving, maintaining and developing the desired operational capabilities. Actions to acquire specific capabilities in the areas of doctrine, organisational structure, training, technical modernization, leadership, education and training of human resources, infrastructure and interoperability are undertaken within the process of programming the development of the Polish Armed Forces.

From the collection of capabilities, there are specific needs that need to be met in order to achieve a given capability. The Dictionary of the Polish Language defines a need as what is needed for proper functioning or is essential, necessary. Operational needs are an identified collection of needs to achieve the assumed operational capabilities of the Armed Forces of the Republic of Poland, developed on the basis of planning scenarios and calculation modules. Implementation of (tangible and intangible) tasks, activities and undertakings which will ensure the operational capability of the armed forces to guarantee carrying out the tasks and missions identified for them effectively. The purpose of determining operational needs is, among other things, to identify optimal requirements for military equipment which is to ensure that the tasks and objectives, often difficult to predict, that were set, shall be achieved.

The following criteria should be taken into account when choosing the best way to achieve a specific operational capability [13]:

✓ operational (military) utility criterion;

✓ the cost criterion (life cycle cost analysis, if the way to meet capabilities may be the purchase, production or modernisation of military equipment);

✓ the criterion of technical and technological capacities (whether there are technical capabilities or whether there is a technology to meet a certain capability);

✓ the criterion of availability of the product on the market to ensure that a certain capability can be achieved;

✓ the time criterion (how long a capability is to be achieved and for how long the armed forces should be able to fulfil it);

✓ the logistic criterion (what will the logistic system be like, which is to create conditions to meet and maintain a certain capability: unchanged system, rebuilt system or system created as completely new one);

✓ the criterion of universality (whether it is a one-off capability or will the fulfilment of this capability be used in other conditions), etc.

When analysing the criteria presented, the selection options and the description of the capabilities, the best ways to meet them should be chosen.

4. Conclusions

The level of defence capabilities of the Republic of Poland is a resultant of national needs and allied obligations. The defence potential available depends on the size and type of operational needs. In fact, it is the operational needs that determine the military and non-military capabilities of the state. It is important that operational needs are correctly identified and defined and then ranked according to the hierarchy adopted, based on risk assessment. The assessment of the degree of fulfilment of operational capabilities will have an impact on the assessment of the state's defence capabilities and thus on the level of its safety and security.

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Comprehensive Risk Assessment of Railway Crossings in Slovak Republic

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Abstract

The article is focused the risk assessment process for railway crossings, at the same contains activities and analytical methods, that are part of risk management. Accidents at level crossings they account for more than a quarter of all accidents on rail within the EU and a significant proportion of accidents at railroad crossings also falls in railway statistics of the Slovak Republic. In terms of safety on the railway track is the most dangerous place Level crossing of the railway with the road. It is practically the only place of direct physical contact between otherwise relatively isolated transport modes. Traffic accidents at level crossings they are not the most common, but their consequences are much more serious, in terms of deaths and serious injuries. Combination of several factors at level crossings is one of the most significant causes of an accident. From this reason these objects need to be thoroughly analyzed, this means taking into account technical and legislative aspects, as well as human factor issues, which would lead to a comprehensive risk assessment at railway crossings.
KEY WORDS: *risk, railway crossings, safety, analysis, Slovak Republic*

1. Introduction

Rail crossings are unique in the world of transport, because they represent the only possibility of an impact of two different infrastructures, which management system depends to different regulations and vehicles with dramatically different performances and design solution. Railway crossings are high-risk areas, where the potential for an accident is high due to the fact that the railway´s management controls only half of the level crossing environment. The other half concerns road users. Nevertheless, that there are legal norms, traffic regulations, standards in road design, ultimately the movements of the participants, they are not organized and monitored by one specific entity so that as railway movements. Every year at level crossings in the countries of the European Union, there are killing occurs and serious injuries to thousands of road users, as well as several million damages on the property and environmental damage.

2. Risk Assessment at Level Crossings

2.1. Determination of Internal and External Contexts

Based on available statistics and the results of accident investigations and emergencies, the main causes of accidents have been identified at level crossings. It is important to assess the impact of external and internal conditions separately for each mode of transport. Rail transport is a type of land transport, in which the value of the positive benefit of transport is often reduced by unforeseen circumstances, but also such, which should ultimately be avoided. Rail transport is relatively safe compared to other modes of transport, but even here it is necessary to take measures to systematically reduce the occurrence of accidents. The grouping of possible causes of accidents in the transport process is shown in Fig. 1.

A combination of several factors is one of the most significant causes of accidents. Fortunately, the control mechanisms which have been gradually developed over the long period of the existence of rail transport, lead to multiple control activities. If the human factor fails, as a rule, no accident will occur. If several errors coincide and the failure of all the workers involved, then the occurrence of an accident is inevitable. According to the latest statistical findings, there is a probability of an accident on the network of Railways of the Slovak Republic in one year it is equal to almost one. Therefore, it is necessary to look for new ways how to increase safety and security, how to introduce a new technique and look for new technological procedures, which will eliminate errors [1-5].

Road transport is a type of land transport, which is currently enjoying unprecedented popularity and growth in the Slovak Republic. The number of means of transport on the road is increasing every year as well as the number of new drivers, which are associated with many negative phenomena, with which creation is associated and the functioning of the transport system. This is mainly an increase in the number of traffic accidents, congestion, endangerment of human life and health, collapses as well as other negatives, which may disrupt the functioning of the

transport system. In road transport, crisis phenomena are described as accidents, incidents and crisis situations. Grouping of internal and external influences, as causes of crisis phenomena in road transport is shown in Fig. 2 [1-5].

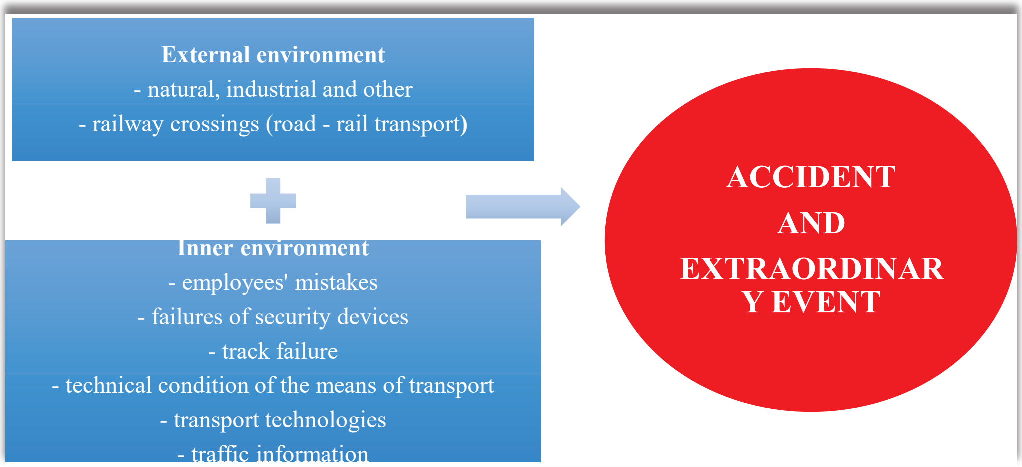

Fig. 1 Basic causes of accidents and incidents in railway transport

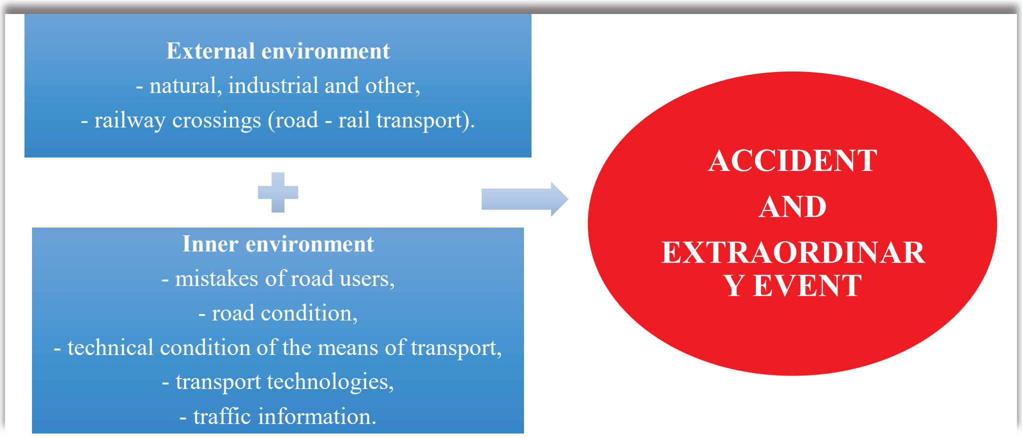

Fig. 2 Basic causes of accidents and incidents in road transport

Most of the above factors affects both components of the risk - the potential magnitude of the consequence and the likelihood of an accident. If their influence is to be suppressed, possibly reduced to a minimum, they need to be thoroughly analysed. From a mathematical - statistical point of view, the occurrence of traffic accidents on roads can be considered, for the rare occurrence of unevenly distributed phenomena. Furthermore, their occurrence can be considered for a discretely varying variable. The risk is for each section of the road network calculated by comparing the incidence of accidents with serious and fatal injuries with the volume of traffic. Relatively highly probable cause of traffic accidents on sections of the road network it is necessary to look for in addition to the human factor also in construction - technical conditions and in the traffic - organizational arrangement of communication. Such places include:

- insufficient or delayed information for the driver (eg caution obstacle);
- incorrect traffic signs, unsatisfactory directional / height parameters of the road;
- busy intersection without traffic directions;
- insufficient or inadequate lighting, missing sidewalks in the urban area [1-5].

2.2. Determining the Scope of Safety Risk Assessment at Level Crossings

In this section, we will define the boundaries for the selection of level crossings. Due to the fact, that there are different types of railway crossings in the Slovak Republic, in setting boundaries for risk analysis, we will be based on statistics. Fig. 3 shows the number of types of level crossings and the number of consequences of accidents on them in 2019.

From these data, we have defined the following criteria for risk assessment for level crossings:

- crossings with light safety devices with barriers;
- crossing with light safety devices without barriers;
- unsecured level crossings.

From a legal point of view, railway crossings are also equipped with traffic signs, which draw attention to level crossings. These are located at a distance of 240 m, 160 m and 80 m in front of the railway crossing. Above the

signboard - 240 m there is one of the two traffic signs - railway crossings with barriers or railway crossings without barriers. The limits for the risk analysis of selected level crossings are shown in Fig. 4.

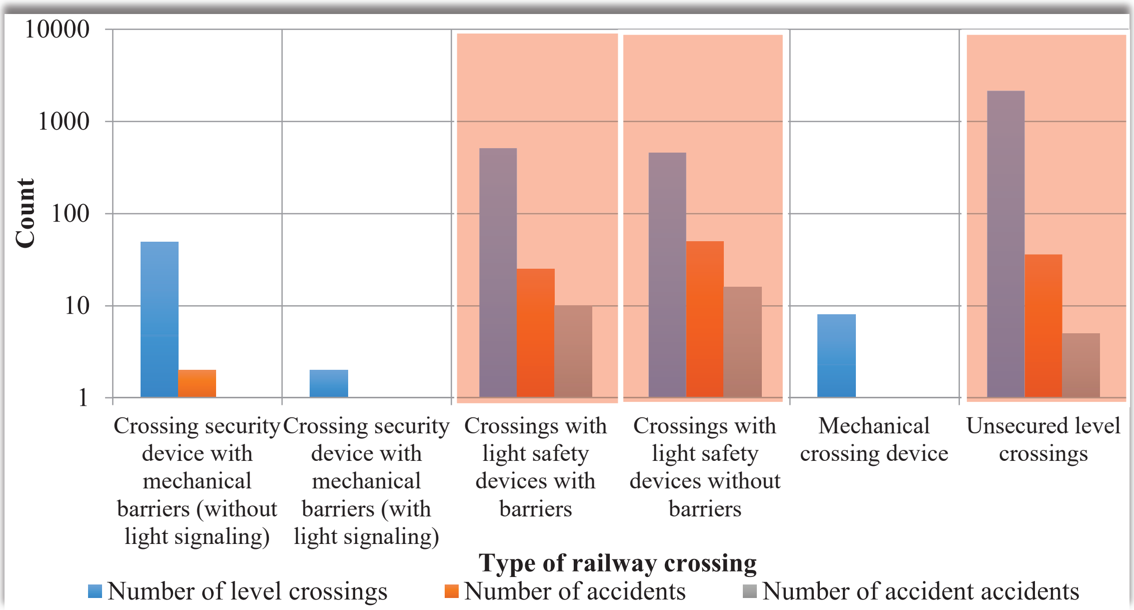

Fig. 3 Number of types of level crossings and number of consequences of accidents [6]

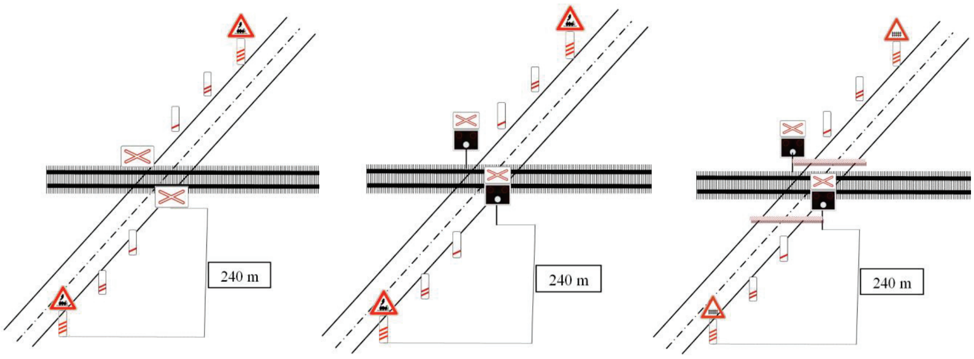

Fig. 4 Criteria for risk analysis

Next part, for the purposes of risk analysis, is dedicated to modelling emergency scenarios at level crossings. Their creation was based on the observed events that occurred in the Slovak Republic. Due to the fact that it is not possible to include all possible scenarios and combinations of accidents, the article selects those scenarios that in the past showed the most frequent occurrence at railway crossings. The scenarios are described in Figs. 5 and 6.

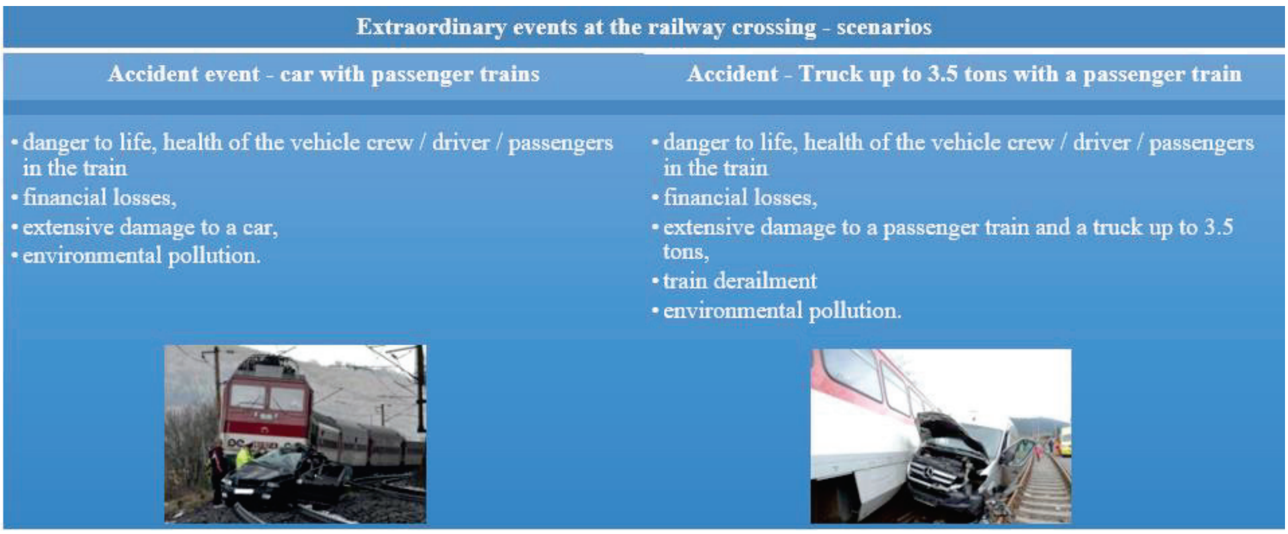

Fig. 5 Crossings - Scenarios (part 1/2)

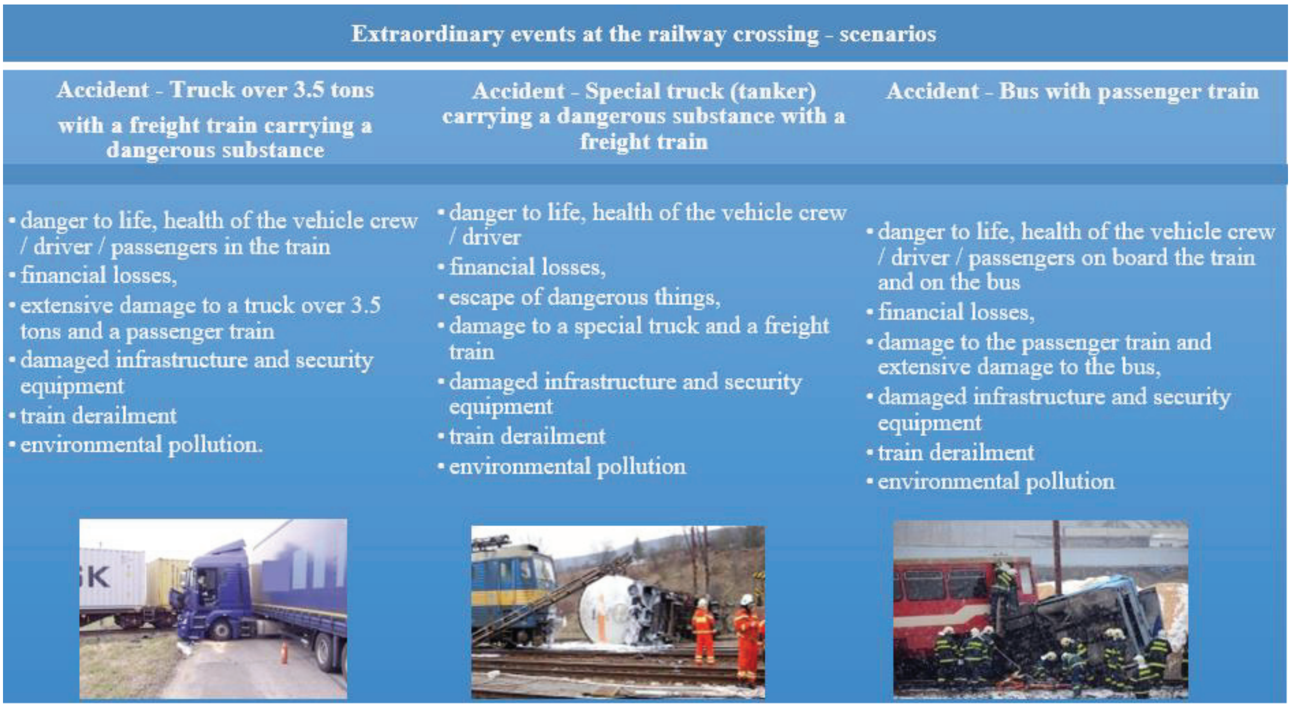

Fig. 6 Crossings - Scenarios (Part 2/2)

2.3. FMEA Method

Risk analysis at level crossings using the FMEA method makes it possible to identify the functions of the transport process and subsequently identify all possible errors, estimate the shortcomings of these errors, identify the causes and parameters of the processes. The identification phase was performed, where the boundaries of the risk analysis were subsequently determined.

The numerical phase focuses on the calculation of the risk level in the form of the *RPN* risk number and is calculated according to the relationship:

$$RPN = PV \cdot VV \cdot PO\,,$$

where *PV* – probability of accident; *VV* – significance of the accident; *PO* – probability of accident prevention.

The values of the parameters based on the scales are given in Table 1. They are compiled on a scale of 1 to 5.

Table 1

FMEA analysis identification table

Probability of an accident	Value	The meaning of the accident	Value	Accident prevention	Value
Unlikely	1	The accident cannot be observed	1	High	1
Very small	2	A negligible accident	2	Central	2
Small	3	Moderately significant	3	Small	3
Central	4	Severe	4	Very small	4
High	5	Extremely serious	5	Negligible	5

To evaluate the degree of risk, we created a group of 10 experts who evaluated each manifestation of the accident according to Table 5. The total value of RPN from the formula, allows comparison of individual accidents in terms of their causes and consequences according to a uniform scale. Subsequently, according to the size of the RPN value priorities can ultimately be set and preventive measures. Table 2 defines the total RPN value and risk characteristics.

Table 2

RPN evaluation table

RPN value	Risk characteristics
1 – 30	Acceptable - the process is safe
31 – 50	Moderate - the process is safe
51 – 90	Unwanted - the process is dangerous
91 - 125	Unacceptable - the process is unacceptable

Table 3

FMEA - accident a car with a passenger train

Identification phase			Numerical phase of risk assessment at level crossings				
Scenario	Manifestation of the accident	Possible consequences of the accident	Possible causes of the accident	Current status			
				meaning	appearance	avoidance	RPN
Personal vehicle with by passenger train	**No consequences of a traffic accident (1A)**	Limited transport process on railways and roads Property and cash losses Leaking fuel	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	3	3	**45**
	With the consequences of a traffic accident (1B)	Endangerment of life, health of the vehicle crew/ driver/ passenger Limited transport process on railways and roads Property and cash losses Leaking fuel	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	5	4	**100**

Table 4

FMEA - accident a truck up to 3.5 tons with a passenger train

Identification phase			Numerical phase of risk assessment at level crossings				
Scenario	Manifestation of the accident	Possible consequences of the accident	Possible causes of the accident	Current status			
				meaning	appearance	avoidance	RPN
Truck up to 3.5 tons with by passenger train	**No consequences of a traffic accident (2A)**	Limited transport process on railways and roads Property and cash losses Leaking fuel Track derailment	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	4	1	4	**16**
	With the consequences of a traffic accident (2B)	Endangerment of life, health of the vehicle crew/driver/passenger Limited transport process on railways and roads Property and cash losses Leaking fuel Track derailment	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	2	2	**20**

Table 5

FMEA accident Event Truck over 3.5 tonnes with freight train - transport of dangerous goods

Identification phase			Numerical phase of risk assessment at level crossings				
Scenario	Manifestation of the accident	Possible consequences of the accident	Possible causes of the accident	Current status			
				meaning	appearance	avoidance	RPN
Truck over 3.5 tons with a freight train - transport of dangerous goods	**No consequences of a traffic accident without leakage of hazardous substances (3A)**	Limited transport process Property and cash losses Track derailment	Failure of the author of the factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	4	1	4	**16**
	No consequences of a traffic accident with leakage of hazardous substances (3B)	Limited transport process Property and cash losses Leakage of hazardous substances Track derailment	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	2	5	**50**
	As a result of a traffic accident without leakage of hazardous substances (3C)	Limited transport process Property and cash losses Track derailment	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	3	4	**60**
	With the consequences of a traffic accident with leakage of hazardous substances (3D)	Endangerment of life, health of the vehicle crew/ driver Limited transport process Property and cash losses Leakage of hazardous substances	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	2	4	**40**

Table 6

FMEA - accident Special truck (tank) transport of dangerous goods with freight train

Identification phase				Numerical phase of risk assessment at level crossings			
Scenario	Manifestation of the accident	Possible consequences of the accident	Possible causes of the accident	Current status			
				meaning	appearance	avoidance	RPN
Special truck (tank) transport of dangerous goods with freight train	**No consequences of a traffic accident without leakage of hazardous substances (4A)**	Limited transport process Property and cash Track derailment	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	3	2	4	**24**
	No consequences of a traffic accident with leakage of hazardous substances (4B)	Limited transport process Property and cash Track derailment Leakage of hazardous substances	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route.	4	2	4	**32**
	As a result of a traffic accident without leakage of hazardous substances (4C)	Endangerment of life, health of the crew Limited transport process on railways and roads Property and cash losses	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	2	4	**40**
	With the consequences of a traffic accident with leakage of hazardous substances (4D)	Endangerment of life, health of the crew Limited transport process on railways and roads Property and cash losses Leakage of hazardous substances	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	3	5	**75**

Table 7

FMEA - accident Bus with a passenger train

Identification phase				Numerical phase of risk assessment at level crossings			
Scenario	Manifestation of the accident	Possible consequences of the accident	Possible causes of the accident	Current status			
				meaning	appearance	avoidance	RPN
The bus with by passenger train	**No consequences of a traffic accident (5A)**	Limited transport process on railways and roads Property and cash losses Leaking fuel Track derailment	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	4	3	4	**48**
	With the consequences of a traffic accident (5B)	Endangerment of life, health of the vehicle crew/driver/passenger Limited transport process on railways and roads Property and cash losses Leaking fuel Track derailment	Failure of the human factor, Technical condition of the vehicle, Technical condition and possibility of the traffic route. Defect in transport technology	5	4	4	**80**

2.4. Risk Assessment

The results in the form of a risk number (RPN) from Tables 3 - 7 are included in Fig. 7. According to the size of the RPN, it is possible to set priorities for corrective and preventive measures.

The final evaluation of the risk level was calculated using the so-called tolerance rates, with the help of which it is possible to set the risk acceptance limit. Using Pareto analysis (Fig. 8), whose purpose is to observe real situations and detecting the accumulation of a large number of consequences into a small number of causes, allowing to define the decisive factors of the observed phenomenon, a diagram and a Lorenz curve was constructed.

The Pareto analysis shows that the risks listed under:

- 1A -1B;
- 3C - 3D;
- 4D;
- 5A - 5B are the most serious.

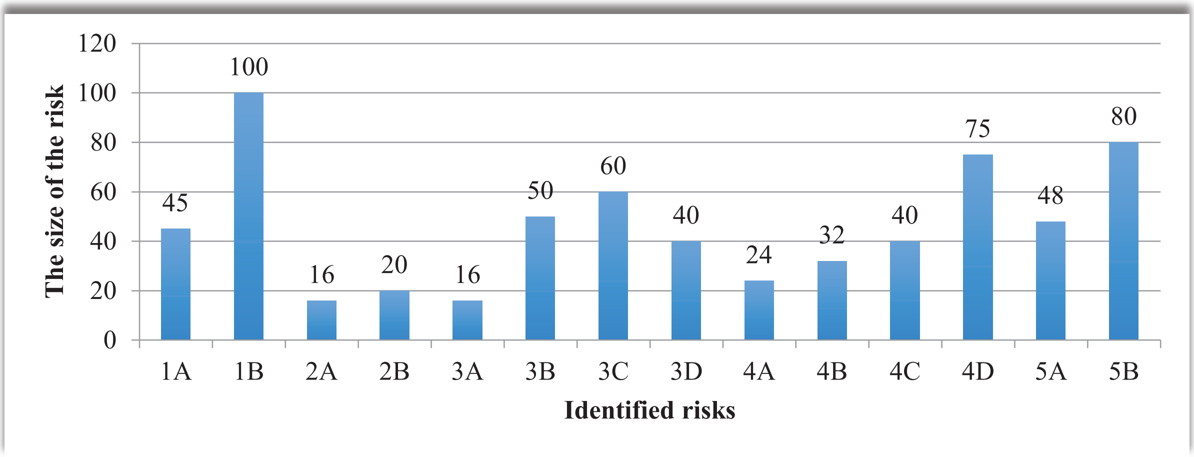

Fig. 7 Results of the risk analysis

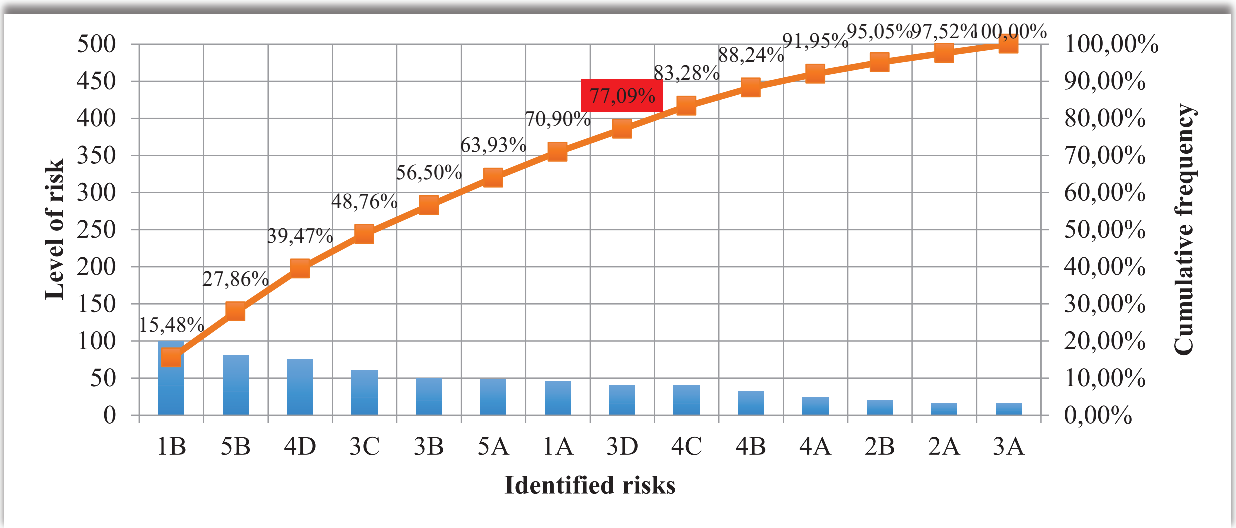

Fig. 8 Pareto analysis

3. Conclusions

Accident - Traffic accident of a passenger car with a passenger train Marking 1A - without the consequences of a traffic accident and 1B - with the consequences of a traffic accident are characterized by a high incidence in the Slovak Republic. Another important fact is the direct threat to life, health of the vehicle crew and in some cases it can also be a life threat, the health of the driver and passengers on the train as a result of an accident. Accident - A truck over 3.5 tonnes with a freight train carrying dangerous goods Marking 3C with the consequences of a traffic accident without leakage of hazardous substances and 3D - with the consequences of a traffic accident and with leakage of hazardous substances. An accident occurring in the Slovak Republic very little, but in the case of an accident under the designation 3D, the consequences are very large. This is a direct threat to the life, health of the vehicle crew / driver, as well as other road users, eventually, the population as a result of an accident or leakage of dangerous substances. Accident - A special truck (tanker) transporting dangerous goods with a freight train Marking 4D - with the consequences of a traffic accident and with the release of hazardous substances. This accident event occurs little, but in case of its occurrence, similar to a 3D accident, we can talk about very fatal consequences. Accident - Bus with passenger train Marking 5A - without the consequences of a traffic accident and 5B - with the consequences of a traffic accident. In this case, there are large accidents within the Slovak Republic with consequences, ie. a large number of seriously injured and killed. The intervention itself at the railway crossing requires the cooperation of each rescue component of the integrated rescue system, the deployment of heavy equipment, etc.

Acknowledgement

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Influence of the Day and Time on the Transport Capacity on the Selected Long-distance Railway Transport Line in the Czech Republic

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Abstract

Rail transport has an important function in the area of passenger transport in the Czech Republic. The aim of the article is to evaluate the effect of the day and time of transport on the range of offered transport capacity on the selected long-distance railway transport line - Ex2 line - providing the connection of the capital city - Prague - with Central and Eastern Moravia in the Czech Republic. This long-distance line is one of the most important train lines in the Czech Republic. The results of the analysis show an influence of these factors on the extent of demanded and offered transport capacity. The highest transport demand in the direction from Prague arises on Friday afternoon, in the direction to Prague the strongest demand is on Sunday afternoon and on weekdays during morning rush hour. The current state of circulation of vehicles as well as infrastructure causes a difference between the offered and demanded transport capacity for some trains. Methods of analysis, synthesis, comparison and correlation analysis are used in this paper.
KEY WORDS: *Czech Republic, timetable, transport capacity, annual report, rail transport*

1. Introduction

Rail transport is of high importance in the Czech Republic as well as in the field of passenger and freight transport. In the Czech Republic, a number of companies carry out rail passenger services, e.g. České dráhy, Regiojet, Leo Express, Arriva or GW Train Regio. The most important railway carrier, which provides more than 90% of the transport work, is the company České dráhy.

Long-distance rail transport has shown a high increase in popularity in recent years, with both the number of passengers transported and the distance travelled increasing over several years. Long-distance rail transport in the Czech Republic consists of a network of Ex and R trains, which are ordered by the State and their operation is subsidized by the Ministry of Transport. The most important long-distance services connecting the largest cities of the Czech Republic at present are the Ex1, Ex2 and Ex3 lines. While within the Ex1 line connecting primarily the cities of Prague – Pardubice – Olomouc – Ostrava – Žilina (Slovak Republic), the Prague – Ostrava section has not been ordered for several years and the carriers provide this operation, as stated by [1, 2] at commercial risk, this is not the case for the remaining Ex2 and Ex3 lines. The Ex2 line provides connection in the Prague – Pardubice – Olomouc – Valašské Meziříčí – Horní Lideč (and further in Slovakia) section, line Ex3 in the section Děčín – Ústí nad Labem – Prague – Pardubice – Brno – Břeclav (and further in Austria or in Slovakia).

At the end of year 2019, a public service contract concerning the passenger public railway transport was concluded which ensured transport services on the mentioned Ex2 line with a contract valid for a total of 10 years. The aim of the article is to evaluate the influence of the day and time on the scope of the ordered and offered transport capacity on the Ex2 line after the conclusion of the new contract in 2019. This new contract was concluded with the carrier on the basis of a public tender. It is the first long-distance route in the Czech Republic, where this type of contract was concluded.

2. Literature Review

Research studies in the field of rail transport examining factors influencing the scope of the transport capacity offered were carried out both in the conditions of the Czech Republic and in the international context.

The important factor, to which an attention has been paid in recent years is rail competition [3]. Open access passenger rail competition in the Czech Republic has developer substantially [4]. This fact leads to the increase in quality of rail passenger transport services provided. In addition to the qualitative impact, the above mentioned also has an impact on fares [5], which affects the state of public finances according to [6], as most rail passenger services are subsidized by the State.

When planning the number of services on the selected route, it is necessary to consider not only the size of the transport demand, but also to set up correctly the vehicles in the daily circulation, as vehicle depreciations also constitute a significant cost item for the transport operator [7]. [8] states that the capacity of the railway is another necessary factor influencing the scope and the quantity of services offered. The high load of some of the line sections then leads to a slowdown in traffic and also to limited possibility of capacity reinforcement of services.

Ensuring sufficient capacity of services is a prerequisite for quality rail passenger transport. When planning capacity by both the client and the carrier, it is necessary to consider the different transport demand depending on the time of day [9]. In the case of long-distance rail routes, the most significant differences in transport demand arise not only depending on the time of day but also on the day of the week [10]. Conversely, in marginal times when transport demand is low, there is a trend to reduce the transport capacity, if it is possible, in order to ensure at least partial efficiency of public transport operations [11, 12]. Public transport requires a long-term strategy. The prerequisite for successful transport planning is not only respecting the change in the number of passengers, but also timetable design or managing the circulation of vehicles [13].

3. Data and Methodology

In order to achieve the article objectives of the standard positivist economic methodology involving description methods, comparison, deduction, synthesis and analysis is used. For analysis of the impact of the day on the scope of the transport capacity offered and ordered, the standard deviation *s* (1), whether there is a match in case of long-distance Ex2 transport line between the number of ordered and actually offered places of transport, there is used a correlation analysis method, specifically Spearman correlation coefficient r_s (2):

$$s = \sqrt{s_x^2}\ , \tag{1}$$

where s_x^2j is a variance,

$$r_s = 1 - \frac{6 \cdot \sum_{i=1}^{n} d_i^2}{n \cdot \left(n^2 - 1\right)}, \tag{2}$$

where d_i are the differences in the order $i_x - i_y$ of values x_i and y_i, n is the number of pairs. The advantage of using of the r_s coefficient is that it is not necessary to assume a linear dependency between the *x* and *y* characters. More about correlation analysis e.g. [14].

The input data for analysis are drawn from both the concluded public service contracts and the carrier's annual reports. Important parts of the annual report are financial statements such as balance sheet, profit and loss statement and notes [15]. Information on the structure of the assets and sources of financing of those assets is provided by the balance sheet. A profit and loss statement provides more details on the structure of costs and revenues in the type or special-purpose breakdown. An important component of the revenue is subsidies or revenue from fares which, according to [16], are subject to value added tax and, for the purposes of sales, the amount excluding value added tax is decisive in this case. Significant cost components of entities providing transport services include the costs associated with the wear-and-tear of vehicles or the labour costs of employees [17].

An integral part of the financial statements and annual report are, according to [18], notes to the financial statements that give more details about the financial information in the statements. Entities keep accounts in accordance with the Czech accounting regulations. In addition to keeping accounts in accordance with applicable national legislation, there is the possibility of keeping accounts also in line with transnational accounting systems such as US GAAP or IFRS [19, 20].

4. Analysis

The Ex2 long-distance transport line provides a rapid connection between the capital city of Prague and the Pardubice, Olomouc and Zlín regions within the Czech Republic territory. Its other function is also the connection of the above mentioned regions with the neighbouring Slovak Republic. The basic time of line is 2 hours. Overview of current services provided on the Ex2 line for train operating schedule valid from 15th December 2019 is shown in Table 1.

Table 1a

Timetable of the line Ex2 for the period from 15th December 2019 in the direction of Praha – Púchov [21]

Number of train / Station	121	123	125	127	129	221	521	523
Prague	5:23	7:23	9:23	11:23	13:23	15:23	17:23	19:23
Pardubice	6:23	8:23	10:23	12:23	14:23	16:23	18:23	20:23
Olomouc	7:51	9:51	11:53	13:53	15:53	17:53	19:53	21:53
Valašské Meziříčí	8:53	10:53	12:53	14:53	16:53	18:53	20:57	22:53
Vsetín	9:10	11:10	13:10	15:10	17:10	19:10	21:13	23:08
Horní Lideč	9:29	11:29	13:29	15:29	17:29	19:29		
Púchov	9:52	11:52	13:52	15:52	17:52	19:52		

Table 1b

Timetable of the line Ex2 for the period from 15th December 2019 in the direction of Púchov – Praha [21]

Number of train / Station	522	520	220	128	126	124	122	120
Púchov			8:08	10:08	12:08	14:08	16:08	18:08
Horní Lideč			8:33	10:33	12:33	14:33	16:33	18:33
Vsetín	4:52	6:51	8:52	10:52	12:52	14:52	16:52	18:52
Valašské Meziříčí	5:09	7:08	9:09	11:09	13:09	15:09	17:09	19:09
Olomouc	6:07	8:07	10:07	12:07	14:07	16:07	18:07	20:07
Pardubice	7:41	9:41	11:41	13:41	15:41	17:41	19:41	21:43
Prague	8:39	10:39	12:39	14:39	16:39	18:39	20:39	22:41

In addition to the stations listed in Table 1, all Ex2 line services also stop at stations Prague-Libeň, Kolín, Česká Třebová, Zábřeh na Moravě, Mohelnice, Červenka, Lipník nad Bečvou and Hranice na Moravě. In the section Prague-Česká Třebová, the Ex2 line performs the function of express service and it has the regional role due to the higher number of stops in the section Česká Třebová – Horní Lideč. From Horní Lideč station, most connections continue to the Púchov station located in the territory of Slovak Republic. It is possible to continue in the Púchov station with the Slovak carrier – Železničná spoločnosť Slovensko in the directions Žilina, Košice or Bratislava. The service no. 221 runs all the way to Žilina, the departure station of the 220 line is also the Žilina station. The termination of the remaining services at the Púchov station is due to limited infrastructure capacity in the Púchov – Žilina section, where the line is being reconstructed. Early morning services (nos. 522 and 520) and late evening services (nos. 521 and 523) are operated only to the Vsetín station due to lower transport demand in Slovakia.

Since the entering of the new contract in 2019, air-conditioned trainsets with wi-fi connection and electric sockets are deployed on the Ex2 line. This is available to first and second-class passengers. The main trainset is most often made up of second-class large-scale carriages of type Bdpee[231], a second-class multifunctional coach of type Bbdgmee[236] allowing the transport of persons with reduced mobility and a first-class coach ARmpee[829]. A part of the multifunctional coach are also seats for passengers with children under 10 years, part of the first-class coach is the bistro section. Depending on the size of the transport demand, the main trainset is supplemented by other vehicles (usually by Apeer or Apee type for the first-class, Bee or Bdpee for the second-class) according to the capacity requirements of the public service contract as captured by Table 2. In the case of the train 220 and 221, the coaches of the Slovak carrier type Bmpz are deployed as second-class coaches.

Table 2a

Required (R) and offered (O) capacity number of seats on the trains in direction Prague – Púchov [22-24]

Train No.	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	R	O	R	O	R	O	R	O	R	O	R	O	R	O
121	280	285	220	285	220	285	220	285	220	345	220	285	220	345
123	280	285	220	285	220	285	220	285	220	405	340	345	220	405
125	420	**285**	300	**285**	300	**285**	300	**285**	300	345	420	**405**	300	637
127	300	285	300	**285**	300	**285**	300	**285**	360	345	360	**345**	300	585
129	300	285	300	**285**	300	**285**	360	**345**	650	637	300	**285**	360	345
221	300	377	300	377	300	377	360	437	590	701	300	325	300	409
521	410	417	410	417	410	417	410	477	470	477	300	285	410	477
523		285		285		285		285		285		285		285

Table 2b

Required (R) and offered (O) capacity number of seats on the trains in direction Púchov – Prague [22-24]

Train No.	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	R	O	R	O	R	O	R	O	R	O	R	O	R	O
522	470	477	410	417	410	417	410	417	410	477	360	477	300	285
520		285		285		285		285		285		285		285
220	300	325	300	377	300	377	300	377	360	521	300	701	300	409
128	300	**285**	300	**285**	300	**285**	300	**285**	360	**345**	300	**285**	360	**345**
126	300	**285**	300	**285**	300	**285**	300	**285**	420	405	300	345	420	**405**
124	300	**285**	300	**285**	300	**285**	300	**285**	360	**345**	360	405	650	**637**
122	220	285	220	285	220	285	220	285	280	345	220	345	570	585
120	220	285	220	285	220	285	220	345	220	637	220	285	330	345

As the data in the table indicate, the required basic capacity of the trainset is usually 300 seats. Depending on the travel time of the service and the day on which the service operates, this capacity is further adjusted. In the public

service contract, the minimum required capacity for trains no. 520 and 523 is not indicated in the publicly available version.

The highest transport capacity is in the direction from the capital city offered on Friday afternoon, the strongest transport demand in the direction to the capital city is, on the contrary, on Sunday afternoon. In the direction of Prague – Púchov there is a lower transport capacity in the early morning and forenoon times, in the direction to Prague the most seats are offered and required on working days in the morning. The result of the analysis comparing the required and actual capacity in the direction from Prague is the finding that for trains nos. 125, 127 and 129, on some days the offered capacity of the number of seats that should be guaranteed by the carrier according to the concluded contract is not respected. The same conclusion follows from the analysis in the direction to Prague for trains nos. 128, 126 and 124. The difference between the required and offered capacity is most often 15 seats. The highest difference is currently in the case of train no 125 on Monday, where the difference in capacity offered and required is more than 100 seats. It should also be noted that every service on the Ex2 line includes the ARmpee coach, which, in addition to the number of 28 seats in the first class, also offers an additional 12 seats in the bistro part of the coach. These places are intended for customers of bistro department to consume dishes purchased here. These 12 seats are not included in the actual capacity offered, as even when selling tickets, reservations cannot be purchased for these seats.

The assessment of the influence of the day and time on the scope of Ex2 line services offered and required is carried out first by evaluating the variances in Table 3. The services nos. 523 and 520, for which the ordered capacity is not published in the contract, are excluded from the analysis. In the case of trains travelling in the direction from the capital city, the biggest differences arise with afternoon services (nos. 129 and 221) both in the range of the planned and actual capacity offered. This is due to the existence of a Friday afternoon rush hour, when the capacity of these services is often twice as high as on other days of the week. There are also relatively high differences in the case of services nos. 125 and 127 when assessing the capacity actually offered. However, the reason for this step is not such a high transport demand, when on Sunday the scope of the offered transport capacity is almost twice as high as the scope required by the transport customer. This occurs due to the need to secure the wagons for turnover services nos. 124 and 122, as because of the setting of low turnover times in the Púchov station there is no time for adding additional coaches. Púchov station also does not have a depo of rolling stock from where these vehicles can be added.

The differences in capacity of services traveling to the capital city arise mainly due to the failure to Sunday afternoon rush hour, when the demand for travel to the capital city is the highest (nos. 124 and 122). The reason for the higher differences with service no. 220 is the need to provide the capacity for the service no. 129 running back from Prague on Friday afternoon. The higher number of seats offered on Friday for the end-of-day service (no. 120) is caused by the change of coaches from train no. 129.

Table 3

Standard deviation

Train No.	required	offended	Train No.	required	offended
121	21,00	27,11	522	48,95	63,13
123	43,71	52,84	220	21,00	119,98
125	54,21	120,40	128	27,11	27,11
127	27,11	101,42	126	54,21	52,84
129	118,41	119,09	124	118,41	120,40
221	100,14	115,50	122	120,76	101,42
521	46,82	63,13	120	38,49	119,09

The last part of the analysis is aimed at assessing of the fact whether there is a consensus between the ordered and the actually offered number of transport seats. This is verified at the 5% significance level of Spearman coefficient of serial correlation r_s which has been defined by (2). The results of this analysis are shown in Table 4. In the case of trains travelling in the direction from the capital city, there is the low value of r_s for the first morning train no. 121 from Prague. This is due to the need to provide capacity for the turnaround train no. 128, where the transport demand is higher. The closer the value of the r_s coefficient is to 1, the higher the match between the offered and the required number of seats in the respective Ex2 line services.

Table 4

Coefficients r_s

Train No.	r_s	Train No.	r_s
121	0,373	522	0,671
123	0,671	220	0,671
125	0,671	128	0,671
127	0,911	126	0,396
129	0,748	124	-0,115
221	0,913	122	0,577
521	0,255	120	-0,009

The r_s coefficient for train no. 124 is negative. In the case of this service, there were deficiencies found out in the analysis from the carrier, since the carrier does not, in this case, does not offer a specified number of seats on certain days determined by a valid contract on the ensuring of transport on this long-distance service line. Similarly, the value expressing the fact that there is no relation between the observed pair of characters is for the last service running from Púchov to Prague (no. 120). In most cases, the differences are caused by the different capacity of the selected train and the capacity of the train from which the trainset at Púchov station changes to the selected turnover train. Different requirements from the Ministry of Transport concerning capacity are given by the extent of the transport demand, when the higher transport demand is in the morning in the direction to Prague, in the afternoon in the direction from Prague.

5. Conclusions

The aim of the article was to carry out an evaluation of the impact of the day of the week and the time of departure of the selected long-distance transport service in the Czech Republic in terms of the required and offered transport capacity. In line with this objective, an analysis was also carried out examining the relation between the scope of the required and the offered transport capacity. The Ex2 line, which is largely operated on the 1st transit corridor of the Czech Republic, whose main function is to ensure a fast connection of the capital city of Prague with Moravia and Slovakia, has been chosen as the selected long-distance transport line in the Czech Republic. This line was selected due to the conclusion of a new contract of the client – The Ministry of Transport of the Czech Republic with the operator – company České dráhy for a period of 10 years with effect from 15th December 2019.

An analysis of the effect of the day and the period during which the service is operating on the capacity confirmed that there exist dependencies between these variables. In the direction to the capital city, there is a higher transport demand in the morning, to which both the Ministry of Transport as well as the carrier responds by setting a minimum capacity of the number of seats on the train. The biggest interest in travelling to the capital city is then not only for this long-distance transport line on Sunday afternoon. This leads to the fact that the number of seats in the selected trains is often more than twice as much as on the normal working day. Despite this fact, this capacity is insufficient in some sections. The strongest transport demand from the capital is on Friday afternoon, when, on the contrary, most passengers arriving in the capital city on Sunday afternoons for work or study head back to their place of residence at this time.

Due to the different transport demand and the different extend of seats on trains, additional reinforcement vehicles are being added to the exposed services. However, the need to add these coaches, due to the limited possibilities of vehicle circulation, in some cases causes differences between the number of seats requested and actually offered. While by the year 2019 the services of Ex2 line travelled to Žilina station, where there were better possibilities for handling coaches, most of the services are currently terminated at Púchov station, where the possibilities for handling coaches are minimal, as there is no vehicles depot in this station. For this reason, for example on Sunday morning and forenoon, the services of Ex2 line runs in the direction from Prague with a large number of coaches in order to provide the necessary capacity for Sunday afternoon rush hour in the direction to Prague.

Rail transport in passenger transport is crucial not only in the Czech Republic. This is confirmed by the growing trend in the number of passengers. One way to make this transport more attractive is the deployment of quality vehicles that have already been requested to be operated on this route by the concluded contract. Another way is the shortening of the travel times, which will be possible to achieve in the following years on the railway section of the Slovak Republic after the completion of the modernization of the Žilina – Púchov section. This fact might be the subject for a further research in this field.

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Determination of the Load-Bearing Metal Structures Residual Operation Time of the Ukraine Railway

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Abstract

In Ukraine railways most of hopper doser wagons is a much higher service life that it is specified by the manufacturer. The residual life of load - bearing metal structures hopper doser and dumping wagons (dumpers) made on the basis of technical diagnostics and typical tests results are shown in the article. The actual thickness ratio analysis of the back frame of the wagons to the nominal values are carried out. Possible places of typical defects occurrence in hopper doser and dumping wagons (dumpers) are determined. It is concluded that the condition of load-bearing metal structures of wagons does not approach the limit after long operation. The obtained practical and theoretical results make it possible to develop a set of measures for the estimation of the residual life of the load bearing metal structures hopper doser and dumping wagons (dumpers).
KEY WORDS: *residual life, hopper dosers, dumping wagon (dumper), technical diagnostics, type tests, operational characteristics, carrying metal structures*

1. Introduction

Most freight wagons owned by JSC Ukrzaliznytsia are used over the service life specified by the manufacturer and have an extended service life. In most cases, the service life of the wagons has already exceeded one and a half years of service life specified by the manufacturer. Due to the lack of ability of JSC Ukrzaliznytsia to update the wagon fleet timely, it is necessary to determine the residual life of the load-bearing metal structures (hereinafter referred to as LBMS) of the rolling stock. Resource (equipment) is a device operating life from the beginning of its operation or after repair and to reaching their limit state, which is determined by the standard process documentation [12]. For different devices, the resource can be expressed in different units of measurement, for example, operation hours, run, years, etc. Residual life is the total operating time, which is projected on the results of the equipment technical diagnostics, from starting the control of its technical condition for passing to the limit state.

2. Problem Description

The general principles of determination of residual life of freight wagons are considered in scientific researches [1, 2, 13]. The features of determining the residual life of scale test cars based on freight wagons are given in the study [3].

The modernization, which would allow extending the service life of the wagon-grain and increasing resistance to the dynamic forces acting on the wagon body frame, was proposed in the article [4]. The work includes investigation of the locations and causes of cracks, and their result became the basis of the proposed modernization of the wagon frame.

The prediction of the residual life of the hopper wagon is given [5]. The main attention in this work is devoted to the selection of samples load-bearing metal structures and the study of the chemical composition and physical and mechanical characteristics of the selected material.

The study of the strength of the body semi-wagons, taking into account its design innovation for ferry transportation is given in the article [7].

The improvement ways of semi-wagons metal constructions and increasing their service life are considered [6].

Most of these scientific publications investigate the increase in the life of different types of freight wagons by improving their design properties [9-11].

Research on the residual life of freight wagons in Ukraine is carried out by scientific organizations. But the techniques of these studies are based on bench-based resource tests and preparation of recommendations for extending the life of freight wagons without sufficient scientific justification.

The study purpose is to determine the residual life of LBMS hopper and dumper wagons (dumpers).

The study purpose is to procedure the analysis of technical diagnostics and typical tests and to provide recommendations for further scientific research on the determination of the residual life of hopper doser and dumping wagons (dumpers) LBMS wagons.

Technical diagnostics is the study of residual life and justification of the continuation possibility of freight wagons operation after the service life end specified by the manufacturer (parts damages detection and components in operation, mechanical or corrosion wear, residual deformations, cracks, bearings and bearings).

The most commonly used wagons in the track facilities are hopper doser and dumper wagons (dumpers).

Hopper doser (Fig. 1a) is a vehicle for transportation, mechanized unloading, track laying, dispensing and leveling of ballast in the construction, repair and maintenance of the railway track. Operating characteristics: design speed 120 km/h, load capacity 60 t, a maximum estimated static load of the wheelset on the rail 210 kN, service life is specified by the manufacturer 25 years.

Dumping wagons (dumpers) (Fig. 1b) is specialized rolling stock and other wagons of the truck park are distinguished by the structure of the body and the presence of specialized equipment for its tilt during unloading. Operating characteristics: design speed 120 km/h, load capacity 60 t, a maximum estimated static load of the wheelset on the rail 212 kN, service life is specified by the manufacturer 22 years.

Dumping from wedges is the estimate of the self-resonant frequency and dynamic stresses in the elements of the LBMS frame and the wagon body. Depending on the used wedges number and their location match with the wagon wheels it is determined the type of oscillations in the passage and dumping the wagon from the wedges.

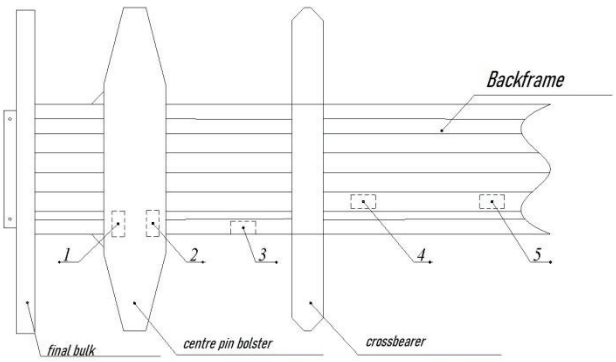
a

b

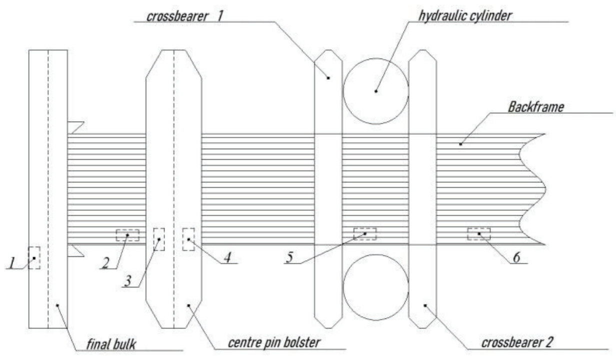
Fig. 1 General view of the freight wagon: a - hopper doser; b - dumping wagon (dumper)

Static structure testing is the stress determination, deformation, body structure elements stability, wagon frame and bogie frame with actual thicknesses available for the static crush test period.

The scheme of the strain gauges installation on the frames of the hopper doser and dumping wagons (dumpers) during the control tests (Fig. 2).



a



b

Fig. 2 The scheme of the strain gauges installation on load-bearing metal structures: a - hopper doser; b - dumping wagons (dumpers)

The impact strength resistance tests are the determination and evaluation of dynamic stresses and deformations in the LBMS wagon body frame when applying the regulatory shock forces through the auto-coupling equipment.

Percussion tests are carried out by rolling the hammer car on a test wagon, which is in a supported and free state. Percussion under typical tests is carrying out with the speeds specified in Table 1.

Table 1

Wagon's percussion number in each condition

Percussion speed range, km/h	Percussion number	
	Supported state	Free state
from 3 to 6 on	3	3
from 6 to 10 on	3	3
from 10 to 12 on	1	1

3. Analysis Results

The possibility to set the new service life of wagons is determined based on technical diagnostics and standard

tests.

The actual corrosion rate is calculated:

$$V_c = \frac{S_n - S_f}{T} \text{ mm/year,} \tag{1}$$

where S_n is the nominal thickness of the element, mm; S_f is the actual thickness of the structural member according to the measurement results, mm; T is the life of the wagon up to the moment of measurements, years.

The residual life is determined by the formula:

$$T_r = \frac{S_f - S_{\min}}{V_c} \text{ year,} \tag{2}$$

where S_{min} is the minimum admissible thickness of the element in terms of strength and durability, mm.

The analyzes of construction years and actual back frame vertical wall thickness made based on the technical diagnostics of hopper doser and dumping wagons (dumpers) works. The nominal thickness of the back frame vertical wall of hopper doser and dumping wagons (dumpers) is $S_n = 9.0$ mm. Table 2.

To determine the wagons residual life (Table 2), we substitute the mean values for the dependencies (1) and (2) and obtain for the wagon hopper doser $T_r = 14.3$ years, for the wagon dumping wagons (dumpers) $T_r = 22.5$ years.

Table 2

The analyzes of construction years and actual back frame vertical thickness of hopper doser and dumping wagons (dumpers)

№ n	Hopper doser		Dumping wagons (dumpers)	
	T, years	S_f, mm	T, years	S_f, mm
1	39	7,3	31	7,7
2	39	7,1	31	7,8
3	45	7,3	31	7,5
4	46	7,2	31	7,7
5	46	7,0	31	7,6
6	46	7,1	32	7,5
7	46	7,0	32	7,3
8	51	6,9	32	7,4
9	53	6,8	33	7,1
10	55	6,5	33	7,1
11	55	6,8	33	7,3
12	55	6,7	33	7,2
13	55	6,8	33	7,4
14	55	6,7	33	7,2
15	56	6,6	33	7,3
Mean value	49,5	6,9	32,1	7,4

The residual life is set by one of the minimum values calculated mathematical relation to calculate the residual life. If the calculations show that the resource is exhausted, then the remaining service life is determined by the results of the bench fatigue test.

Determining the residual life during typical tests, an assessment of fatigue resistance indicators is carried out, taking into account the stress of the load-bearing structures of the wagon during the test.

The assessment of fatigue resistance is as follows:

$$n = \frac{\sigma_{a,N}}{\sigma_{a,e}} \geq [n], \tag{3}$$

where $\sigma_{a,N}$ is the endurance limit (in amplitude) of the full-length part in the case of the symmetrical cycle and steady load test-based $N_0 = 10^7$ cycles, MPa; $\sigma_{a,e}$ is the calculated value of the dynamic voltage amplitude of the conditional symmetric cycle, reduced to base N_0, equivalent to the damaged action of the real mode of operational random voltages during the service life, MPa; $[n]$ is the allowable fatigue resistance factor.

The endurance limit calculated value is determined by the formula:

$$\sigma_{a,N} = \overline{\sigma_{a,N}} \times \left(1 - z_p \times \vartheta_{\sigma_{a,N}}\right), \tag{4}$$

where $\overline{\sigma_{a,N}}$ is the endurance limit (in amplitude) of the full-length part; $z_p = 1,645$ – the quantile of the distribution corresponding to the one-sided probability $P = 0,95$; $\vartheta_{\sigma_{a,N}} = 0,5$ – variation coefficient of the endurance limit.

$$\overline{\sigma_{a,N}} = \frac{\overline{\sigma_{-1}}}{(K_\sigma)_K}, \tag{5}$$

where $\sigma_{-1} = 225$ MPa – endurance limit; $(K_\sigma)_K$ is the value of the overall coefficient of field endurance reducing details.

$$\sigma_{a,e} = \sqrt[m]{\frac{N_c}{N_0} \times \sum \sigma^m P}, \tag{6}$$

where $N_0 = 10^7$ is the base number of cycles; m is the exponent in the equation of the fatigue curve in the amplitude; N_c is the total number of dynamic stress cycles per estimated service life. Actual service life is accepted; $\sigma^m P$ – the value of stress level taking into account its mass fraction during operation.

$$m = \frac{A}{(K_b)_k}, \tag{7}$$

where A is the coefficient according to [8]; $(K_b)_k$ is the value of the endurance overall coefficient of field endurance reducing details relative to the endurance limit of the straight standard specimen; m – is determined according to [8].

$$N_c = \vartheta_e \times T_p, \tag{8}$$

where T_p is the total time of the dynamic stresses.

$$T_p = B \times T_K, \tag{9}$$

where B is the conversion factor of the calendar estimated service life in years during continuous movement in seconds; T_K is the actual total dynamic stress time.

$$\vartheta_e = \frac{a}{2\pi} \times \sqrt{\frac{g}{f_{sd}}}, \tag{10}$$

where a is the coefficient for the body framing [8]; $g = 9,81$ m / s^2; f_{sd} – static deflection.

$$B = 365 \times \frac{10^3 \overline{L_C}}{\overline{V}}, \tag{11}$$

where $\overline{L_C}$ is the average daily run of the freight wagon under study; $\overline{V}$ is the average speed of the wagon understudy km/h.

The calculated value of the n is fatigue resistance coefficient in the test wagon seats [8] are shown in Table 3.

Table 3

The calculated values of n in the test wagon places

№ channel	Hopper doser			Dumping wagons (dumpers)		
	$\sigma_{a,N}$, MPa	$\sigma_{a,e}$, MPa	n	$\sigma_{a,N}$, MPa	$\sigma_{a,e}$, MPa	n
1	6,5	17,7	8,9	5,4	35,4	7,2
2	22,6	73,7	2,2	2,9	40,3	8,5
3	18,7	77,4	2,6	2,2	21,6	14,4
4	33,4	233,9	1,3	10,1	36,2	5,4
5	30,9	128,2	1,5	13,5	76,3	3,2
6	29,0	89,6	1,9	26,5	161	1,6
7	17,8	200,2	1,5	10,6	55,0	4,3
8	36,6	164,3	1,5	7,7	24,6	7,3
9	4,6	82,4	4,3	1,1	20,8	18,1
10	9,4	41,3	5,1	19,5	79,3	2,6

According to the obtained results, reducing the fatigue resistance factor to the minimum recommended value corresponds to service life for hopper doser of at least 65,5 years and 55,5 years for dumping wagons (dumpers).

The results of technical diagnostics of hopper doser and dumping wagons (dumpers) for the period 2016-2019 are shown in Table 4.

Table 4

Statistical analysis of technical diagnostics of hopper doser and dumping wagons (dumpers) for 2016-2019

Type of freight wagon	Number of diagnosed wagons 2016-2019 year, unit	Number of detected defects 2016-2019 year, unit	The ratio of detected defects to the diagnosed wagons, %
Hopper doser	1173	186	15,9
Dumping wagons (dumpers)	620	65	10,5

As a result of technical diagnostics of hopper doser and dumping wagons (dumpers), the done works in-depth analysis was carried out and defects were systematized, which made it possible to identify the weakening in the wagons LBMS, according to the currently valid the JSC Ukrzaliznytsia regulatory documents, such wagons must be excluded from inventory rolling stock.

4. Conclusions

According to the researches results, it was determined that the condition of load-bearing metal structures wagons after long operation does not approach the limit.

After analyzing the operational characteristics of hopper doser and dumping wagons (dumpers), it was found that their average daily run does not exceed 42 km, and the speed - 18 km/h, these values are 70% less than projected. Thus, the obtained practical and theoretical results make it possible to develop a science-based methodology for estimating the residual life of load-bearing metal structures of freight wagons used on the railways of Ukraine.

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Remarks on the Safe Navigation Conditions in the Port of Klaipėda

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Abstract

The Port of Klaipėda plays a great role in various contexts: including historical, economical, political, hydrotechnical etc. Nowadays, the port, is situated in the south-eastern part of the Baltic Sea, takes significant activity in the marine trade of the Baltic Sea region, which is prominent for its sandy coasts and sediment transport that affects the activity and development of the port. The port faces quite hard and challenging situation in hydrotechnics and hydrodynamics. Thinking about the future of any port, investigators developers must take into consideration situation about the past, the present and the future. Some historical sources sometimes remain lost, forgotten or unrecognized. The aim of the paper is to present the unpublished materials dedicated to the hydrotechnical development of the Port of Klaipėda in the south-eastern part of the Baltic Sea that has remained of limited accessibility (important cited authors are: T. Daukantas, V. Merkys, N. Shishov and J. Dubra).
KEY WORDS: *Klaipėda Port, navigation conditions, hydrography, 20th century.*

1. Introduction

Since old times the port of Klaipėda was situated in the estuary of the Danė river and Curonian Lagoon in the south-eastern part of the Baltic Sea basin. The Curonian Spit dunes were quite a good shelter for the port and city from westerly storms. The estuary of Danė river was deep enough to accommodate seagoing vessels of those times. The entrance to the port was quite complicated, as vessels had to navigate between the sinister northern and southern shoals which changed their positions quite frequently in the coast of the Baltic Sea and the positions could be marked by buoys and poles only temporarily. The way to the Dane port was shown by the first primitive lighthouse – a simple, coal-fired lantern hanged on a pole, called „swings of coal ", which was depicted in the sketch by Ch. Hartknoch of 1684 (Fig. 1).

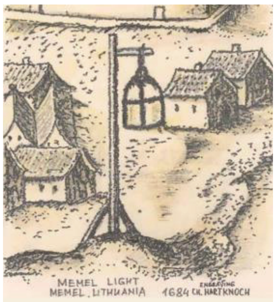

Fig. 1 Memel lighthouse after Ch. Hartknoch (1684)

The development of Klaipėda city and port was highly influenced by the first timber sales trade office established in 1743 which gave way for the export of timber, the main Klaipėda export commodity. In 1773, in order to facilitate the discharge of cargo in the Klaipėda Strait from the Curonian side, an overpass was built, which was the beginning of the port in the Klaipėda Strait. Timber exported from Klaipėda was widely used for shipbuilding in Europe. In 1808 Prussian authorities transferred the management of the port to the merchants of the city who executed the works of port reconstruction with the support of the state treasury. As trade increased, the entrance to Klaipėda port was enhanced further. After a hundred years from the establishment of the lantern mentioned above, a stationary tower lighthouse was built on the dune nearer to the sea. In 1834-1841, with breaks, the northern mole of the port was built, and in 1847-1861 the southern mole was built as well. Dredging of the fairway also started. Although the first steamship appeared in 1824, sailing ships continued visiting the port till the very end of XIX century. The development of Klaipėda port lasted quite long, even after the beginning of XX c., as it was in the outskirts of the Prussia [15].

2. Study of Reference Materials and Discussion

Klaipėda port is the most important object of the transport system of Lithuania. Located in the favourable position in terms of transport, connecting the transport systems of Russia, Belarus, Ukraine, Kazakhstan states and other eastern states with many countries in the West. A well-developed railway and road infrastructure allow the port to develop trade and tourist connections with maritime transport arteries not only in the Baltic Sea, but also worldwide.

Klaipėda port is located in quite a complicated geographical position in terms of hydrotechnics. The Eastern Baltic coast is covered with fine sand, which frequently captures ships turning aside from the fairway. A powerful flow

of fine sand moves along all the coast usually towards the north, covering ports and hydrotechnical buildings of the sea coast. Majority of winds and almost all most powerful winds are onshore at the Eastern coast of the sea. The waves formed at the sea cause hazards for ships not only in the approaches, but also in port basins. Oscillatory waves resulting from long waves with the interval of 0.5-3 minutes are formed in the port basins and they are especially dangerous for moored ships [14]. Due to the outflowing waters of the Curonian Lagoon and strong winds, strong currents can form. Because of the fresh water surface outcoming Curonian Lagoon flows and more salty and dense incoming sea water bottom flows frequently the two-layer, or double, currents form, that often cause problems for ships (see Fig. 2). Low water levels are problematic for vessels with deep draught, more often during the cold season. Very high increases of water level created by storms and hurricanes. Fog is observed 40-60 days per year. Although ice cover is rarely formed at the coast and in the port, but during the very cold winters they cause a lot of problems. Sometimes very thick ice floes (up to 60-70 cm) flow from the Curonian Lagoon to the sea. Ship hulls are chaffed by thin ice, also called new ice.

Accurate hydrometeorological information is essential for safe navigation as well altering depths in the port basin and its approaches. Long-term meteorological and hydrological research data is necessary for the development of the port. Before data required for such a type of research was collected by the port employees due to economic considerations. After the war this type of data was collected by various agencies for various purposes and quite frequently at different levels. The locations and measurement devices for measuring wind, one of the most important parameters for the operation of the port, were often changed [10]. Therefore, we do not obtain long-term, reliable information. Monitoring grounds, the height of the devices, their coverability changed many times. It is not easy to gain accurate hydrometeorological information. It was very well in 1902 – 1944, when it was possible to find out the wind speed, direction, and swell not only in Klaipėda, but also in Liepaja and Brusterort, just having a distant look at the semaphore built in the Kopgalis [8].

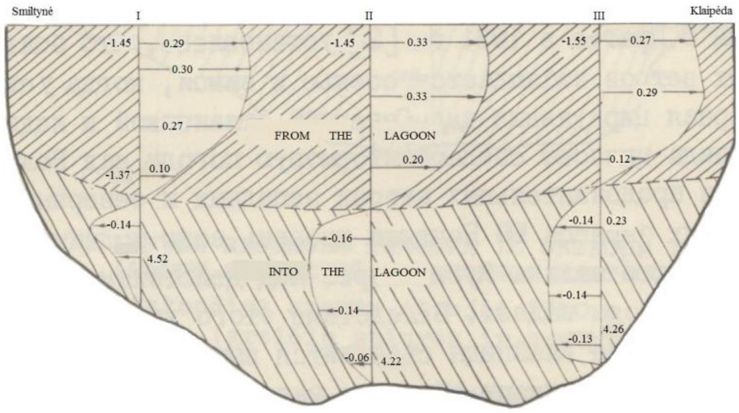

Fig. 2 Double currents in the Klaipėda Strait

In 1923 when Klaipėda became a part of Lithuania, the modernization of the port was a serious challenge. The first to take this job was the former Master, the Minister of National Defence Teodoras Daukantas (1930). According to him (Fig. 4), the port was protected from SW and S direction storms only by 40%. By analysing the problems of 13 similar foreign ports, he evaluated four options. The best protection against storms is provided to the Curonian coast, but it is narrow, there is no room for constructing a railway line with cargo station appropriately. If the port was constructed adjacent to the port entrance, at Melnragė, it would be necessary to remove sediments from the port area constantly. It was analysed in the scheme of the port, first drawn by German hydrotechnician O. Schulze (Fig. 3**).**

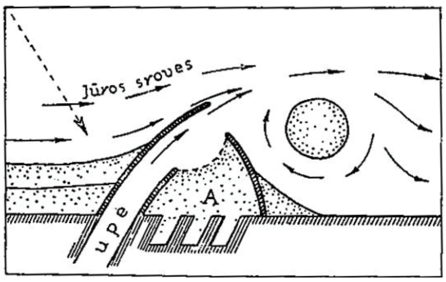

Fig. 3 Area unsuitable for the construction of the port according to scheme by O. Schulze, which was published by T. Daukantas [1]

It is worth noting, that much later an analogous option was offered by Japanese scientists. The southern part of the Klaipėda Strait is well sheltered in terms of wind. However, it has been recognised as less suitable for the construction of port infrastructure. So only the northern coast with the best port infrastructure, unsheltered from winds and swell by 60% remained for the gradual development of the port towards the south-east (Fig. 4). The author of the study analysed not only the impact of winds, swell, sediments, ice, but also evaluated every option of the project in terms of financial cost.

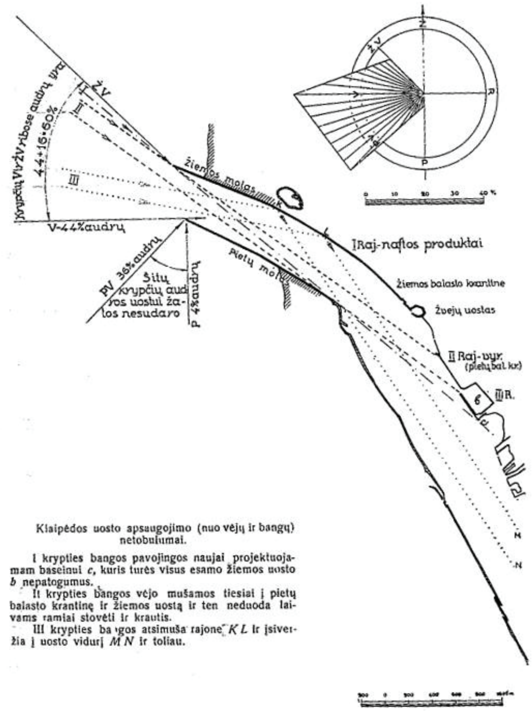

Fig. 4 Issues of Klaipėda port gates according to T. Daukantas [1]

After a decade professor V. Merkys, who was in the position of Klaipėda port vice-director and the Head of Water Council prepared a manuscript about the proposed reconstruction of the Klaipėda port, including quite a wide survey about the history of Klaipėda port development since 1252 [15]. It was pointed out, that prevailing SE winds push water of the Curonian Lagoon towards the Klaipėda Strait, while waters brought by the Nemunas River enter the Curonian Lagoon, leave their sediments there and being less turbid, achieve high destructive flood flushing effect. During floods in the Curonian Lagoon they clean the Klaipėda Strait from the sediments brought from the sea significantly. He was the first who offered to protect the port from the waves scrolling from the sea and decrease the flow of marine sediments to the port by groynes.

When the demand for the Soviet Union to export oil products through the ice-free Baltic Sea ports arose in 1956, the comprehensive research of Klaipėda and Ventspils ports was planned. The Soviet Union, planning to export oil products to other countries, designated the most southern ice-free and less militarized port on the Eastern Baltic coast – Klaipėda – for this purpose. Šventoji and Papė did not suit due to the flows of sediments. In 1957-1966, the Lermornijproject expedition consisting of around 60 hydrotechnical professionals, led by the senior specialist of this institute, Nikolaj Shishov, started the full-scale research of these two ports and their approaches [16]. The specialists from Sojuzmornijproject, Sochi institute, where the model of Klaipėda port was installed, Latvian Institute of Geology, State Hydrological Institute, Klaipėda HMO and other institutions participated in that project.

Almost all research data was collected by means of measurements without models. The scope of the work (in Russian) constituted 13 huge volumes, which were stored in the Technical Department [16]. Ventspils was selected as the main port for the export of oil products, it was deepened to 13 m and adapted for the export of light oil products, and the northern part of Klaipėda port was dredged to 11 m and the heavy fuel oil export terminal was constructed. The moles of the northern part of the port were reinforced with tetrapodes. The measurements of waves were carried out in the port basin and its approaches in the open sea. According to the suggestions by V. Merkys it was provided for a protective stone groyne, intended for the decrease of both sediment settling in the port and oscillatory waves, but it was not constructed. The port moles were not lengthened although it was planned to do so. The sediments, constantly accumulating in the port approaches had to be frequently removed using dredging grabs. The amounts of dredged material were 362 thousand cubic meters annually. N. Shishov‘s co-worker I. Korobova proposed an idea of digging ditches for collecting of sediments in both sides of the fairway in the approach to the port where the sand carried from the south or north would have got trapped and cleaning them, as if it would have decreased the sediment coverage of the fairway. Later on, she refused this absurd. Yet another evil was proposed for the Masters of ships – not to go straight between the moles, but to make a turn of 23°16‘ just after breaking water ends of the moles, where frequent south-westerly winds push the vessels towards the tetrapodes. R. Knaps measured at the open sea in situ, that the flow of sediments is directed towards North and contains 250-500 cubic meters of sediments annually [12]. The research of heave of the oscillatory waves was started in Klaipėda water level measurement station (mareograph) [3]. The port was deepened from the port gates to the estuary of the Dane River. Smaller boulders were digged out, the greater ones were blown up. This research was carried out till around 1972. Later Klaipėda HMO had to investigate the Baltic and North seas [4]. In addition, large vessels arrived at Klaipėda more frequently – when they were proceeding, it was not allowed to perform oceanographic research in the port.

In 1980 the Solidarity movement started in Poland. In order to supply military technical equipment to the soviet military unit located in GDR, in Moscow it was decided to carry military cargo by shipping lines, bypassing land roads through politically unstable Poland. The construction of a seagoing ferry terminal was intended in Klaipėda port, through which railway wagons had to be transported via the line, connecting Klaipėda and the German port of Mukran, now called Sassnitz. This line of 270 miles was the shortest route to Germany. There was some unrest against the construction of such huge object in Klaipėda, as it was planned to transport radioactive materials using this line. The marine part of the object was designed by the association Kasmorniproject from Azerbaijan, referring to the research, carried by Lenmornijproject. The ferry terminal construction lasted for almost four years and on 3rd October, 1986 the international ferry terminal, transporting railway wagons, started its operation with the arrival of the first German ferry Mukran at Klaipėda port. In the Curonian Lagoon the present area of ferry terminal was formed by narrowing the passing between Kiaulės Nugara shoal and the Curonian peninsula. The hydrometeorological conditions of the ferry line were evaluated [2].

Fig. 5 Northern part of Klaipėda port after the 2001-2002 reconstruction (source: https://map.openseamap.org/)

When Russia executed the economic blockade of Lithuania in 1991, an initiative to construct a crude oil terminal on Lithuanian coast already arose. Officials and some scientists suggested to construct a mole at right angles to the coast till the required depth where tankers could berth. Four Danish hydrotechnicians were invited and they had to propose a project for the construction of a terminal to the north of Klaipėda up to Karklė. After the exploration of the location and having prepared a technical project for the construction they offered to build the terminal next to Karklė. From 16 evaluators the only one to vote for Karklė option was J. Dubra. I thought that there it would be easier to cope with the flow of coast sand sediments. Also, next to Karklė there was fishing port adjacent to the estuary of the Rikinė rivulet during the interwar prior, the building of which was blown up by soviet border-guards. Only a part of its foundation remained. Nobody wants the well-known *Globe Assimi* disaster to repeat in the port of Klaipėda when the shipping increased in the port. It is not understandable, why other evaluators wanted to construct the oil product reservoir next to Kopūstai village and to build a pipeline to Mažeikiai Oil Refinery and the mole to be built. The project prepared by Danes was rejected and fierce discussions on the selection of terminal location continued. During the next stage it was allowed to search for the location for the terminal from Klaipėda till the state border with Latvia. This time most of our evaluators wanted to have the terminal near Klaipėda. Besides two evaluators supported the Būtingė option. According to J. Dubra consideration, this option was the best, as that location is closer to Mažeikiai and the pipeline for the release of treated industrial sewage from Mažeikiai Oil Refinery had already been built. There was no need to coordinate the project with environmentalists, historians, farmers, etc. This option was also selected by the Lithuanian government, withstanding the pressure from both Lithuanian and Latvian movements of *greens*. The construction works were executed before 1999 under the lead of the USA company *Williams International*. Annual turnover of the terminal is about 14 million tonnes of oil products. From the beginning of Būtingė Oil Terminal operation, 7 minor oil spills happened, the largest of which was 59 t in 2001. The scandal was exaggerated, as it was not estimated, that a double amount of oil mixed with water compared to the largest oil spill outflow from the Klaipėda Strait to the sea [5-7].

Unsafe navigational state of Klaipėda port raises many problems and solutions to enhance it are sought for. Japanese shipping company was invited which offered to build a port next to Melnragė. This project was opposed already by T. Daukantas [15]. The best solution was offered by foreign designers, who performed the reconstruction of northern port area in 2001 – 2002, which had already been offered by prof. V. Merkys in 1940. The moles were reconstructed by Danish and Dutch company Aarsleff Ballast. Dredging works were executed by Danish company Rhode Nielsen, the technical supervision of the project was done by French company BCEOM [11]. The project of port entrance reconstruction which lasted till 17th October, 2002 is one of the largest and most successful projects in Lithuania (see Fig. 5). The port entrance was dredged from 12 to 14,5 m, the breakwaters were reconstructed. The

northern mole was lengthened by 205 m, while the southern one by 278 m. It is essential that the rotated moles decreased the scroll of waves and especially the long waves the resulting to the oscillatory waves to the port significantly and vessels could stay at the berths without being pushed by the wind in the Strait, as before. The port has become the safest, without accidents of large ships [9, 13].

The glory of this very important project with challenging implementation was slightly darkened by the grounding of the outbound Argentinian tanker Princess Pia flying Panama flag adjacent to the southern mole. Having made a turn from the fairway the ship ran over the derelict of the previously sunken ship and ballast water tanks were damaged at the bottom of the ship. As the ship had double hull, heavy fuel oil did not spill. The vessel was allowed to proceed under the conditions of thick fog, she was piloted by a coastal pilot and the vessel was prepared for voyage poorly, as ship‘s radio location station error was minus 12° .

In order to increase Lithuanian energy independence, the dangerous in terms of human safety Liquefied Natural Gas (LNG) terminal was built in the southern part of Klaipėda port, adjacent to Kiaulės Nugara shoal in 2013-2015. Therefore, the buffer zone around the LNG degasification plant is provided for and the depth of 15 m was reached for the accommodation of LNG carriers.

The remaining problem is ship piloting to port limitations if wind is stronger than 20 m/s, fog conditions, quite rarely forming ice floes and a lack of actual information on hydrometeorological conditions in Klaipėda port and its approaches. It would be an aspiration to decrease the amount of sediments carried to the Curonian Lagoon and increase the depth of the fairway to 17-18 m.

3. Conclusions

The most important reports and conclusions obtained in the flow of the 20th century, still remain particularly important nowadays. Historical works of T. Daukantas, V. Merkys, N. Shishov, R. Knaps and J. Dubra should be discussed when new installations and channels are constructed as the response to the challenges of worldwide marine transportation.

The remaining major problem in the Klaipėda port is piloting limitations of ships if wind is stronger than 20 m/s, because of fog conditions, ice floes that form quite rarely and a lack of actual information on hydrometeorological conditions in Klaipėda port and its approaches. The amount of sediments carried to the Curonian Lagoon should be decreased and the depth of the fairway should be increased up to 17-18 m.

Acknowledgements

This paper is partly based on some unpublished remarks compiled by my father dr. Juozas Dubra (1936-2018), the pioneer of oceanography in Lithuania.

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Proposals for the Use of Renewable Energy Sources for Traffic Control Devices Power Supply

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Abstract

The article presents a brief analysis of existing power supply systems in various types of rail traffic control devices used on Polish railways. The authors also analized the demand for electrical power necessary to supply selected types of rail traffic control devices. Possibilities of using specific types of renewable power sources to supply energy for railway traffic control devices were outlined. Considering the lack of explicit recommendations on power demand on Polish railways, each facility should be considered individually. It was proposed a method for calculating the capacity of batteries to supply railway traffic control devices, which allows significantly reduce the costs of energy supply. Cost-effectiveness of such solutions can be positive in the cases where is no power grid or the power sources are located in a long distance. Nowadays under the conditions of widespread use of renewable energy, the cost of equipment should decrease significantly. Each installation of a power supply with renewable energy sources must be preceded by local tests on the possibility of using more than one method of producing energy.
KEY WORDS: *renewable energy sources, traffic control devices, power supply*

1. Introduction

The main task for rail traffic control devices is to ensure safety in passengers and freight transportation. Railway traffic control systems also determine the efficiency of traffic in terms of rational and consistent with the requirements of determining the frequency of travels and their directions, and ensure minimizing of the likelihood of threat to railway traffic. In connection with the implementation of responsible functions in the transport process, they must be supplied continuously. The issue of using appropriate power supply methods for these devices appeared together with the use in rail traffic control systems of the first components and circuits whose operation required the use of voltage or electric current. With the development of traffic control technique and the introduction of subsequent generations of railway traffic control electrical systems, ensuring proper power supply to these devices has become increasingly important.

Railway traffic control systems and devices are classified mainly in terms of their functions or in terms of the way how dependencies and setting functions are implemented. Therefore, issues related to the power supply conditions for rail traffic control systems and devices can be characterized based on their classification by type and location [1].

Considering the lack of explicit recommendations on power demand on Polish railways, each facility should be considered individually. Each installation of a power station from renewable energy sources must be preceded by local tests on the possibility of using more than one method of producing energy [2].

2. Characteristics of Rail Traffic Control Systems in Terms of their Demand for Electricity Supply

The characteristics of rail traffic control systems in terms of their energy needs, and hence the power requirements can be demonstrated by their classification:

1) in terms of the type of equipment:
   - key devices with shape signaling, key devices with traffic lights;
   - mechanical devices with shape signaling, mechanical devices with light signaling;
   - electromechanical equipment;
   - relay and hybrid devices;
   - computer devices;
2) in terms of their location on the area:
   - station devices - in this group will also be discussed a semi-automatic block system, as its components are located at stations or serviced traffic posts, and therefore their power supply is used to supply these stations;
   - line devices with the separation of automatic line block devices and devices used at single-level junctions of railways with roadways;
   - track vacancy and turnout control devices, which have been separated into a separate group due to their cooperation with both station and line devices, and the use of specific types of these systems often requires the

introduction of additional power requirements.

In design and operational practice, however, are occurred mixed solutions, in which standard circuits for one device type are used to other types of devices as their modification. As an example could be circuits typical for relay used in mechanical devices, such as for example electric operation of switches, relative track insulation and switches. In this case, the rules for supply of modified devices must also take into account the requirements of the introduced circuits. The classification mentioned above coincides with the currently preferred concept for recognizing and presenting requirements for rail traffic control systems when developing technical and operational standards for individual categories of railway lines.

External power supply for rail traffic control systems (high and low voltage transmission line, overhead and cable lines, transformer stations, power connections) should meet the requirements:

- regulations for the construction of electrical power equipment;
- principles of protection against electric shock;
- surge protection rules.

General requirements for the power supply of railway traffic control devices:

1. Supply voltage - the correct operation of the devices should be ensured with the following power source tolerances:
   - AC + 10%, - 15%;
   - DC ± 10%;
   - frequency ± 5%.
2. The term "normal work" means that the system meets:
   - functional requirements;
   - functional requirements related to security;
   - security requirements.
3. Exceeding the supply voltage limits must not cause a hazard.

Table 1 shows a summary of the specific power consumption of selected rail traffic control elements.

Table 1

Summary of power consumption for selected rail traffic control elements

No.	Name of the energy consumer	Power consumption [VA]
1.	Track circuit - with relay: - inductive - electronic	 70 40
2.	Switch or derailer circuit with engine: - single phase - three phase	 1320 3 × 450
3.	One light on a semaphore	45
4.	Repeating indicator: - single - duplex	 170 310
5.	Transformer (in idle state) of rated power: - 45 VA - 109 VA - 200 VA	 30 75 100
6.	The switch drive control circuit in El-type devices	80
7.	Computer supplying devices	2 × 750
8.	Automatic crossing signalling	500 - 1500

3. Sun as an Energy Supply Sources

The prospects of depletion of fossil fuel stocks and concerns about the state of the human environment significantly increased interest in renewable energy sources in the nineties and, as a consequence, led to a large increase in their use in several countries. Since 1990, the amount of energy (heat and electricity) produced by solar raised twice, and from wind energy - four times.

Renewable energy technologies have already developed to such an extent that they can compete with conventional energy systems. The modular nature of most renewable energy technologies allows their gradual expansion as needed, which facilitates their financing.

The sun is the largest and most efficient source of energy available to humanity. During the whole year, around 1000 kWh of solar energy reaches per square meter of Earth's surface in our climate zone. In Poland, the average intensity of solar radiation is from 900 – 1200 kW-h / m^2. In Poland, the average daily sunshine measured as the amount of solar energy per 1 m^2 from October to March is 1.3 kWh/m^2, and in the favorable period, i.e. from April to September 4.3 kWh/m^2. The worst sun conditions prevail in December when the length of the day is the shortest.

Then the value of % insolation comes from diffused radiation, and the average insolation is only several dozen (20-30) watts per square meter. In addition to day length and sunshine, the amount of direct solar radiation is affected by sun height, atmosphere transparency, cloud cover. The Fig. 1 shows the average annual sunshine in Poland.

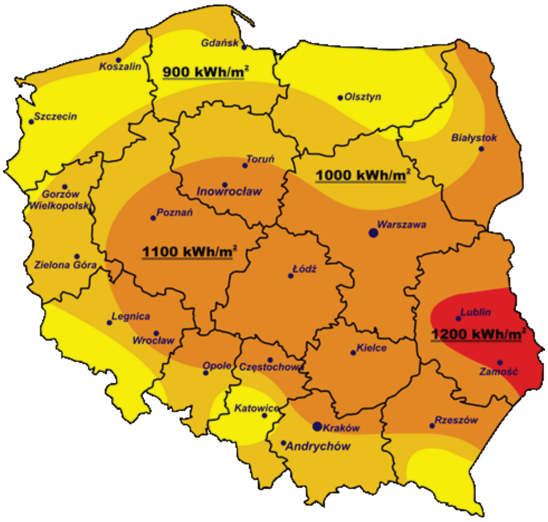

Fig. 1 Solar radiation intensity in Poland [10]

The amount of solar radiation that can be used by the collector is much smaller than the total solar radiation reaching the earth from the sun and is 0.7 kW/m^2. The reason for this are the losses of transmitted energy resulting from distraction, absorption, collector losses (losses in the solar battery and system elements)

Solar photovoltaic plants, due to their simple construction and ease of automation as well as free and easily available primary energy carrier, are perceived as the basic source of electricity generated from renewable resources. The solar power plant consists of solar batteries and an electronic power converter. Considering the fact that the cost of solar panels over the past 10 has decreased by 90% [3-6], it makes investment in this direction economically profitable. Transforming the DC voltage, unregulated, generated by the solar battery to the form required by the network, to which the power plant or consumer is connected, introducing galvanic isolation between the solar battery and the consumer, adjusting the position of the solar battery operating point and selecting the point with maximal power. Depending on the operating system and the type of network or receiver to which they are connected, solar power plants differ in the design of the power electronic converter. Power plants working in AC systems are equipped with inverters, usually with galvanic isolation, working in DC systems - with converters, also with galvanic isolation. Isolation is compulsory in many countries for protection against electric shocks or atmospheric surges. In order to maximize the use of solar energy the effective mean is using of "sun trackers" - devices tracking the movement of the sun in the sky. Determination of azimuth and altitude of the sun is possible at any time and for any geographical coordinates using the following formulas [1]:

$$H = arcsin\left[cos(L)cos(\delta)cos(h_s) + sin(L)sin(\delta)\right]; \tag{1}$$

$$A = arcsin\left[\frac{cos(\delta)sin(h_s)}{cos(H)}\right] \text{ if } cos(h_s) > tg(\delta)/tg(L); \tag{2}$$

$$A = -arcsin\left[\frac{cos(\delta)sin(h_s)}{cos(H)}\right] \text{ if } cos(h_s) < tg(\delta)/tg(L), \tag{3}$$

where H – elevation angle; A – azimuth; L – latitude of the installation area; h_s – hourly solar angle; δ – solar declination.

In Polish conditions, solar batteries should be oriented to the south. The angle of inclination to the horizontal plane should be approx. 50-55° in winter and 34-37° in summer. In some designs, solar batteries can be placed on special bases that position them perpendicularly to the sun's rays. The installed capacity of solar batteries, incorrectly marked in the catalogs as Wp (watt peak), corresponds to the solar radiation 1000 W/m^2 and the temperature of the semiconductor junction 20°C. Such conditions occur sporadically in Poland. For this reason, the installed capacity of the solar battery is only used for about 1000 hours per year. Using the formulas given above to track the sun, this time can be increased to approx. 1200 hours per year. On average, in Poland, it's possible to acquire approx. 100 W from one square meter of battery surface. Table 2 shows the average annual energy consumption for selected rail traffic control devices.

Table 2

Average annual energy consumption

Devices	Annual energy consumption (kWh)	Average monthly consumption [kWh]	Average daily consumption [kWh]	Average hourly consumption [kW]
Automatic block section	5101	425,08	14,17	0,59
Level crossing	5425	452,08	15,07	0,63
DSAT devices	7789	649,08	21, 64	0,90

When assessing the generation power of a photovoltaic installation (PVI), it must be remembered that the intensity of solar radiation, kW / m^2 of an inclined surface, is generally determined by the expression [7]:

$$I_T = I_B R_B + I_D R_D + \rho\left(I_B + I_D\right)\frac{1-\cos\beta}{2}, \tag{4}$$

where I_B and I_D in the above expression are the intensities of direct and scattered radiation on the horizontal plane, which are determined from the reference data; ρ - Earth albedo; R_B, R_D - coefficients necessary for recalculating the direct and scattered components for an inclined surface: $R_B = \dfrac{\cos\theta}{\cos\varphi}$ - for direct radiation, where φ is the angle of the Sun at the zenith, θ is the angle of incidence; R_D - for scattered radiation, using existing models [8]. Here, the first term describes direct radiation, the second - scattered, and the last - reflected.

In the case of using a PVI for autonomous operation, when performing calculations, it is necessary to take into account, first of all, the stable mode of providing consumers with electric energy, and not the maximum of electric energy, which is more typical for network PVI. Consider an example of the influence of the angle of inclination of the photovoltaic panel on the level of electric energy generation (Fig. 2).

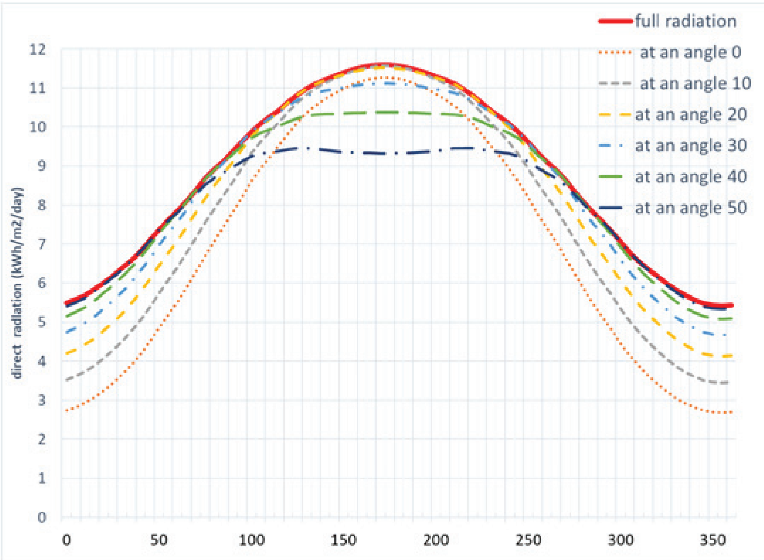

Fig. 2 Dependences of the intensity of solar radiation throughout the year when the angle changes from 0 to 50°

The figure shows the power that comes to the earth's surface and the possible options for placing modules at different angles from 0 to 50° during the year. When performing the analysis, the geographical data of Warsaw (latitude 37°) were used, data on the components of solar radiation were obtained from [9]. From the obtained dependences, it can be concluded that the most favourable operation mode of an autonomous PVI will be observed with angle of inclination of 50°, for other angles, although the total annual energy generation is greater, there is a generation deficit in the most unfavourable months. When assessing the capacity of the system for the most unfavourable period, the battery capacity is overestimated. Given the fact that energy storage today is the most expensive component, this leads to unreasonable rise of the total cost of the entire system.

4. Selection of Battery Capacity

Assumptions for calculating the battery capacity:

1) Operating time without RES for medium load 50 hours;

2) Average daily energy consumption according to the data showed in Table 2;

3) The maximum consumption time is skipped due to the temporary nature that does not affect the battery capacity;

4) The battery operates in the temperature range from -20 to+50 ^{0}C, therefore its capacity in extreme conditions is 50% of the nominal capacity;

5) At the end of the battery's service life (about 5 years), a decrease in capacity from 100% to 50% of the rated capacity is assumed;

6) When operating at medium power levels (standby state), the discharge current is so small that it does not affect the instantaneous battery capacity;

7) During the autonomy period, all the system's energy needs are met from the battery without recharging;

8) The assumed maximum current consumed by the devices is three times higher than the average current.

The approximate calculations for the automatic line block interval are shown below.

Because these devices are powered by three-phase alternating voltage with an effective voltage of 230 V, the battery will have a voltage 48 V, which at low power is a telecommunications standard and standard inverters powered from this voltage are available. The inverter efficiency is approximately 93%.

Average current: 350 W / 48 V = 7,29 A

Current correction due to inverter efficiency: 7,29A / 0,93 = 7,83 A

Maximum current: 1050 W / 48 V = 21,87 A

Energy consumption in 50 hours: 10 kWh × 50/24 = 20,83 kWh

Battery capacity estimated based on energy: 20830 W·h / 48 V = 434 A·h

Battery capacity on the basis of autonomy time and average consumption: 21.87 A × 50 h = 1093,5 A·h

Battery capacity on the basis of maximum power consumption for current C / 10 218 A·h

Battery capacity on the basis of maximum power consumption for current C / 5 109 A·h

Battery capacity on the basis of maximum power consumption for current 1C 21,8 A·h

Battery capacity on the basis of maximum power consumption for current 5C 10,9 A·h

It can be suggested a battery with a capacity of 500 A·h, with the possibility of expansion to 1000 A·h.

5. Conclusions

Analysis of the types of renewable energy sources that could be used to supply the rail traffic control devices confirmed the hypothesis that solar systems are the most favorable. Actions taken towards the use of renewable energy sources to supply rail traffic control devices should not only apply to the power supply system but also to consumers, by use of devices with lower energy consumption. The use of renewable energy sources to supply traffic control devices will not only contribute to environmental protection, but can also make railway transport completely ecological.

Acknowledgments

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Variation in Diesel Engine Glow Plug Heat-up Parameters Depending on Duration of Use

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Abstract

Starting diesel engines at low ambient temperatures, glow plugs lose their initial heat-up parameters over an extended period of time, thereby lowering the heat-up temperature and interfering normal engine start-up. The glow plug operates in two phases - the heat-up phase, when the glow plug heats from 850 to 1250°C, for about 4-7 seconds, and the afterglow phase, which can last up to 180 seconds. For conventional glow plugs S-RSK is used as a nickel control resistor, and for second-generation glow plugs GSK2 a cobalt iron (CoFe) alloy is used for the control resistor. Research has found that the maximum heat-up temperature of glow plugs used for about five years, or 100 000 km, is on average 17% lower than that of analogue new glow plugs; the time at which the maximum temperature reached is, on average, 31.5% higher for used glow plugs but the starting current for used glow plugs is about 16% higher in comparison to new glow plugs. During research it was observed that glow plugs fitted with more modern diesel engines, like common rail, are less subject to wear created changes than glow plugs used in older engines.
KEY WORDS: *glow plug, diesel engine, heat-up temperature*

1. Introduction

The successful ignition of diesel fuel is based on 3 elements: placement and surface temperature of the glow plug and control of combustible mixture formation [9]. The first 2 elements show glow plug meaning in realization of ignition especially for engine starting in low outdoor temperatures. It generates necessary heat in the combustion chamber till 850 to 1000°C in seconds providing properly engine operation. It is very important especially in a northern climate, where diesel engine operation could be disturbed even at temperature starting from +5°C if faulty or old glow plugs are used. Such exploitation could be resulted by an increased amount of smoke and louder sound of the engine, especially, after a cold start, and also further leave an impact on the reduction of power and increase of fuel consumption. Glow plugs are designed for the use as cold start assist in diesel engines, but different studies exist on their assist also with natural gas, methanol, liquid nitromethane combustion [8].

Nowadays it is not more acceptable to wait for some 10 s for light up of a glow plug before engine starting, therefore technologically advanced glow plugs could be met in the market allowing to reduce light up of glow plug as much as possible. Such quick-heating glow plugs in comparison to conventional ones allow to reducing light up till 6 seconds due to the use of heater made from metal [5].

Glow plug is a protected tubular shaped heating element sealed in a plug body. This heating element is protected from corrosion and hot gases by resistant shell filled by magnesium oxide (MgO) powder. The selection of magnesium oxide as an insulator is based on the following reasons: (1) it is used for resistance against wire heater corrosion; (2) ensure good electrical isolation; (3) ensure a comfortable fit between the heater and the tube [3]. Therefore there is possible to outdraw an enemy of such type of glow plugs – corrosion. Once the glow plug has been penetrated by corrosion and the heating spiral is accessed by air, it will burn out.

The durability of such glow plugs also depends, in the most direct way, on the engine starting times. Stop-start technology introduced by the automotive industry in the last decade with the aim of reduction of CO2 emissions, requires glow plugs with an extended lifetime [6], as also improvement of other elements of the automotive start-up system, like starter, battery, etc. [4]. The increase in the concentration of emissions is particularly relevant in places where the start-stop system is most frequently shut down and restarting the engine based on the impact of different factors, such as pedestrian crossings near shops and congestions [1] in such way reducing idling time. Additionally, it should be taken in mind that the durability of glow plugs also decreases if the preheating time is shortened [5]. Therefore, different solutions, like a material improvement, should be found to ensure proper diesel engine operation.

Another solution is the ceramic type glow plug, which has a ceramic heater element inside allowing to reach 800°C in 2 s. The material used for such glow plugs (silicone nitrate) ensures ideal resistance to heat, corrosion, and thermal shock, which means also a better durability [5].

Usually, service life of glow plugs varies based on engine type, maintenance, mileage, etc. At the moment, the most popular glow plugs used in the market in Latvia, where the average age of a car is more than 10 years, are S-RSK and GSK2. Conventional glow plugs S-RSK (came onto the market in 1980s), and there is used a nickel control resistor,

second-generation glow plugs GSK2, have a cobalt iron (CoFe) alloy control resistor (Fig. 1).

The new generation of glow plugs GSK2 differs from S-RSK with its resistance, which increasing more rapidly with the growth of temperature. It means that GSK2 glow plugs can reach temperature faster: 850°C in 4 s. Besides that, it can be in operation of 3 minutes after engine start, which could be resulted in effective engine work in the idle phase ensuring lower emissions and noise level [7].

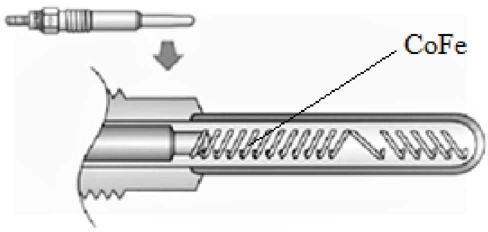

Fig. 1 Geometry of heating element of glow plug GSK2

In order to meet the Euro-5 and Euro-6 standards, only GSK2 glow plugs are used, which also ensure optimal burning. Heating curves of S-RSK and GSK2 glow plugs are shown in Figure 2.

A variety of manufacturers produce glow plugs designed for certain characteristics of the car's electrical system. As a result, the nominal voltage may vary – between 6 and 24 V. Glow plugs with post-heating functions are installed with additional resistance. Before starting the engine, the heating is performed at the maximum power, after starting the engine, the power is reduced to reduce the load of the control spiral. Depending on the type of glow plug, its resistance is 0.5-1.8 Ω, and the heating temperature is 1000-1350°C.

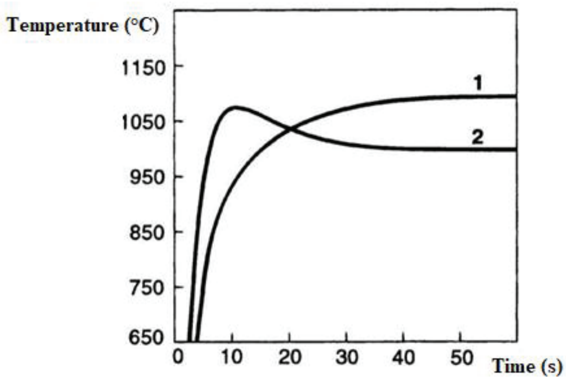

Fig. 2 Comparison of the heating curves for different glow plugs: *1* – GSK2; *2* – S-RSK.

However, research on the durability of glow plugs is limited. Karpe [4] has been focused on extending the lifespan of the diesel engine glow plug, where regulating coil was prepared by laser welding and powder pack aluminization was implemented. Finally, he concluded that weld may become a critical area, if the aluminium concentration in the FeCrAl alloy would be increased.

Paulin [6] has realized research with the aim to prevent the high-temperature degradation of the ferritic FeCrAl alloy used on heating resistors in glow plugs. He concluded that heating resistors made from Kanthal AF can be optimized by appropriate oxidation before mounting in the glow plugs, but the self-healing mechanism for recovering the cracks in a continuous protective oxide layer needs to be involved for the life-time extension of the plugs.

Besides that there are also a number of researches, where glow plugs have been studied mainly in cold start assistance applications in gasoline and natural gas engines, focusing on combustion stability and efficiency [2], while researches on the durability of the used glow plug is still missing.

As glow plugs work under aggressive conditions, they are not only being mechanically damaged during a specified period of time, but also changing their heating parameters – speed and maximum temperature. Therefore this study draws attention to variation in the heat up parameters of glow plugs in relation to the length of their use.

2. Materials and Methods

The research was focused on 2 types of glow plugs and its application possibilities for a longer period selecting 12 different mass-produced glow plugs of different models used for 4 to 5 years with the mileage range of 80-100 thous. km. A limited number of different glow plugs are associated with the use of one type of glow plugs in different brands of diesel engines. There were no visible visual defects of the selected glow plugs and the resistance fulfilled the condition <5 Ω. Glow plug used in the study came from diesel engines of different generations. The technical characteristics of selected glow plugs are shown in Table 1.

New glow plugs were selected taking into account the following additional conditions: (1) the heating

temperature must be not less than 850ºC; (2) the current strength during heating must be between 6 and 15 A; (3) cold glow plug resistance must not exceed 5 Ω, (4) the heat-up time must not exceed 10 s, (5) glow plugs must not have visible defects which may affect their functioning, (6) the energy source must be in conformity with the technical specification of the glow plugs.

Table 1

Used glow plugs and their characteristics

No.	Manufacturer, component number	Resistance for cold glow plug, (Ω)	Resistance for cold glow plug, (Ω)	Voltage used for glow plugs, (V), manufacturer-defined
1.	BERU, 0100276015	1.1	0.9	11.0
2.	BERU, 0100226203	1.2	0.8	11.0
3.	BOSCH, 0250202020	1.2	0.9	11.0
4.	BOSCH, 0250403001	1.0	0.7	4.4
5.	BOSCH, 0250201036	1.0	0.9	12.0
6.	NGK, Y732J	1.4	1.0	12.0
7.	DENSO, DG-005	0.9	0.9	11.0
8.	BERU, 0100226371	0.9	0.9	11.0
9.	NGK, Y503J	1.4	1.1	11.0
10.	DENSO, DG-117	0.8	0.8	11.5
11.	BOSCH, 0250202022	1.1	0.9	11.0
12.	BERU, 0100226173221	0.8	0.8	12.0

The following measuring instruments were used to determine the required parameters: (1) multimeter - the model is with a built-in fuse 20A (It was able to withstand the current of glow plug at the time of warming < 15A, but for safety purposes, before the multimeter in the string there was connected fuse (15A). This multimeter also performed resistance measurements for cold glow plugs to select samples for experiments by discarding damaged copies.); (2) voltmeter DT9205A; (3) digital stopwatch; (4) infrared thermometer – UA950, temperature measuring range from -50 to +950°C; (5) digital contact thermometer TES 1310, max temperature measurements up to +1300°C; (6) power supply source – battery 12 V; (7) rheostat for the change of the voltage to the type specified by the manufacturer of the glow plugs; (8) different consumables, such as the switch, wires, fuses, clips, etc.

The experiment was initiated by fixing glow plugs in the test bench and by the addition of the power supply clips to it. Then the thermometer and temperature sensor was switched on placing it on the heating element of the glow plug and draw up the stopwatch. The further accessory switch was turned on to take time. In parallel, the readings of the ammeter were recorded at the time of switching on and at the time of reaching the maximum temperature.

When the maximum temperature was reached, the time and the readings of the ammeter was recorded. The device was switched off, the power clips were disconnected, the checked glow plugs were removed, and the next glow plugs were inserted, and the measurements were repeated in the same order. The principle scheme of the electrical circuit is shown in Fig. 3.

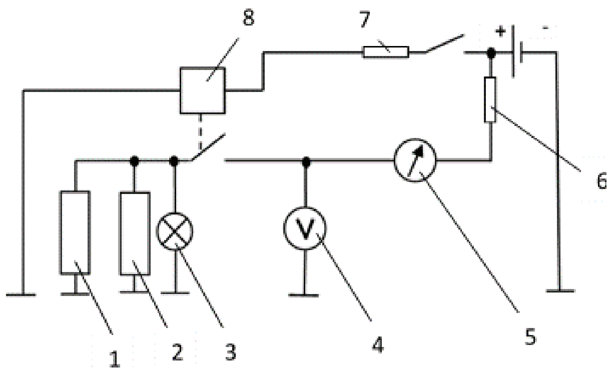

Fig. 3 Principle scheme of an electrical circuit used for the testing of glow plugs: *1* – new glow plug; *2* – used glow plug; *3* – control lamp; *4* – voltmeter; *5* – rheostat; *6* – fuse 20 A; *7* – fuse 5 A; *8* – relay.

The detected level of each component was averaged as the result of three replications for each pair of glow plugs to decrease the uncertainty. For the new glow plugs, the time was measured from the time of switching on to the maximum temperature of the corresponding used glow plug.

In general, the following parameters were measured: (1) maximum heating temperature (°C); (2) the time at which the maximum temperature is reached (s); (3) current at the start of heating and during temperature maintenance (A).

3. Results and Discussion

All results of the experiment are summarised in Table 2, but the relative changes in the parameters of the glow plugs are shown in Fig. 4.

Table 2

Variation of glow plug parameters

No.	Condition	Manufacturer, component number	Maximum heating temperature, (°C)	The time at which the maximum temperature is reached, (s)	Current at which glow plug is switched on, (A)	Current strength at maximum temperature, (A)
1	old	BERU, 0100276015	998	11.6	12.4	5.07
1	new	BERU, 0100276015	1123	8.7	8.84	3.92
2	old	BERU, 0100226203	974	15	12.26	6.45
2	new	BERU, 0100226203	1016	12.7	10.48	4.61
3	old	BOSCH, 0250202020	825	17.4	12.39	5.56
3	new	BOSCH, 0250202020	907	16.9	9.55	4.66
4	old	BOSCH, 0250403001	1032	11.8	10.77	6.49
4	new	BOSCH, 0250403001	1132	10.3	9.63	6.46
5	old	BOSCH, 0250201036	734	31	6.82	3.91
5	new	BOSCH, 0250201036	872	28	6.48	3.62
6	old	NGK, Y732J	652	104	8.59	4.91
6	new	NGK, Y732J	705	80.7	7.23	4.63
7	old	DENSO, DG-005	552	143.4	7.2	4.57
7	new	DENSO, DG-005	653	91.3	6.59	4.11
8	old	BERU, 0100226371	650	139	5.59	3.44
8	new	BERU, 0100226371	706	103	5.27	3.25
9	old	NGK, Y503J	463	106	7.23	3.88
9	new	NGK, Y503J	608	57	4.80	3.14
10	old	DENSO, DG-117	423	105	5.54	3.52
10	new	DENSO, DG-117	542	59	5.49	3.29
11	old	BOSCH, 0250202022	232	147.3	5.5	3.51
11	new	BOSCH, 0250202022	544	28.7	4.34	2.68
12	old	BERU, 0100226173221	426	156.7	4.43	2.42
12	new	BERU, 0100226173221	464	95.3	3.58	2.36

Results show that maximum achieved temperatures for used glow plugs are on average 17% lower compared to analog new glow plugs.

The time at which the maximum temperatures are reached for used glow plugs is on average 31.5% higher, which is very important as the preheating time is limited. Therefore, the glow plug may not be heated to the desired temperature required for a successful engine start.

The starting current for used glow plugs is about 16% higher than for new ones. This is also an important factor as it directly impacts the capacity that is consumed during heating and therefore also impacts battery discharge time, which is particularly important in the cold season. Current strength at the moment, when the maximum temperature is reached, for used glow plugs is about 11.4% higher than for new ones, which also have a direct effect on battery discharging time.

Usually, it is stated that glow plugs from direct injection (DI) diesel engines have better durability based on system operation features allowing them to operate them less frequently. This research overturns this fact showing that exactly glow plugs from DI engines are losing their original parameters more rapidly than in case of indirect injection (IDI) diesel engines. For example, glow plug from 1.9 TDI (marked as No. 11) engine showed a heating temperature reduction for 57.4%, while glow plug from 1.4 TDCI (marked as No. 9) engine showed a heating temperature reduction for 23.9%. On the other hand, glow plugs from 1.9 D (marked as No. 3) and 2.4 D (marked as No. 4) engines showed a heating temperature reduction only by 8.8 to 9.0% after approximately 5 years of operation.

Obtained results allow us to conclude that the reduction of heating temperature could be due to more aggressive burning conditions in DI diesel engines. Despite to this it was found that glow plugs, which are used in modern diesel engines, like common rail, and operate at very higher temperatures (850-1200 °C) are less exposed to wear created changes like those used in older generation engines, which are heated much longer time at the same moment reaching lower temperatures than the new type glow plugs. This is due to the fact that the levels of compression for the older generation were much higher than for younger generation engines therefore heating for them was less necessary. But for younger generation engines, many improvements have been made to achieving better results.

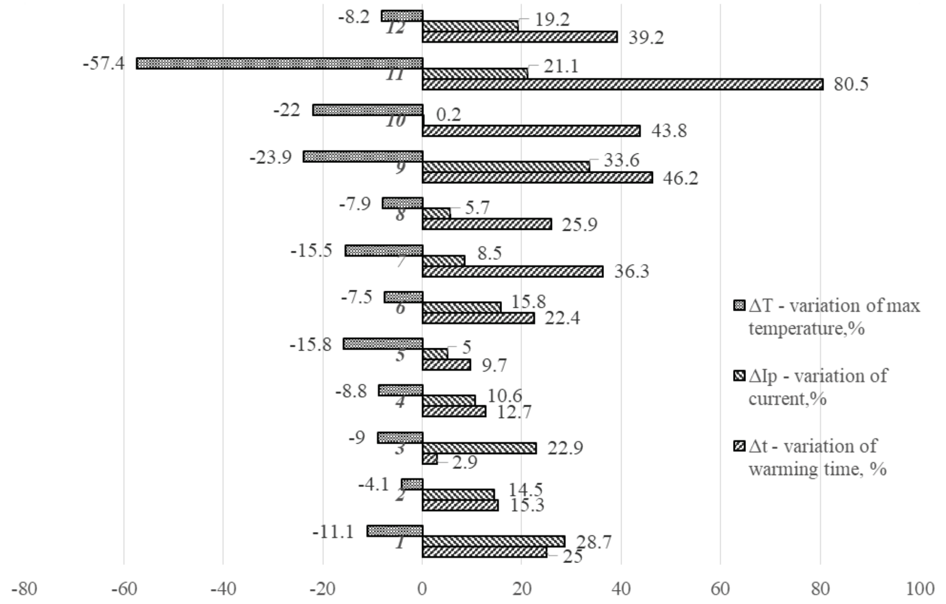

Fig. 4 Relative change of glow plug parameters

4. Conclusions

This study demonstrates a variation of main working parameters of used and new glow plugs – max temperature, current and heating time. Compiling the data obtained from the experiment, it is clear that glow plugs after 5 years usage, or approximately 100 thousand km mileage, have lost their original parameters, thereby failing to ensure that diesel engines are normally started at low ambient temperatures. It means that a higher current is needed to start used glow plugs and keep their maximum temperature. This creates an additional load for the battery, thus removing the power required to run the starter. Additionally, some differences in durability could be observed for different types of engines showing reduction of heating temperature more rapidly for DI engines.

Therefore, regardless of the technical characteristics of the glow plug or even the manufacturer, glow plugs should be changed after an exploitation period of 5 years or about 100 thousand mileage.

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The Impact of Legislation on the Human Resources Management of Freight Transport Companies

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Abstract

The organization and quality of transport activity have an impact on the functioning of the entire national economy of the state, on its socio-economic development and growth of living standards. Transport creates the conditions for the optimal use of economic and social potential; enables and promotes the free movement of persons, goods, freedom to provide services and the free movement of capital, which creates the conditions for the functioning of the EU's single internal market. Transport plays a key role in the globalization environment; within the transport system, road transport has a priority position, both in passenger and freight transport. Due to the ever-increasing importance of road freight transport in terms of global trends, it is necessary to pay attention to carriers but also to employees - drivers of transport companies. In the environment of the 21st century, companies compete in the complex and challenging context of globalization, new knowledge and technological development, while facing current labor market challenges. In the current turbulent environment, the management of road freight transport companies is exposed to complex tasks in ensuring competitiveness under demanding external conditions affecting the operation of the company, including strict legislative requirements. This growing economic pressure has led to an urgent need to improve internal management systems. Human resource management has a special position here. The paper focuses on the analysis of the legislative impact on the management of human resources in road freight transport and the identification of current problems in relation to the workforce.
KEY WORDS: *driver, human resources, legislation, management, freight transport, transport company*

1. Introduction

The success of mastering the content side of traffic management depends on the level and ability to plan, organize and control activities, provide and lead people so that the transport and transportation process works successfully. The road transport manager uses his management skills - competencies, while his success depends on how he can combine scientific knowledge with practical experience and his personal preconditions. The art of driving should be seen as one of the crucial keys to the success of managers - especially in transport, where the involvement of the human factor is very important. Human resource management in the company is one of the most important parts of company management; it is thanks to the human factor that companies can successfully develop their business. However, the current state of human resources management in the road freight transport sector is critical, especially in view of the insufficient number of human resources - professional drivers. The general goal of human resource management is to ensure that the company is able to meet its goals through people [1]. Human resources management in its current form represents a comprehensive managerial approach to human resources and the development of the human potential of the organization. It is managerially oriented, in the sense that it involves not only personnel specialists, i.e. mainly personnel, but also all managers at all levels of management of the organization and that it is derived from the organizational mission and strategy. The purpose of human resource management is to induce a synergistic involvement of people in operational and development organizational processes in an effective, legitimate and cultured way, with the aim of achieving organizational goals [2]. Human resources management is becoming an important tool for increasing the productivity of the company, HR professionals participate in change management, and they become a partner of management and a guarantor of the quality of personnel processes, the use of advanced personnel - information systems. Strategic and administrative activities are separated, while those with low added value are often outsourced. Functional personnel management has a crucial role in the competitiveness of the company [3].

The management of human resources in transport has certain specificities, which are mainly linked to globalization, which is taking place in the world and which has caused changes in transport. These are changes of both microeconomic and macroeconomic nature [4]. 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 [5]. Certain external factors also need to be taken into account in the human resources management system itself, as the quality of human resources in road freight transport itself sometimes has an impact on seemingly unrelated factors such as the environment and the quality of the urban environment [6]. Human resources management in road transport has its own specifics, with emphasis on reliability of the worker and employee orientation to the customer. It is therefore essential that every road transport company creates the conditions for the continuous development of its workers. It should be borne in mind that a worker in a road transport undertaking is an executive member of that undertaking.

Therefore, it is necessary to use such methods when recruiting workers in road transport, which will ensure a sufficient number of workers in the company. The actual recruitment of workers to the road transport company can be ensured in the following two ways:

- In-house - represents a relatively costly way for a company to acquire an employee, but it is assumed that such an employee will last longer in the company;
- Through a recruitment agency - it represents a relatively quick acquisition of a worker for the position of a driver, but such a worker usually does not stay in a long-term position [7, 8]. Several models are used to recruit employees in road freight transport, and the most popular personality models include the FFM model, which is a five-factor model. This model focuses on the following five factors of the surveyed employee: - openness, conscientiousness, extraversion, reviews, and neuroticism. Thanks to these factors, it is possible to describe the relationship between a person's personality and his work performance [9, 10]. The impact of the legislation on road freight transport business is great. There are many and numerous regulations, rules or laws governing not only business but also the management of employees in this area. The article focuses on the analysis of legislative rules affecting the management of human resources in road freight transport companies and current problems associated with the workforce in this sector using the method of secondary data analysis, synthesis, deduction and interview with transport managers.

2. Analysis of the Legislation Impact on the Human Resources Management of Freight Transport Company

Running a road haulage business requires all legal and legislative requirements, but also requires a number of documents, permits and bureaucracy. The carrier must respect all regulations of the Slovak Republic, these regulations are called national. However, this business is also regulated by the European Union. Its rules and regulations take precedence over national ones. In particular, the European Union's common road transport policy is intended to ensure equality and fair conditions for all in this competition. These measures concern not only the financial side of the company (taxes, fees, tolls) but also technical standards (dimensions and weight of cargo), social standards and, last but not least, environmental measures, which the European Union is paying more and more attention to. Pursuant to Act no. 56/2012 Coll. on road transport, each company must meet specific conditions for obtaining a license to do business in this area. The basic condition is entry in the commercial register either as a legal entity or as a natural person - self-employed person. However, a limited liability company has one important advantage over a trade, because the liability is up to the amount of the company's assets, while in the case of a trade, the self-employed person is liable with all his property. The road freight transport company has a great financial responsibility. According to the European regulation the transport company is obliged to have registered capital and reserves of at least EUR 9 000 if it uses one vehicle and EUR 5 000 for each additional vehicle [11].

Business conditions

The carrier is obliged according to Act no. 56/2012 Coll. on road transport:

- Operate road transport in accordance with the transport regulations;
- Mark each operating vehicle with its trade name;
- To provide a technical base equipped for the operation, maintenance, technical inspection, parking and garage of vehicles and for the care of vehicle crews, passengers and cargo in the scope of provided transport services;
- To ensure that each vehicle in operation has proof of the authorization granted to operate road freight transport;
- To employ only a person who has a certificate of professional competence; in the case of a person from another member state, a recognized professional qualification and, in the case of an alien from a third country, a driver attestation and a work permit;
- To employ only those drivers who have completed compulsory basic qualifications or regular training;
- To notify the transport administrative body of the person he has appointed as the transport manager or a change in the person of the transport manager;
- To be insured against liability for damage to the goods carried in: national transport, if the carrier operates national road haulage or in international transport if the carrier operates international road haulage.

Professional competence in transport

The head of transport (transport manager) is a natural person who is employed by the company, or a natural person - entrepreneur, or another natural person with whom the company has a contract and who manages transport activities for him. According to Act no. 56/2012 Coll. the road haulage undertaking must have at least one transport manager. The transport manager must meet 3 basic requirements: minimum age is 21 years, integrity, legal capacity. Professional competence for the operation of road freight transport is acquired by a natural or legal person for a period of 10 years after the demonstration of knowledge through an examination before an examination commission. Pursuant to Regulation (EC) No 1071/2009 exam consists of a written and an oral part and its content is the following 8 subjects: Civil Law, Commercial Law, Social Law, Tax Law, Business and Financial Management, Market Access, Technical Standards and Technical Aspects of Operation, Road Safety. A prerequisite for a good transport manager is not just a good economist, logistician or economist. They must also master legal matters in practice or have a thorough knowledge of the vehicle fleet and thus ensure road safety. Often the head of transport and the head of the company is

one person, but this is not the rule. The head of the company may be its owner, but for whom the head of transport is performed by someone else. The transport manager is therefore the one who, on the basis of his professional competence, is authorized to perform the functions associated with the operation of the transport company and is fully responsible for these activities [12].

The legislation covers various areas of human resources management of freight Transport Company, for example organization of driver working time, compulsory basic qualifications and driver training, remuneration etc.

Organization of working hours, driving times, breaks and rest periods

Working time under Directive 2002/15 / EC includes drive; loading and unloading; cleaning and technical maintenance. Also any other work performed for the safety of the vehicle, passengers or cargo, or for the fulfillment of certain legal obligations directly linked to a specific transport activity (such as customs formalities) and any other time during which the driver is on duty. According to Act no. 462/2007 Coll. the employer is obliged to schedule the employee's working time per week so that it does not exceed 60 hours. The average weekly working time of a transport employee, including overtime, may not exceed 48 hours for four consecutive months. If a transport employee performs night work, the average working time may not exceed ten hours in 24 hours for six consecutive months [13]. Night work is scheduled for between 10 pm and 6 am. Unless otherwise provided, the following shall not be included in the working time of a transport employee - time needed to travel from home to work and back, break time at work, rest period, on-call time. On-call time is the time during which the employee in transport does not have to be at the workplace, but is obliged to be available to the employer to start performing work on his instructions over the specified weekly working time. Unless otherwise provided, the employer may order an employee to work on call for a maximum of 300 hours per calendar year, but may not exceed 24 hours during the week and 72 hours during the calendar month. On-call time is remunerated at least in the amount of the minimum hourly wage if it is performed as part of a work shift or at least 20% of the minimum hourly wage if it is outside the work shift. The performance of work during on-call time above the specified weekly working time is overtime work. According to Regulation No 561/2006 the daily driving time must not exceed 9 hours, but may be extended to a maximum of 10 hours a week. The weekly driving time must therefore not exceed 56 hours. The total accumulated driving time during two consecutive weeks shall not exceed 90 hours. After four and a half hours' driving, the driver shall have a continuous break of at least forty-five minutes, unless he begins to take a rest period. This break may be replaced by a break of at least 15 minutes, followed by a break of at least 30 minutes. The driver takes daily and weekly rest periods. If the part of the daily rest period included in the 24-hour period is at least 9 hours but less than 11 hours, then the daily rest period in question is considered to be a reduced daily rest period. The daily rest period may be extended to a regular weekly rest period or to a reduced weekly rest period. A driver may have a maximum of three reduced daily rest periods between any two weekly rest periods. In every two consecutive weeks the driver shall draw at least two regular weekly rest periods, or one regular weekly rest period and one reduced weekly rest period of at least 24 hours [14]. However, this reduction shall be replaced by adequate rest taken in full before the end of the third week following the week in question. If the driver so decides, daily rest periods and reduced weekly rest periods outside the base may be taken in the vehicle, provided that he is equipped with suitable sleeping facilities for each driver and the vehicle is not in motion.

Emergency measures in relation to the spread of COVID - 19

On 31 March 2020, on behalf of the Crisis Staff, the National Labour Inspectorate granted a temporary exemption from the application of the provisions of Regulation (EC) No. 561/2006 for drivers involved in the transport of goods in the Slovak Republic from 18 April to 31 May as follows:

- The maximum daily driving time increases from 9 am to 11 am;
- The maximum weekly driving time increases from 56 hours to 60 hours;
- The total accumulated driving time for two consecutive weeks increases from 90 hours to 96 hours;
- The driver has a continuous break of at least forty-five minutes, if he does not start to take a rest period, after five and a half hours of driving;
- The minimum daily rest is reduced from 11 to 9 hours.

These exceptions were approved by the National Labour Inspectorate because of the unplanned delays of drivers at border crossings as well as delays in customers due to the coronavirus pandemic due to measures taken to protect health from the spread of the coronavirus. However road safety must not be affected by this decision. Employers remain responsible for the health and safety of their employees - drivers, as well as for the health and safety of other road users.

Compulsory basic qualification, regular driver training and driver qualification card

Mandatory basic qualification, regular driver training and driver qualification card are regulated by Act no. 280/2006 Coll.

Basic qualification

The basic qualification is the level of knowledge and practical skill required to drive a vehicle safely, for which a type D, D1, DE or D1E driving license is also required. The examination is performed after the end of the basic qualification courses, no later than six months after its completion, including the repeated examination, and its content is the following 3 categories:

- Improving rational driving behavior based on safety regulations;
- Application of regulations;

- Health, road and environmental safety, services and logistics [15].

First aid courses are also provided as part of the basic qualification course. However, the driver does not have to complete it if he has completed such a course as part of the training to obtain the relevant driving license in the last twelve months before the start of the basic qualification course. The certificate of basic qualification is a certificate of basic qualification, which is issued to the driver by the district office in the seat of the region on the basis of the test report.

Regular training

Regular training is an update of the level of knowledge and practical skills that a driver needs to perform his profession with an emphasis on road safety, defensive driving and the rationalization of fuel consumption. According to this law, defensive driving is safe driving, which will enable the driver to observe and predict risks in road traffic, using methods of not getting into a crisis situation. The driver must complete the first training until the due date of his basic qualification certificate and the second until the expiry date of the previous periodic training, which is issued for 5 years. Regular training courses are aimed at repeating and deepening the level of knowledge and skills provided in basic qualification courses. The certificate of regular training is issued by the district office in the seat of the region after the end of the course of regular training on the basis of a written application.

Driver qualification card

A driver who holds a certificate of basic qualification or a certificate of regular training shall be issued a driver qualification card by the district office at the seat of the region on the basis of a written application. Basic qualification and periodic training shall be indicated in the driver qualification card by a code. This driver qualification card can be replaced by a standard driver's license as long as the above-mentioned code is recorded in it.

Recruitment and selection of employees

Recruitment and selection of employees in the road freight transport company has been a problematic area of human resources management in Slovakia and throughout Europe in recent years. The main reason is a shortage of professional drivers around the world and their average age is rising every year. There are not only a few drivers, but with their age, many of them will soon retire. We are talking about an age category that began at the turn of the 1990s and is currently over 50 years old. This group is the most numerous in road freight transport, and when the time comes for retirement in about 10 years, there will be no one to replace them and the gap that is already created on a huge scale will be irreversible. The shortage of professional drivers in Europe has been a growing problem in recent years. The opening of borders and the employment of drivers from Eastern European countries have helped, unfortunately only temporarily. Where the "hole" of patchwork at the opposite end arose, and therefore in countries where drivers came to Western Europe for driver work and better conditions - especially salary - there was also a shortage of drivers. While Poland has improved these drivers by more than 185,000 drivers between 2013 and 2018 in Ukraine and Belarus, where these drivers mostly come from, they report an acute situation. Ukraine lacks 100 to 120 thousand professional drivers. In Belarus, the employment office is more interested in road freight drivers than nurses or doctors [16]. As we have said, the problem has only been solved temporarily because, according to the Union for International Road Transport, the European sector is facing the biggest driver shortfall in decades. Recent surveys have shown a driver shortage of 21%, meaning that every 5th position for road haulage driver is vacant. This is a very difficult task for employers not only in conducting interviews with potential new employees but also in the distribution and amount of work that will not be lost. However, this trend will not fall far from the next year, but on the contrary will rise rapidly, and it is expected that in this period (2020) it could be as much as 40%. This is in an industry such as road freight transport, which serves the daily lives of all of us, unimaginable and difficult to solve. To better illustrate this situation in specific numerical indicators, we will use Germany and England - two excellent economies and huge countries. While in England there are up to 50 vacancies a day in Germany, the average age of a driver is 47, which means that in 2027 about 40% of them will retire, creating a massive shortage of 185,000 vacancies [17].

Rewarding of employees

Remuneration is the feedback of the employer for the work of the employee. It is simply the monetary value that the employer gives to employees for their services [18]. Modern organizations and effective managers create a motivational culture gradually, through various ways of valuation [19]. Employees are remunerated according to the proper and legal principles of the Slovak Republic. Most often, drivers are paid from the number of kilometers traveled, of course unofficially, which suits some drivers, but other not. This favors employers who respect EC Regulation no. 561/2006, which regulates the remuneration of drivers in road transport. Under this regulation, the employer may not provide any remuneration, financial or non-financial, for the number of kilometers traveled or the number of tonnes of goods transported, as this could jeopardize road safety. Act no. 311/2001 Coll. however, it talks about minimum requirements and forms of driver remuneration [20]. One of the wage forms is also the so-called performance wage, which, however, may not, according to Act no. 462/2007 to motivate or otherwise encourage the violation of the driver's working hours. The time wage makes up the vast majority of the total wage and is determined by the time worked and the time spent in the vehicle, and thus in summary by the number of hours spent at work. Drivers also receive diets valid according to Act 401/2012 Coll., which sets the basic rates of meals for business trips abroad.

Employee motivation

The concept of motivation expresses the fact that in the human psyche there are specific, not always fully

conscious internal driving forces - motives, motives - which orient a person and his behaviour in a certain direction activate him in a given direction and maintain the aroused activity. Externally, the action of these forces then manifests itself in the form of motivated activity. Properly motivated people have clearly defined goals and take steps that they expect to lead to the achievement of these goals. Such people are motivated from within, which can be considered the best form of motivation. However, the vast majority of people need to be somewhat motivated from outside. Effects on the psyche of an individual from outside are referred to as stimulation and we define it as an external action as a result of which there is a change in human behaviour through a change in mental processes, through a change in his motivation. In the case of stimulation, it is therefore a process of conscious and intentional influencing the activity of another person [21, 22]. Motivation of employees is needed and will be needed as long as road freight transport depends on the human factor. Although there is a lot of talk about the impact of new information technologies that should replace the human factor (autonomous vehicles), this area is still only in the development and testing phase, and therefore the employee is one of the key factors for road haulage companies [23]. Currently, the area of human resources in road transport is experiencing a shortage of drivers. On the one hand, this can be addressed by increased motivation to recruit new staff, but many road transport companies are realizing that driver shortages will become an increasing problem and are starting to focus on autonomous vehicles and automated driving for logistics [24]. The motivation of workers in freight transport improves their work commitment, labour productivity and work performance, which in many cases contributes to increasing the operational and logistical capacity of individual companies operating in freight transport [25].

3. Discussion

According to our survey, the biggest problem in managing human resources in road freight transport companies is the lack of drivers, which deepened during the coronavirus crisis, insufficient financial rewards for the amount of work performed, unfavorable working conditions and the possibility of motivating employees. The labor force in road transport is aging, but the arrival of a new generation is limited by law. On 28 October 2019, the National Council of the Slovak Republic approved an amendment to the Road Traffic Act, which in its original wording also included a reduction in the age for road haulage drivers from the current 21 years to 18 years. It is not a major problem of lack of drivers, but a young person wants to get a job after high school but discourages him when he is not old enough to do so, so he chooses another industry. The nature of the driver's profession has changed, and more and more demands are being placed on the driver. He has to master the rules for his work, a foreign language and also the increasingly demanding technologies in the vehicle. The driver's responsibility grows and if he works well, he also evaluates the whole company in the given environment.

In Europe, about a fifth of the posts of professional drivers are currently filled. Of the total number of drivers, only 2% are women. An increase in the number of women professional drivers could solve the problem of lack of drivers. However, in order to make this profession more attractive to women, working conditions and safety need to be improved. Nor can the ongoing automation process be relied upon. The fact that the automation of road freight transport is so often mentioned when mentioning the problem of the lack of drivers is only a path to the worse. In fact, humanity is not close to achieving fully automated road freight transport, and therefore young or new potential drivers then do not see perspective and the future in this profession.

As part of improving working conditions, it is important to ensure more safe car parks and safety for drivers. Safe parking spaces are an important part of this work, as it often happens that semi-trailers are stolen in their sleep, often injuring the driver and causing huge material damage. The potential danger also stems from possible sexual harassment, etc. Secure car parks should be set up across Europe by motorways so that the driver does not have to take a rest period in the car park of a petrol station or a rest area without a camera system.

The Council of EU in April 2020 adopted a major reform of the EU road transport sector, known as the mobility package**.** The new rules will improve drivers' working conditions, introduce special posting rules for drivers in international transport, and update provisions on access to the haulage market. The new rules are designed to ensure a balance between improved working and social conditions for drivers and the freedom to provide cross-border services for operators, and will also contribute to road safety. In addition, they will provide clarity for the sector regarding previously ambiguous provisions and put an end to their uneven application between member states. The package consists of a regulation governing access to the road haulage market and to the profession of road haulage operator or road passenger transport operator; a regulation on maximum work and minimum rest times for drivers and positioning by means of tachographs; and a directive revising enforcement requirements and laying down rules on posting of drivers.

The motivation of the employee himself is relatively key as its absence can lead to a breach of the very safety of the transport of goods and also to a certain waste of resources of the transport company, which will ultimately be reflected in the economic results of the transport company [26]. Motivation itself can take several forms, not only as direct benefits for the drivers themselves, but also indirect benefits, such as the fact that the road haulage driver drives an ecological car with alternative fuel, which increases his sense of awareness that his activity - driving such a vehicle contributes to the protection of the climate and the environment [27]. An important factor in motivating employees in road transport is also the corporate culture of the company in which drivers work. 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 [28].

4. Conclusions

The human factor is the most important element in the road freight transport company for the fulfillment of company goals, when fulfilling them the employees apply their professional and qualification preconditions, they realize their work motivation. Employees interact with all other factors, because all partial management processes are implemented by people. The knowledge, skills and abilities of employees complement each other and create a new quality for the company, there is a synergistic effect. Suitable employees, with their professional and qualification profile and mutually coordinated activities, implement and use all other critical factors; the overall success of a company is therefore based on the human factor. Demands for human potential, alignment of employees' activities with the company's goals need to be managed. From the point of view of human resources management, all its functions are critical, starting with human resources planning, recruitment and selection of employees, their evaluation, remuneration, motivation, education and development, as well as care for the work environment and relationships. In the conditions of road freight transport companies, it is necessary to combine the modern understanding of personnel activities with the requirements of legislation and the turbulently changing external conditions of a globalized world.

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Utilization of Tribodiagnostics for the Evaluation of Technical Condition of Mechanical Gearboxes

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Abstract

This paper focuses on the evaluation of the technical condition of a mechanical four-speed gearbox, which is permanently fixed to a mechanical two-speed auxiliary gearbox of a passenger off-road vehicle. To monitor the technical condition of the mechanical gearbox, we used one of the diagnostic methods, which in this case was tribodiagnostics. The mechanical gearbox was monitored throughout its lifetime until failure occurred. The article describes in detail the test equipment on which the technical condition of the mechanical gearbox was monitored. A device that works on the basis of atomic emission spectrometry was used for the evaluation of oil samples taken from the gearbox. The abrasion metal content in the gear oil was monitored by this device. The aim of the experiment was to monitor the technical condition of the mechanical gearbox with a focus on the wear of individual gears and rolling bearings in the mechanical gearbox. The article presents the results of the experiment with a verbal commentary on the technical condition of the mechanical gearbox.
KEY WORDS: *tribodiagnostics, atomic emission spectrometer, technical condition of mechanical gearbox*

1. Introduction

Tribotechnics is a field that uses knowledge from the research of friction, wear and lubrication in order to reduce the coefficients of friction, or optimize the friction process and reduce the wear of mutually moving bodies. Tribotechnical methods of diagnostics use the lubricating medium in complex mechanical closed systems as a source of multidimensional, complex information about processes, changes and wear regime, which take place in the systems. Tribotechnical diagnostics solves two major issues:

- detection of the condition, extension of applicability and prediction of lubricating oils degradation;
- detection of the mode, location and trend of wear of the mechanical system (vehicle combustion engine, gearbox, hydraulic system, etc.) by assessing the presence of foreign substances in the lubricant, both quantitatively and qualitatively.

Monitoring of operational degradation of oils is performed by simple operating methods, chemical (analytical) methods (set by state standard) and special tribodiagnostic methods.

Detecting wear of mechanical systems lubricated with oil is based on the recognition that the oil has a certain percentage of impurities after a specific period of operation. It is mainly the metal abrasion (wear particles) that is dispersed in the oil and which, after quantification by some suitable method (e.g. atomic emission spectrometry, spectral analysis, polarography, ferrography, etc.) enables indirect monitoring of mechanical changes in the oil-containing system. Certain conclusions are drawn from the observed amount of metal abrasion, growth intensity, shape, size and material composition, etc. The severity of the failure and the urgency of corrective action can be inferred from the above parameters. An important diagnostic circumstance is the possibility of locating the site of increased wear. Depending on the type of metal abrasion and if we know the material of the lubricated and rinsed parts of the system, it is possible to determine the friction pair in which the degradation wear increases sharply [1].

2. Program of Monitoring the Technical Condition of Mechanical Gearboxes Using Gear Oils

In order to provide sufficient efficiency, the mechanical condition monitoring program should include the three following categories of analysis:

a) analysis of gear oil properties (lubricant properties);
b) analysis of gearbox oil contamination (external contamination of lubricant);
c) analysis of particles in the oil (contamination of the lubricant due to wear - inside the equipment).

ad a) The basic function of the gearbox oil analysis is to help determine the basic properties of lubricating fluids. Many factors, including time itself, can change important physical and chemical properties of the liquid. If left unnoticed by the user, unsatisfactory grease can unexpectedly destroy the gearbox of the vehicle, causing extensive damage and prolonged shutdown.

The standard to which oil properties should be compared are those of the new gear oil. If some of the properties of the new gear oil are not known precisely, effective monitoring of the oils used is impossible. The first step will be to

determine the properties of the new gear oil and this step should be repeated each time the gear oil is replaced with a different one. When testing used oils, it is also important to use always the same laboratory, the same instruments and procedures as when determining the properties of a new gear oil.

Depending on the environmental characteristics and the type of vehicle group in which the lubricant is used, the choice of test characteristics may vary. Common tests include kinematic viscosity, total acid number, total alkalinity number, infrared analysis (e.g. content of antioxidant and anti-abrasion additives), and emission spectrometry (e.g. additive elements, such as zinc, molybdenum, calcium). When a lubricant fails due to oxidation processes, many properties of the lubricant often change exponentially. Early detection at the beginning of the failure can prevent costly intervention. The risk grows with increasing efforts to extend the gearbox oil change periods up to the so-called lifetime gearbox oil.

ad b) The analysis of the gearbox oil contamination is related to the operation of a motor vehicle, where it is common for undesirable contaminants to enter lubricating oils. In fact, for most groups of motor vehicles, solid dirt is the number one cause of friction-related failures. Water can also enter the mechanical gearboxes when driving over a water hindrance; then water is in contact with the mechanical gearboxes. These may be the major causes of failure of the lubricant essential functions [2].

Many users do not realize that even if they use new, high-quality lubricants, particles and other contaminants can penetrate the gearbox oil and cause corrosion and malfunction of the vehicle gearbox. Therefore, when engine oil contamination is regularly monitored and controlled, important objectives for the proactive maintenance and durability of mechanical gearboxes of motor vehicles are achieved [3].

ad c) Analysis of particles in gear oil is used to determine the presence of wear particles in mechanical gearboxes. It helps to monitor the technical condition of mechanical gearboxes in motor vehicles. The lubricant serves only as a carrier or source of information to be obtained. As friction increases, the number of larger particles, the size, shape and concentration of the particles increase. These allow us to monitor the internal condition of the friction surfaces and to indicate the type of wear.

The most commonly used methods for determining the presence of particles in gear oil are the following:

a) *atomic emission spectrometry* used to determine the abrasion metal content in the gear oil (for example, iron, aluminium, copper, chromium and lead). The method is suitable for the determination of metals in the samples of gearbox oil, engine oil, hydraulic fluid, biological samples and for environmental control, industrial application, analysis of geological samples, etc. Atomic emission spectrometry is a suitable method for single element analysis of samples with high variability in composition, where the number of metals to be determined in the sample is small but their selection varies. This method is described in more detail in the next chapter because it was used for the analysis of gearbox oil samples from a mechanical gearbox [2];

b) *atomic absorption spectrometry* is one of the most widespread analytical methods of trace element analysis. It allows the determination of nearly seventy elements, all metals and metalloids, in concentrations from tenths of grams to concentrations lower than 1 μg. The atomic absorption spectrometry (AAS) is based on the specific absorption of monochromatic radiation by free atoms of the monitored element in the ground electron state. This technique is used in the operating materials analytics mainly for the measuring of wear metal quantities, e.g. Fe, Al, Cu, Sn, Pb, Zn, etc. The principle of the AAS is the absorption of radiation by free atoms in gaseous state, while it is necessary to atomize the sample before the analysis [2];

c) *ferrography complements emission spectrometry*. This method makes it possible to determine the particle size, shape and material. The wear detection in mechanical systems lubricated with oil is based on the knowledge that after a certain period of operation the oil reflects the state and operating conditions. This information is delivered, for example, by a metal abrasion that is dispersed in the oil and which, after quantification by a suitable method, allows indirect monitoring of mechanical changes in the system in which the oil is used. Image analysis is currently being applied. It uses a microscope attached to a computer for particle evaluation; therefore, subjective evaluation is not necessary. Within the analytical ferrography, individual particles are evaluated microscopically. They bear information on the actual technical condition of the lubrication system and lubricated parts as well as on the wear of individual friction pairs. The evaluation of the ferrogram is performed on a bichromatic (special) microscope created by a combination of a biological microscope for examining transparent preparations. Particle image evaluation software is used for the actual particle evaluation [2];

d) *infrared spectrometry FTIR* (Fourier Transform Infrared Spectroscopy) is based on the absorption of infrared radiation as it passes through a sample that changes the rotational vibrational energy states of a molecule in dependence on the changes in the dipole moment of the molecule. The resulting infrared spectrum is a functional dependence of energy, usually expressed as a percentage of transmittance or absorbance units, on the wavelength of incident radiation. The advantage is high speed compared to other methods and small amount of sample needed. Infrared spectrometry is a method designed primarily for the identification and structural characterization of organic compounds and for the determination of inorganic substances (antioxidants, water, carbon black, oxidation, nitration, sulfation and glycol). An unknown analyzed sample can be identified using special software and digitized libraries of infrared spectra. The spectra analysis is based on the knowledge of wavelengths corresponding to specific compounds or characteristic structural groups [2];

e) *laser counters and particle classifiers*. This method is unique for its multi-function in the field of tribodiagnostics. The device uses advanced algorithms (fuzzy logic, neural networks) for particle analysis and allows to determine the number of particles and wear fragments and their size distribution, to identify the particles according to their mechanism of occurrence, to sort the analyzed particles (separate impurities, water, air bubbles, etc.), to statistically

process the results (number of particles per 1 ml, maximum and average particle size, mean values, standard deviation, analyzed volume, number of digitally processed images, etc.), to inform about each class of wear (adhesion, abrasive, fatigue, total number of particles), to calculate and draw trend lines, i.e. predict possible future technical state, present results in pictorial, tabular, graphical form (histograms), etc. The result of the analysis is information about the condition of the gear oil and especially information about the current wear mode and technical condition of the equipment from which the oil sample was taken. This is the case of the mechanical gearbox of a motor vehicle. The device records all particles up to 100 μm and also detects air bubbles that the software excludes from the calculation if they are larger than 20 μm. The measurement is done automatically and extends the image analysis capabilities by assigning particles according to shape to groups and type of wear [2].

3. Experiment Description

The experiment measuring the life of the mechanical gearbox was carried out on a test stand (Fig. 1) at input speed of 2000 rpm. During the experiment, the mechanical gearbox worked 3613 hours, which is about 160000 km on a given motor vehicle. During the entire experiment, the gears were shifted as if the manual gearbox was used in normal operation.

Ten experts were approached and on the basis of their expert opinions, gear shifting was carried out in the main and auxiliary gearbox. The mechanical gearbox was also loaded as in operation during the experiment, which was one of the basic rules of the measurement. The Air-cooled brake AHB-12 and Control unit for break AHB12 (see. Fig. 1) were used to simulate driving resistances.

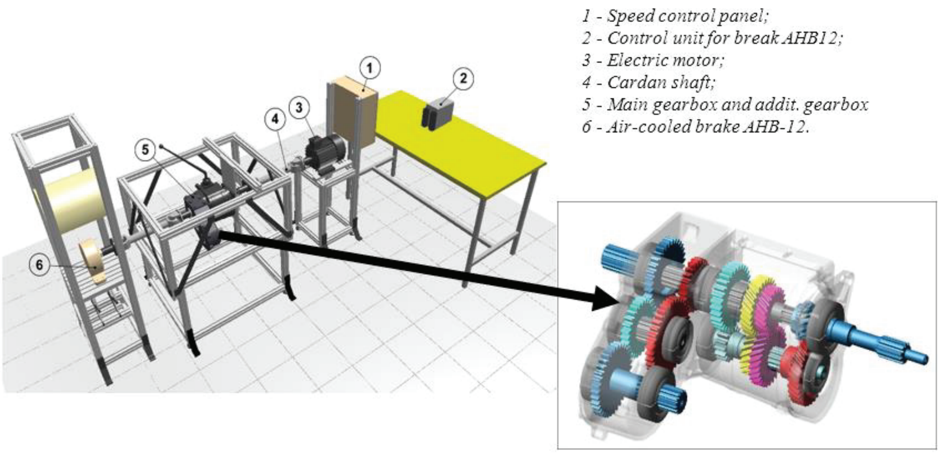

Fig. 1 Testing stand for acoustic and vibrating measurement – 3D model [4, 5]

Atomic emission spectrometry with a rotating disc electrode was used for the analysis of samples taken during the lifetime of the mechanical gearbox (Fig. 2). The principle is that the element's atoms in plasma of several thousand degrees emit ultraviolet or visible radiation, which after decomposition in the spectrometer gives a line spectrum.

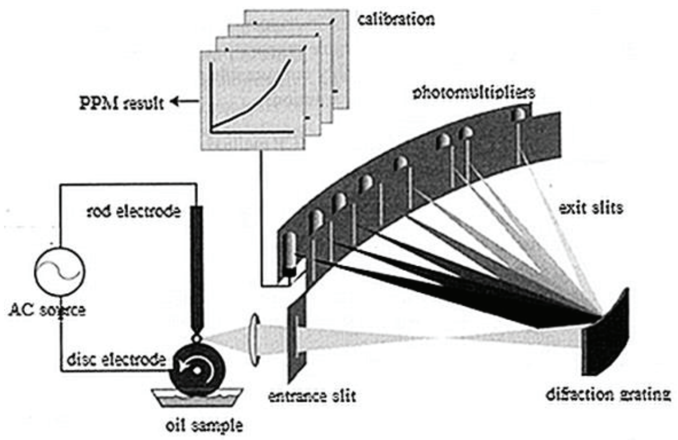

Fig. 2 Diagram of atomic emission spectrometer with rotating electrode [2]

Individual lines of these sets correspond to spontaneous transitions of excited valence electrons from higher to lower energy levels. The energy released at the transitions is emitted in the form of radiant quantities (photons) with a wavelength given by the difference in energy of the higher and lower energy levels. The fact that each element emits a characteristic atomic spectrum under the above conditions, the lines of which have a precisely defined and constant wavelength according to that relationship, is used in the spectral analysis. The emission spectra of the atom are complex,

with the number of lines rising from a few tens in the alkali spectra to several thousand lines in the spectra of iron, tungsten, titanium, and vanadium. Therefore, only some lines are used to prove this, especially those with high concentration sensitivity expressed as the lowest element concentration at which the respective line can still be observed in the spectrum under the given conditions. The most intense lines of a given element spectrum always correspond to the energy transitions between the first excited and the basic energy level. Transitions between the excited and the basic energy level always correspond to intense lines of the spectrum. These lines are called the last or residual lines, because the gradual decrease of the element's concentration in the plasma will disappear from the spectrum last.

4. Results and Discussion

In the main and auxiliary mechanical gearboxes, gear oil 80W/90 was used, which is intended for the said gearboxes. The gear oil 80W/90 is produced from selectively refined components of petroleum origin. The base oil must be treated with at least an antifoam, antioxidant, high pressure and anticorrosive additive, additive increasing viscosity index and a friction modifier so that the final product meets all the required characteristics. The application of additives with chlorine and residual dark oils is not permitted. Gear oil SAE 80W/90, API classification GL-5 has been designed for year-round lubrication of mechanical gearboxes and transmissions with high pressures in gears and hypoid gears working under various combinations of high speeds, high loads and impact loads in trucks and passenger cars for which the oil of the given viscosity and performance class is prescribed.

As part of the experiment, 32 samples were taken from the main gearbox and 32 samples from the additional gearbox. Then 3 measurements were made for each sample and an arithmetic mean was subsequently produced. This was performed due to measurement inaccuracies. Metal and non-metallic particles in the gear oil were monitored as part of the measurement, namely the presence of iron, copper, chromium, silver, aluminium, boron, barium, calcium, cadmium, potassium, manganese, magnesium, molybdenum, nickel, phosphorus, lead, silicon, tin, titanium, vanadium and zinc. Based on a detailed analysis, three elements were selected, namely iron, copper and chromium due to a change in the amount in ppm of these particles in the gear oil. Other elements were also present in the gear oil in small quantities except boron and lead. These elements did not change in quantity over kilometres during the experiment.

The Fig. 3 shows the results of measurements over the life of a mechanical gearbox from a passenger off-road vehicle with a combustion engine. In the graph, three elements are monitored for which changes occur over the lifetime. These elements include iron, copper and chromium. These elements were monitored in both the main gearbox and the additional gearbox. It can be seen here that the course of the individual elements in the main gearbox and the additional gearbox is similar. In the gear oil, the greatest presence of iron is caused by the wear of individual gears and rolling bearings that are made of steel.

Based on a detailed analysis of the presence of selected wear particles in the gear oil, depending on the lifetime of the main and additional gearboxes, we conclude that the life of the gearbox as a whole is 140000 km.

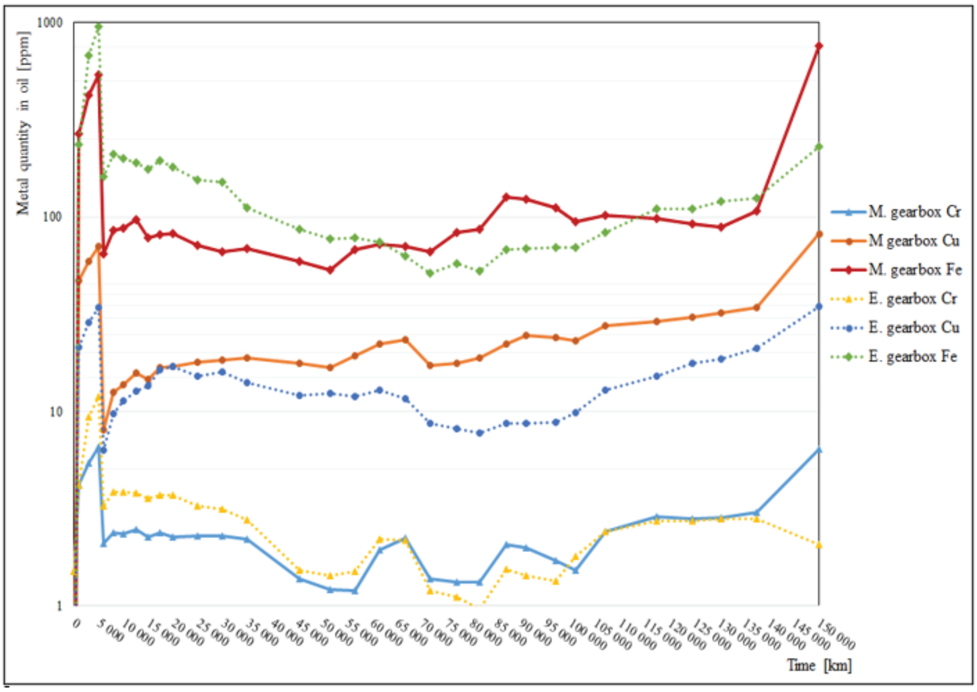

Fig. 3 Presence of selected metal and non-metallic elements in gear oil 80W/90 in logarithmic decimal scale

5. Conclusion

The aim of the experiment was to monitor changes in the properties of gear oil 80W/90 in the main and additional

mechanical gearbox of a passenger off-road vehicle. Based on continuous monitoring of the gear oil properties, we continuously evaluated the technical condition of these two groups. Based on the analysis of the monitored elements, a summary Fig. 3 has been constructed, where we conclude that the maximum effective lifetime of the main and additional mechanical gearboxes is around 140000 kilometres, based on the presence of wear metal and non-metallic elements. These values are in accordance with the values that were observed using vibration diagnostics and acoustic diagnostics.

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Modeling the Quality of Current Collection Under the Conditions of a Growing Speed of Rolling Stock

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Abstract

The use of high-speed electric rolling stock necessitates increased requirements for the reliability of its operation. Particular attention should be paid to the interaction of the contact line with current collectors. An important area is the development of tools for modeling the interaction of catenary with current collectors. At present, in some sections of railways, there is a need to increase the speed of trains and adapt the requirements for the design of the contact lines, which allow to the owner of the infrastructure to achieve the correct parameters for dynamic interaction on the pantograph-contact line interface in the point of view of the requirements of Energy TSI. In this work the authors discussed the problem of the equivalenting the contact line during the simulation.
KEY WORDS: *catenary, interaction, pantograph, simulation, equivalenting*

1. Introduction

Authors of the article discussed the problems of modeling of the interaction of the contact line and pantograph and validation of the simulation according to standard PN EN 50318: 2019-02. The questions of improving the design of contact lines and pantographs were discussed from the moment of the emergence of electrified railways. Currently, it is well known that the achievement of optimum quality of current collection in terms of economic feasibility can be achieved only by ensuring uninterrupted contact at the point of contact of the contact line and the pantograph. To date, the issue of minimizing the cost of servicing the infrastructure of electrified railways for the transmission of electricity for traction need remains important and relevant. An important aspect, even at the design stage, is the selection of the optimal parameters of the contact lines and pantographs for specific operating conditions which can be realized by modeling of their interaction.

2. Main Material

Mathematical simulation of the dynamic interaction of pantographs and contact line is an effective tool for the development and improvement of contact line systems. Simulation allows us to study the influence of the parameters of the contact line and current collectors on the quality of the current collection without conducting expensive full-scale experiments. Conceptually mathematical models of contact lines, pantographs and models of their interaction can be divided into analytical and simulation models. But it should be emphasized that any model should be tested for adequacy. Analytical models, in turn, can be divided into models with lumped parameters and distributed ones. The most known models are presented in Table 1.

Table 1

The programs for modeling interaction between overhead contact line and pantograph [18]

Model	Producers
CATMOS	Germany (Balfour Beatty)
SICAT Dynamic	Germany (SIEMENS)
PrOSA / SIMPAC	Germany (HNI Institute at the University of Paderborn + DB Research and Technology Center)
OSCAR	France (SNCF + SDTools)
INPAC	France (Alstom)

The creation of adequate models for the interaction of current collectors and contact line with a high degree of detail of these systems is a complex science-intensive task. In accordance with international experience, it can be most effectively solved with the cooperation of specialists in the subject field (contact lines and current collectors) with specialists in the field of applied mathematics. One example of a model with lumped parameters, which also takes into account dynamic processes, though with a number of assumptions, is a model in which, when determining the trajectory of the pantograph and the tension curve along the run, are generally given the maximum run in the anchor section. It is

divided into a number of individual segments. The distributed parameters are replaced by concentrated and reduced to the point of contact. This model does not allow to fully take into account the oscillation processes that occur during the interaction of the pantograph with the contact line, but based on a large number of experimental studies, the accuracy of model prediction was improved by introducing correction coefficients. It is relevant for contact lines designed for speeds up to 160 km/h.

An example of a model with distributed parameters is a model where a contact line is presented as a system with distributed parameters, the catenary wire and the contact wire are replaced by a single wire, which has a total pressure and mass [1]. This conditional wire has an arrow deflection of the real contact wire, and its energy is equal to the potential energy of the contact line. A typical example of the application of the finite element method in modeling problems of interaction of contact lines and pantograph was the method of calculating the interaction on the basis of the modified finite element method [2].

When studying the interaction process of the catenary with current collector, it is especially important to take into account all factors that have a significant and systematic impact on this process. In [3], the authors present the results of using a numerical model, which takes into account the detailed design of the upper part of the current collector. The lower and upper frames of the current collector are represented by one concentrated mass, and the double slide WBL 88, unlike standard models [4], is presented as two separate masses, each of which is connected to the frames by spring-damping connections. The results presented in the work show that the first current collector slide in the runs of the electric rolling stock receives greater mechanical loads (dynamic pressure, shocks) than the second. This corresponds to the results of studies presented in [5, 6]. But the authors of work [4] mentioned that this phenomenon is not thoroughly studied - the model presented in the work does not take into account the possibility rotation of the current collection double slide.

A significant error in comparing the simulation results with the experimental ones is also present in [7]. OSCAR software [8] is a three-dimensional finite element model of the catenary, that interacts with the current collector. The current collector is presented in the form of a three-mass model. The number of current collectors may increase - the model becomes multi-mass. This software is aimed at analyzing the distribution of tension along the contact wire, its aging processes, the interaction of the contact line with the current collector. But it should be noted that the simulation results using the OSCAR software significantly depend on the type of current collector model. To achieve sufficient accuracy of results, it is necessary to conduct a number of complex experimental studies.

Also, insufficient detailing of the catenary elements along the anchor section degrades the quality of modeling its interaction with current collectors. In [9] the basics of development the catenary finite element model and four-mass model of current collector are described, it is a part of software package called CALPE 6.0 and is a modern implementation of PANDA [10].

But it should be noted that despite the software implementation of the developed catenary finite element model and current collector, as well as its use by a separate division of Adif Spanish railway company Renfe, this software does not take into account such parameters as spans of different lengths in the anchor section, number of drops in the span, change the catenary height along the anchor section. The proposed methodology for the study of the catenary dynamic interaction with current collectors in [11] shows that an important factor for rating the catenary interaction with the current collector is the air flow. The catenary is represented as a finite element model, and the current collector - as a multi-mass model. At the same time, different time integration algorithms are used for the catenary and current collector.

Current collection quality assessment

For evaluation, the criteria adopted in world practice are used in accordance with international standards [18,19]:

- IEC 60913. Railway applications - Fixed installations - Electric traction overhead contact lines;
- EN 50119. Railway applications - Fixed installations - Electric traction overhead contact lines;
- EN 50367. Railway applications - Current collection systems - Technical criteria for the interaction between pantograph and overhead line (to achieve free access);
- "TSI Energy". The technical specification for interoperability relating to the energy subsystem of the trans-European high-speed rail system - 2002 and 2008 editions;
- EN 50317. Railway applications - Current collection systems - Requirements for and validation of measurements of the dynamic interaction between pantograph and overhead contact line;
- EN 50318. Railway applications - Current collection systems - Validation of simulation of the dynamic interaction between pantograph and over-head contact line;
- EN 50206-1. Railway applications - Rolling stock - Pantographs: characteristics and tests. Pantographs for main line vehicles. - European Standard, CELENEC, 1999;
- UIC 794. Pantograph-overhead line interaction on the European high-speed network;
- UIC 794-1. Pantograph / overhead line interaction for DC-electrified rail-way lines;
- UIC 799. Characteristics of ac overhead contact systems for high-speed lines worked at speeds of over 200 km/h;
- UIC 799-1. Characteristics of direct-current overhead contact systems for lines worked at speeds of over 160 km/h and up to 250 km/h.

The main criteria for assessing the quality of current collection are based on a statistical analysis of contact force. At present, during simulations, presenting current collectors as 2 and 3 mass models is sufficient [12-17].

Simulation program validation

To ensure an adequate assessment of the catenary operation and current collectors, as well as the possibility of comparing the simulation results with experimental ones, it is mandatory to conduct experimental studies using specialized diagnostic tools and in accordance with PN EN 50318 [17].

To validate the model, the results of the calculation of the dynamic interaction of the reference models of the current collector and contact line with normalized data are compared in accordance with the standard. The reference model of the catenary consists of 10 identical spans 60 m long; The reference model of the current collector is two-mass. Simulation is performed at two speeds of 250 and 300 km / h. Checking the model is carried out on the basis of an analysis of the values of eight parameters characterizing the process of interaction between the current collector and the contact line.

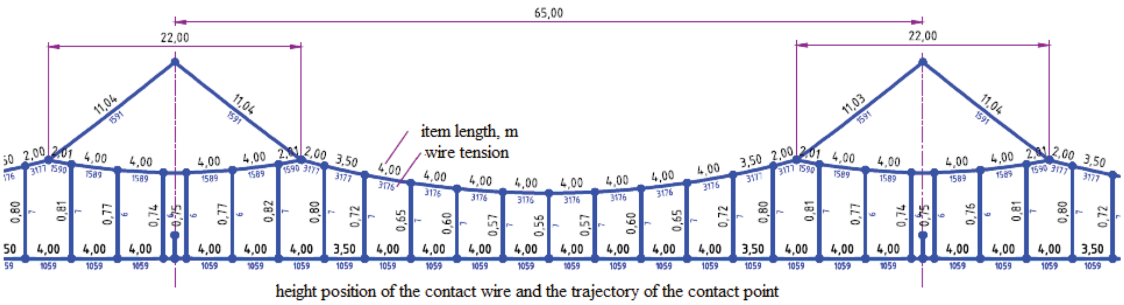
The model validation stage is considered passed only if all parameters fit into the ranges of values normalized by the standard (Table 2) [17]

Table 2

Range of results from reference model

	Range of results	
Speed [km\h]	250	300
F_m [N]	110 to 120	110 to 120
σ [N]	26 to 31	32 to 40
Statistical maximum of contact force [N]	190 to 210	210 to 230
Statistical minimum of contact force [N]	20 to 40	-5 to 20
Actual maximum of contact force [N]	175 to 210	190 to 225
Actual minimum of contact force [N]	50 to 75	30 to 55
Maximum uplift at support [mm]	48 to 55	55 to 65
Percentage of loss of contact [%]	0	0
NOTE The value in the table are based on results from five independent simulation methods. These methods have been checked with results from line tests		

The problem of equivalenting of contact line during simulation



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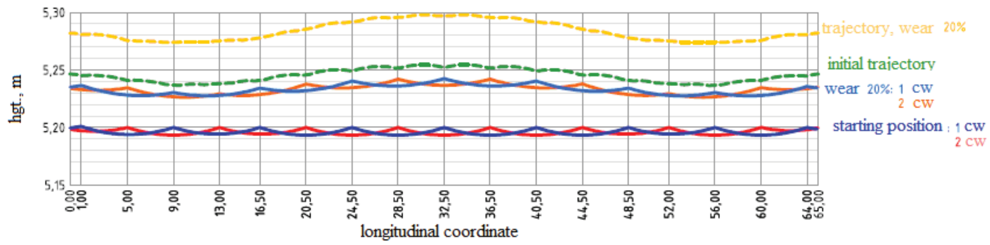

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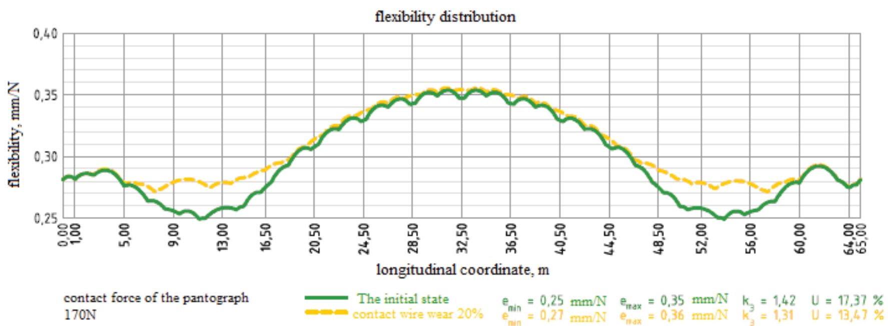

c

Fig. 1 Static model of the suspension 2C120-2C-3 (curves are shown for constant contact force 170 N) a) the design scheme of the contact line; b) the position of the contact wire in the initial state and with constant contact force (with zero wear and 20% wear); c) flexibility of contact line with zero and 20% wear

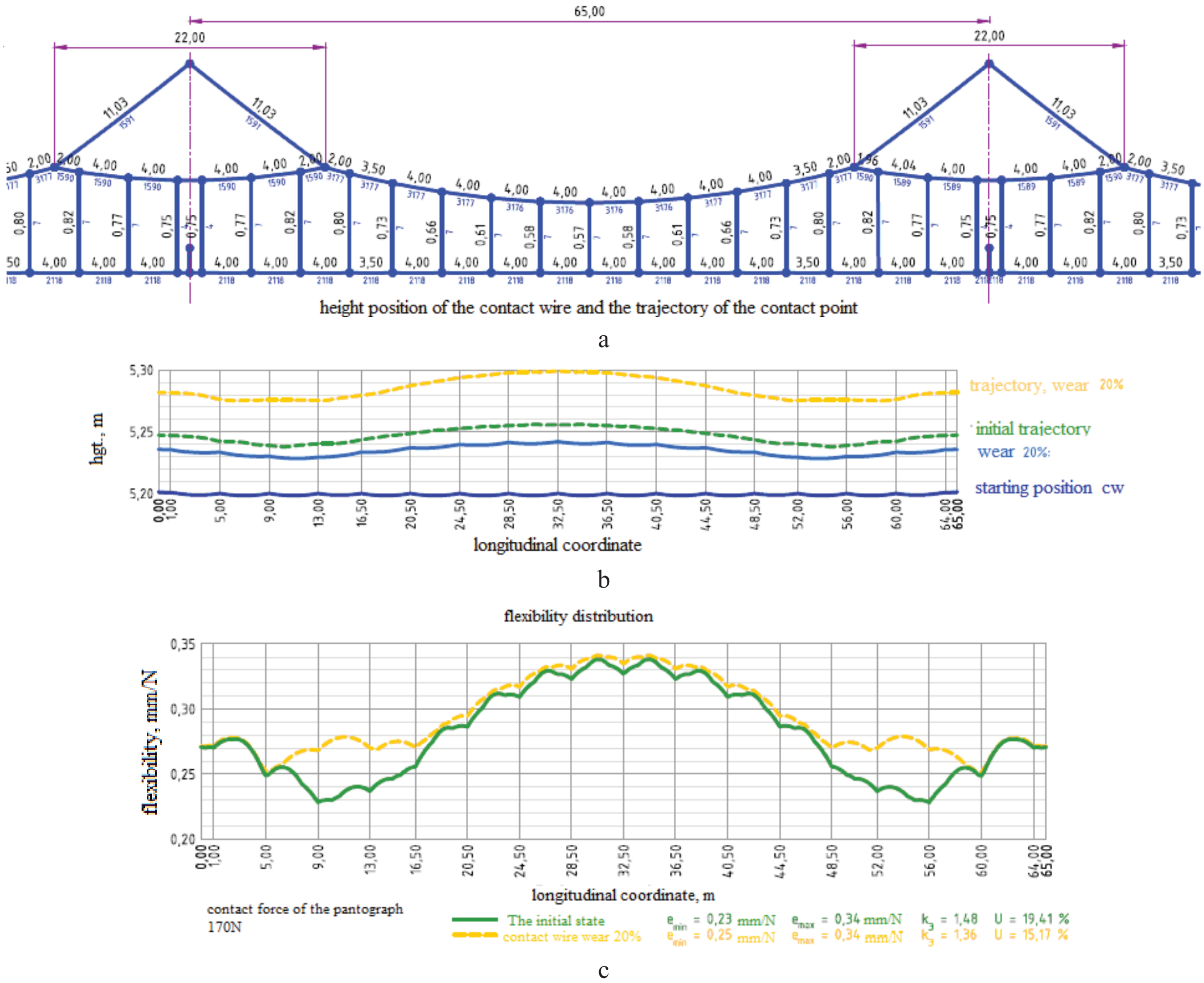

Fig. 2 Static model of equivalent contact line (curves are shown for constant contact force 170 N); a) the design scheme of the contact line; b) the position of the contact wire in the initial state and with constant contact force (with zero wear and 20% wear); c) flexibility of contact line with zero and 20% wear

At present, in some sections of railways, there is a need to increase the speed of trains and adapt the requirements for the design of the contact lines, which allow the owner of the infrastructure to achieve the correct parameters for dynamic interaction on the pantograph-contact line interface in the point of view of the requirements of Energy TSI. Proposed changes to the contact line parameters that the Contractor will propose to obtain the correct dynamic interaction parameters on the pantograph-contact line interface should be verified by simulation. The presented models and recommendations should take into account the parameters of the contact line based on safety factors in accordance with PN-EN 50119. In addition, it is important in this regard to study the influence of contact wire wearing on a structurally adapted contact line, which allows its operation at high speed, and determine the maximum contact wire wearing, for which the parameters determining the correct dynamic interaction will correspond to the limits given in TSI Energy. At the maximum percentage of wear of the contact wire, it is necessary to take into account the influence of the tension of the wires (if it changes as a result of the recommendation) on their mechanical strength, as well as questions regarding the interaction at the contact point of the pantograph-contact line due to changes in the mass of the contact wires.

Therefore, at the stage of dynamic simulation of the interaction of the contact line and the current collector, the problem of equivalenting the contact line is important. For example, the contact line 2C120-2C-3 [20], which is operated on Polish railways, has a double catenary wire and two contact wires. Below are the results of the equivalentization of this catenary by replacing the contact wires with a single contact equivalent wire and replacing the dual contact wire with an equivalent one wire (Figs. 1-2).

The equivalent error in representing the flexibility of the contact line can be found by the formula:

$$\delta = \frac{1}{N} \cdot \sum_{i=1}^{N} \frac{|e_i - e_{ecvi}|}{e_i} \cdot 100\%, \tag{1}$$

where N is the number of measurements in the simulation; e_i - the flexibility of the original contact line; e_{ecvi} - flexibility of the equivalent contact line.

The calculations by Eq. (1) showed that the equivalent error in the above case varied within 2-10%.

3. Conclusions

Today there are a large number of tools for catenary, current collectors and their interaction modeling, but each of them has limited application. A promising direction in the development of catenary simulation models is the application of the finite element method, and for the modeling of current collectors it is common to use multi-mass models. In operation, there are often problems of increasing the speed of trains on the electrified section. In this case, it is necessary to simulate the dynamic interaction of the contact line and pantographs. It is important to equivalent the real contact line, to replace the double wires with equivalent ones. It has been shown that the error from elasticity equivalentization varies from 2 to 10%, which may be sufficient for simulation without model restructuring procedures (especially if the finite element method is used).

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The Simulation Model of Ventilation Systems for Ship's Enclosed Spaces

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Abstract

The article presents the results of research of simulating the ventilating schematics for ship's enclosed spaces (pantries; propeller shaft tunnel; locations of fuel tanks, ballast tanks, storage tanks) when performing the welding work in them by means of one of the methods of computational fluid dynamics (CFD). The problem statement of the research is associated with the fact that in full-scale conditions, it is impossible to study a general picture of the contamination of ship's enclosed spaces at different relative arrangements of openings for supplying clean air and removing contaminated one. The research was carried out using a set of developed simulation models of the distribution of air flows throughout the space, on the basis of which, taking into account the findings made, in the article the recommendations for selecting the ventilating schematics for ship's enclosed spaces when designing the ventilation systems for such spaces are given. The recommendations can be used both when arranging temporary ventilation systems for ship's enclosed spaces in the process of repair work on the ship, and when designing stationary process-related ventilation systems for such spaces before beginning her construction.
KEY WORDS: *ship's enclosed spaces, computational fluid dynamics (CFD), visualization of air flows, simulation models, solid models, ventilating schematics*

1. Introduction

It is known that ship repair is associated with a significant scope of work, in the process of which harmful substances are emitted directly to the ship's spaces [1].

A number of ship's spaces are small enclosed spaces (compartments of the ship) without any ventilation systems. According to existing concepts, ship's enclosed spaces include various process-related spaces (pantries; propeller shaft tunnel; partition-off room of auxiliary boiler; locations of fuel tanks, ballast tanks, storage tanks) [2]. In addition, on some oil and chemical tankers, special deckhouses are installed to site the liquid nitrogen tanks in them, which, of course, also belong to ship's enclosed spaces, and where it is necessary to maintain a certain air temperature regime.

The operating conditions of such spaces or the performance of repair work in them require the ensuring of supplying a sufficient quantity of clean air and the removing an appropriate volume of air with harmful substances generated when conducting the process operations - cleaning, cutting, welding, painting, etc.

The choice of a rational schematic for ventilating a ship's enclosed space should be made on the basis of simulation modeling of the aerodynamics of air streams and engineering calculations, as a result of which technical parameters and a design solution of the supply and exhaust ventilation system that will be used during the period of performing the repair work in this space are determined.

Enclosed spaces on ships of any type differ in their volume and configuration, and their number can reach 30–40 units per ship. In addition, structurally, such spaces can have internal ribbing, which significantly affect the aerodynamics of ventilation streams.

Therefore, when simulating the schematics of supply and exhaust ventilation for ship's enclosed spaces, it is rational to consider these spaces as two different types: type 1—enclosed spaces without ribbing; type 2—enclosed spaces with ribbing. Without preliminary simulation for both types of spaces, it is impossible to determine the effective relative arrangements of openings for the supply and exhaust duct stubs, at which the necessary sanitary and hygienic parameters of air are maintained at the workplace.

Simulations of air flows can be performed using specialized software (for example, SolidWorks Flow Simulation) [3]. This software implements numerically solving the Navier–Stokes equations (including the continuity equation), the law of conservation of energy, and performs three-dimensional visualization of air flows together with solid objects (internal or external task). The adequacy and accuracy of the computational mathematical simulation model is determined by the totality of factors and assumptions taken into account in simulation modeling [4].

When selecting ventilating schematics for various types of spaces, computational fluid dynamics (CFD) simulation gives fairly accurate and reliable results of the distribution of air streams, velocities, pressures, and temperatures, on the basis of which it is possible to carry out the development of design solutions for real ventilation systems. Therefore, when

elaborating rational ventilation schematics for ship's enclosed spaces, a set of computational fluid dynamics (CFD) simulation models of air flows in such spaces was developed with various arrangement combinations of openings for supply and exhaust air.

Computationally simulating air flows in a particular enclosed space consists of two stages: the first stage is creating the model (models) of solid object; the second one is creating the model (models) of air flows.

2. A Description of the Research and Pictorial Representation of the Results Obtained

When conducting the studies, two types of spaces were taken into consideration (without ribbing and with ribbing). For clarity, simplification, and the possibility of comparing the results of the experiment, the geometric dimensions of the spaces of both types were taken the same. Analyzing the air flows was conducted taking into account the results of the modeling carried out by the method of electro-hydrodynamic analogy (EHDA), which are given in [5].

As a source of polluting air of the spaces, the process of performing welding work (electric arc welding) inside these spaces was taken into consideration.

The volume of the space is 432 m^3, the dimensions in the plan are 12 × 6 m, and the height is 6 m. The range of the supply and exhaust air flowrates taken into consideration in the models is 432–1728 m^3/h, that is, one-fold (minimum) and three-fold (maximum) air exchange was carried out. The developed solid models of two types of spaces are shown in Figs. 1 (a, b, c) and 2 (a, b, c).

On the created models of spaces, various arrangement combinations of openings for supply and exhaust air were studied on the basis of six schematics taken into consideration (in accordance with six solid models of spaces):

1. The spaces of type 1, which include schematic 1 – 3:
   - Schematic 1 (Fig. 1, a) – supplying and removing air is carried out in opposite directions along the diagonal. It is obvious that with this arrangement of openings, the structure of the air flow will not change when the sides of supply and removal are swapped.
   - Schematic 2 (Fig. 1, b) – the supply air opening is located in the longitudinal wall of the space (in the middle); and the exhaust air opening, in the transverse one (in the corner).
   - Schematic 3 (Fig. 1, c) – the supply air opening is located in the longitudinal wall of the space (in the corner); and the exhaust air opening, in the transverse one (in the corner).
2. The spaces of type 2, which include schematic 4 – 6:
   - Schematic 4 (Fig. 2, a) – the locations of the supply and exhaust air openings are similar to schematic 1.
   - Schematic 5 (Fig. 2, b) – the locations of the supply and exhaust air openings are similar to schematic 2.
   - Schematic 6 (Fig. 2, c) – the locations of the supply and exhaust air openings are similar to schematic 3.

The calculations of the distribution of velocities in the space according to schematics 1–6 are shown in Figs. 3-5 for two values of the quantity of air supplied: 432 and 1728 m^3/h. In so doing, air velocities were measured in the horizontal section of the space at a height of 1.5 m (Figs. 3-5).

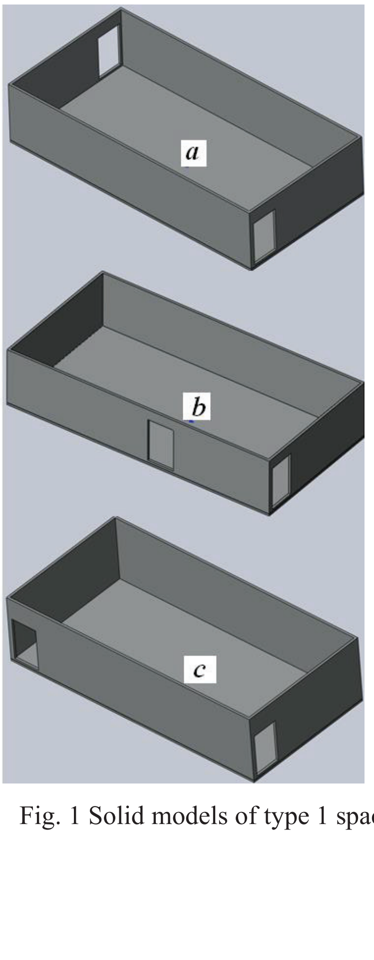

Fig. 1 Solid models of type 1 spaces

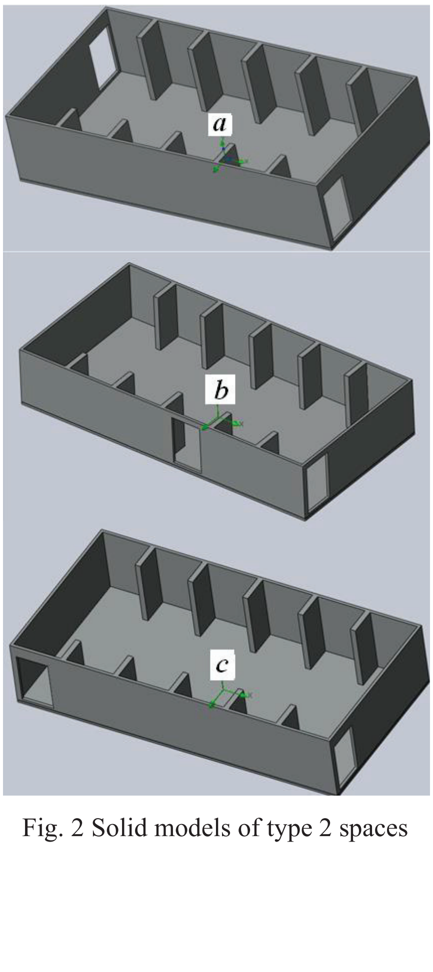

Fig. 2 Solid models of type 2 spaces

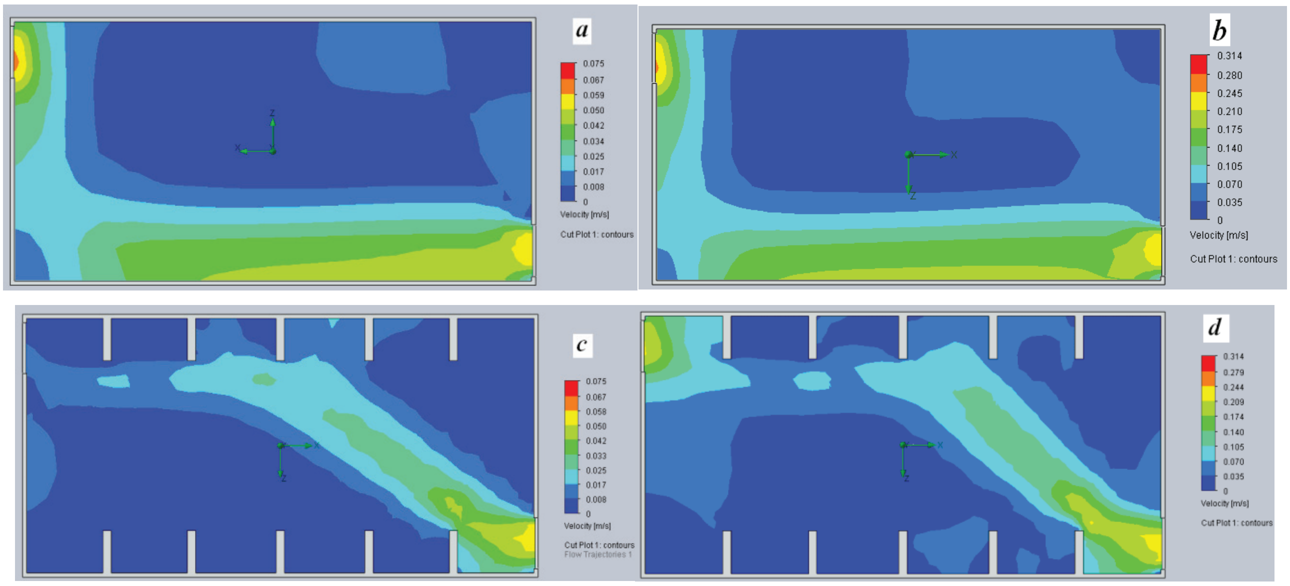

Fig. 3 Visualization of air flows according to schematics 1 and 4

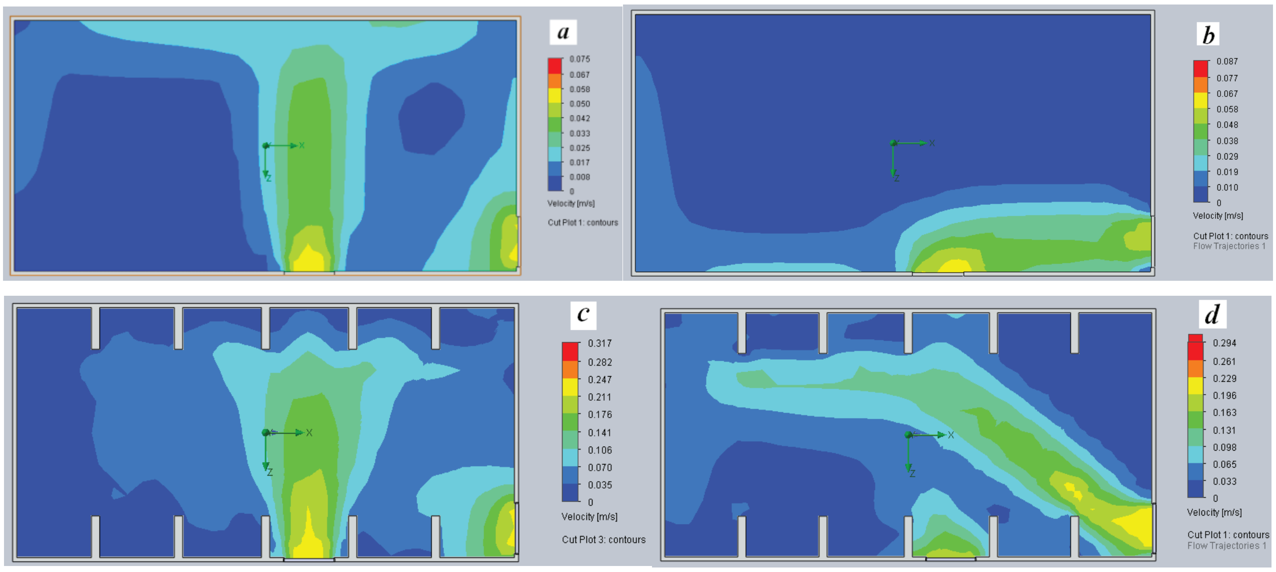

Fig. 4 Visualization of air flows according to schematics 2 and 5

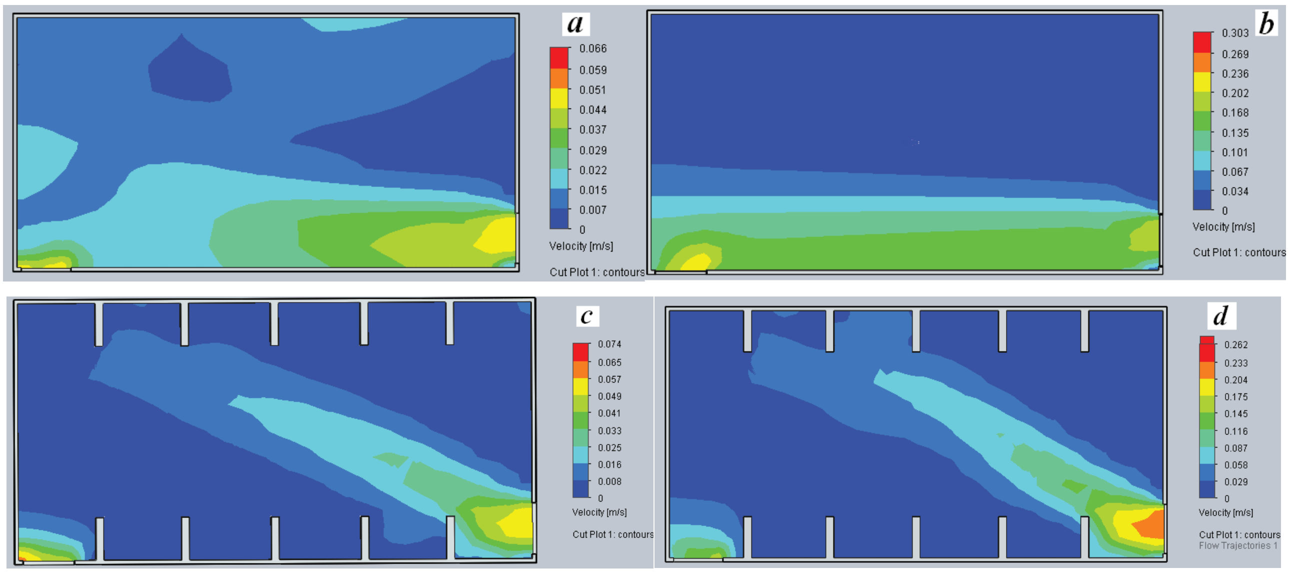

Fig. 5 Visualization of air flows according to schematics 3 and 6

The visualization of air flows according to schematic 1 (Fig. 3 a, b) demonstrates that in the space without ribbing (type 1), the air streams propagate along the longitudinal wall of the space, however, the air velocity with the one-fold air exchange with a supply air flowrate of 432 m^3/h (Fig. 3, a) has low values, which does not provide effectively removing contaminated air from the space. This is especially important when performing welding work in such a space. With this ventilating schematic, it is more rational to maintain the three-fold air exchange, which does not lead to an increase in air velocity above standard values. At the same time, higher velocities (higher than at the one-fold air exchange) ensure more voluminous removal of harmful substances. To provide effectively ventilating the space in the opposite direction, it is necessary to swap the supply and exhaust openings.

The visualization of air flows in the space with ribbing (type 2) according to schematic 4 (Fig. 3, c, d) demonstrates that ribbing is a significant obstacle to air streams. For such a space, it is rational to carry out ventilating with the three-fold air exchange with a supply air flowrate of 1728 m^3/h. In so doing, welding work should be performed on the opposite (larger) side of the space (the main air flow is deflected to this side). To perform welding work on the other larger side of the space, it is necessary to change the air flow in the opposite direction.

The analysis of the model of ventilating the space without ribbing (type 1) according to schematic 2 (Fig. 4, a, b) showed that it is rational to perform welding work in the part of the space in which the supply and exhaust openings are located (in this part, maximum air velocities are observed). In so doing, the maximum efficiency of ventilating is observed when air is supplied to the center of the space with a flowrate of 1728 m^3/h.

When ventilating the space with ribbing (type 2) according to schematic 5 (Fig. 4, c, d), ribbing changes the air flows, but does not interfere with ventilating with almost the same efficiency both when air is supplied to the center of the space (Fig. 4, c) and when air is supplied from the side of the transverse wall (Fig. 4, d).

For the case of venting the space without ribbing (type 1) according to schematic 3 (Fig. 5, a, b), it is recommended to perform welding work in the part of the space in which the supply and exhaust openings are located. If it is necessary to perform welding work on the opposite side of the space, to use such a schematic is not rational, since stagnant zones in which there is no air circulation are formed on the opposite side.

When ventilating the space with ribbing (type 2) according to schematic 6 (Fig. 5, c, d), air circulation is hindered by ribbing both at a supply air flowrate of 432 m^3/h (Fig. 5, c) and at a flowrate of 1728 m^3/h (Fig. 5, d). The analysis of air flows according to this schematic showed that it is rational to perform welding work in such a space only in the immediate vicinity of the supply air opening.

3. Conclusions

The research conducted showed that the arrangement combinations of openings for supply and exhaust air taken into consideration enable one to achieve effectively ventilating the spaces only in certain zones.

When using in practice the ventilating schematics considered, it is rational to perform ship repair work in the zones of direct impact of the supply and exhaust air jets. In so doing, in the zones of performing this work, an appropriate air velocity (0,2 – 0,5 m/s) should be provided. In addition, one should take into account that if the supply air opening is located in the immediate vicinity of the workplace, the air jet will scatter the contaminants being emitted from the place of their formation throughout the space.

The performed analysis of all the ventilating schematics taken into consideration revealed the process of forming stagnant zones as they move away from the main air stream. In so doing, the area of stagnant zones increases as the locations of the supply and exhaust duct stubs approach each other, which, in turn, leads to forming unacceptably high concentrations of contaminants in these zones. In addition, increased concentrations of contaminants are also observed in the locations of ribbing, which create stagnant air reservoirs (with low air velocities).

On the basis of the analysis results of the research conducted, the main conclusion was made that when performing repair work (including welding work) in ship's enclosed spaces, at least three-fold air exchange should be provided for such spaces.

The results of the studies conducted, the conclusions made, and the recommendations stated can be used when designing the stationary process-related ventilation systems for ship's enclosed spaces before beginning construction of the ship, as well as when arranging the temporary ventilation systems in such spaces in the course of performing repair work on the ship.

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SMART Technologies for Control the Entry and Exit of Vehicles to Logistics Centers

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Abstract

Systems for the control and registration of persons' entries and the entry and exit of vehicles are, together with video surveillance systems, intruder and hold-up alarm systems, fire detection and fire alarm systems and mechanical barriers, an integral part of security systems in organizations. The system of protection of persons and property also consists of physical protection and organizational or regime measures. Access control systems and their use describe the technical standards of the EN 60839 series, which are mainly aimed at the electronic access control of persons. The paper describes the vision of using SMART technologies and contains a proposal of using already available solutions in practice and their possible implementation in a selected organization. It includes a case study of innovative security solutions in logistics centres by implementing a CCSIPRO system and an analysis of the possibilities that modern systems can offer management to support management. The article also describes the risks associated with the implementation of SMART technologies for object security.
KEY WORDS: *smart, logistics, modern, technology*

1. Introduction

Modern technologies are transforming today's business. We use them to increase the efficiency and effectiveness of logistics processes. Their use is possible in various areas of logistics. The concept of smart logistics is defined in Dembińska's studies [1, 2] as the use of technology that automates tasks and limits people's efforts. The term intelligent logistics (Logistics 4.0.) Is introduced in connection with the concepts of Industry 4.0. The implementation of SMART technologies changes the possibilities of modern organizations and brings them new possibilities for the implementation of CLOUD technologies and advanced analytical functions.

The modern age brings with its increased demands on individual processes in all industries. We require these processes to be faster, more efficient, but also, for example, cost-effective, user-friendly or environmentally friendly. The further we go, the more we strive to gradually replace a person not only in demanding physical work, but also in decision-making processes in management. We require them to be intelligent.

2. SMART Technology and Communication Between Components

As in the earlier publication Goddart et al. [3] noted that the term "SMART technology" can historically be traced back to the early 1980s. At that time, it was exclusively a matter of the army and defense, later they also penetrated in the aviation industry. Today, we already encounter SMART technologies daily, in the form of mobile devices, tablets, advanced computer algorithms, hardware and software.

The essence of SMART technology today is mainly that we can interconnect these technologies or systems into networks, often with the possibility of connecting to the Internet and the possibility of remote access to them. Scheafer [4] states that SMART technologies are much more than just devices connected to the Internet, because today they are very complex networks in which individual devices communicate and work together to achieve different goals. Scheafer also emphasizes the importance of simple operation, which should be a basic criterion for effective management.

Many other authors, such as Foroudi et al. [5] also describes that SMART technologies have not only successfully penetrated our private lives but are enjoying great popularity in large companies in all industries and services. The large logistics warehouses, which are extremely demanding on the management of individual processes, are no exception. And this contribution will be devoted to modern technologies that are used in logistics warehouses.

Logistics centers require demanding technological solutions that should simplify the whole process. Security is no exception. Today, we also know modern access control systems [6], which can effectively and clearly monitor and record the entry of people into certain areas or buildings. We can use the same in the case of logistics centers, where it is important for us to monitor motor vehicles when entering and exiting the companies.

SMART technology, a concept that currently resonates in many industries. It is intended to be an intelligent solution, although it cannot be said that the previous solution was not intelligent. Basically, it is about connecting

technologies over the Internet and their mutual communication.

Currently, there are a few technologies to monitor the movement of people, vehicles, or goods in logistics centers. One of the most used technologies is RFID technology.

Radio Frequency Identification (RFID) is a technology for the identification of objects using radio frequency waves. The information is stored in electronic form in small chips / tags that allow reading and writing of this information using readers. Similarly, as with barcodes, the information is recorded on a data carrier - RFID tag, which contains a small chip with antenna and memory. Each RFID tag contains so-called EPC code (Electronic Product Code), which is the unique serial number of the tag [7].

Radio Frequency Identification (RFID) is a contactless automatic identification used to transmit and store data using electromagnetic waves. Radio frequency identification systems are capable of:

- record;
- store;
- provide information stored on tags in real time [7, 8].

Very similar like a RFID technology is NFC technology. Near Field Communication (NFC) is an electromagnetic wireless technology used to communicate between two devices. Communication takes place at very short distances. The major difference and advantage of NFC technology is the fact that it does not need pairing of two devices like a Bluetooth technology. After place two devices at a distance at least 4 cm (working within 10-20 cm but at least 4 cm is secure data transfer), the devices will begin to communicate immediately. The communication is in the band 13.56 MHz and the transmission rate is in the range of 106-424 Kbit/sec. RFID technology also operates in the 13.56 MHz band, so that NFC devices can communicate with RFID devices. The transfer is "Half-Duplex". At that one moment is one device as a transmitter and the other as a receiver or contrariwise. It is not possible to receive and transmit data at any time. An advantage is the energy saving of both devices. NFC devices use their own open source protocol. NFC technology is divided into active or passive devices (tags). NFC tags can store digital content in text, URL, images, short videos, and more up to 32 kBytes [9].

Both technologies can be used to monitor the movement of people, vehicles, or goods in logistics centers. The advantage is the variability of their use, the number of already existing technical solutions, simplicity of implementation and relatively low price. The implementation and interconnection of technologies can be realized through modern software tools created for this aim. Fig. 1 shows possible areas where smart technologies can be implemented in logistics centers. There is a relatively large number of software tools on the market for the management and control of logistics processes (TIMOCOM, EMANS, Murata and others). In addition to the solution of logistics processes, few offer a solution of security processes.

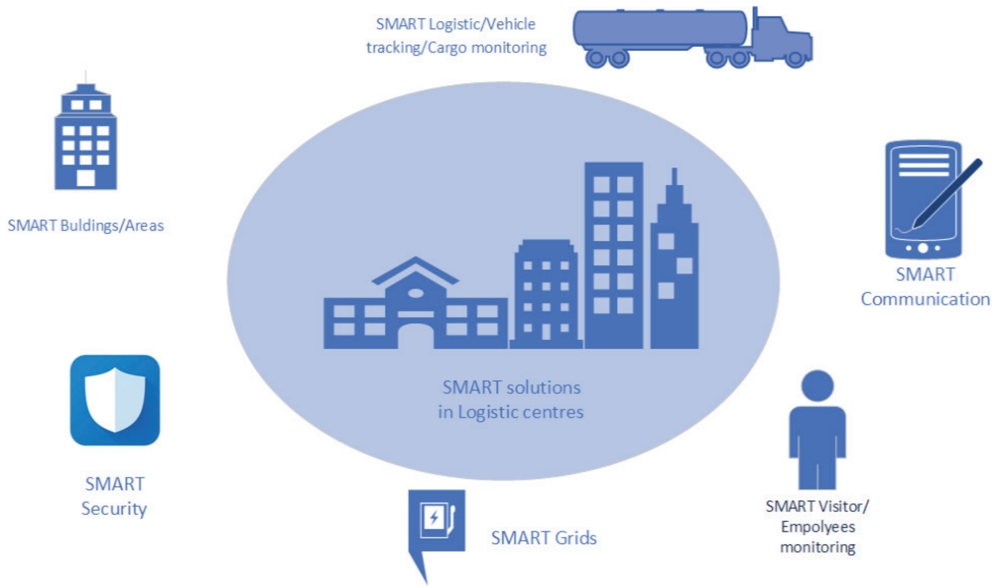

Fig. 1 SMART solution in Logistic centers

3. Case Study of Implementation SMART Technology in Praxis

An example of the use of modern SMART technologies in logistics centers is the CCSIPRO system patented by DIS Ltd., which cooperates with the University of Žilina in Slovakia and is implemented in some companies in Slovakia and abroad. Because DIS Ltd. was focused on the physical protection of property, the solution is based on the support of security processes and then other functions were implemented to enable the tracking of vehicles and cargo. Some features of CCSIPRO are shown in Fig. 2.

All scanned data from elements implemented within the system are sent to the CCSIPRO server. Signal and message transmissions must be the most reliable [10].

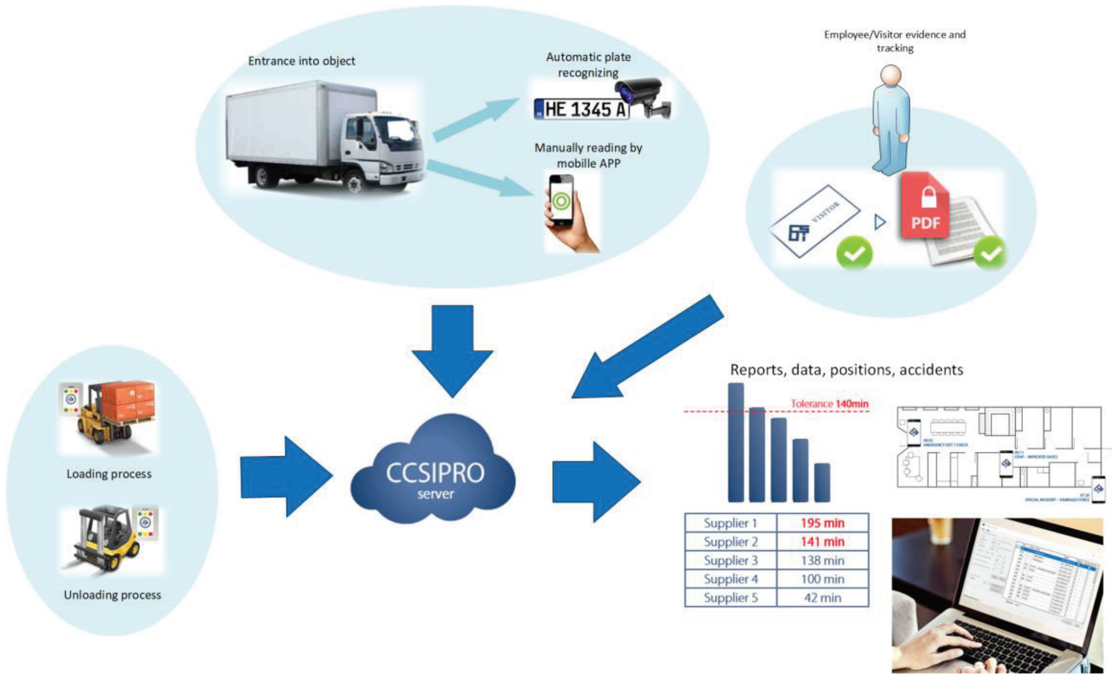

Fig. 2 Some features of CCSIPRO

Automated generating of dispatch notes will speed up the process of obtaining the data about a supplier, delivery, vehicle, and cargo areas. The dispatch note is ready for printing immediately. We can provide for the affirming signature in the dispatch note electronically by a signature tablet.

Persons entering the building for the first time are registered in the system at the entrance to the building and are assigned the iBeacon Bluetooth Low Energy BLE module. These are modules with a communication range of 50 m used to monitor the movement of people in the building, which log on to signal receivers (beacons) and send them information about the person's location. Currently, in threat of COVID-19, it is possible to connect the system with thermal cameras measuring the temperature of people entering the building.

Based on the collected data, it can be possible to create individual reports according to customer requirements. The content of the reports can be changed to the user needs (the person for who is the report generated). The reports can be read via the CCSIPRO online system using a web browser. CCSIPRO is fully customizable automatic report system bringing regular overviews on professional level. Every aspect, object, logistic and security element connected with CCSIPRO systems provide accurate and the most recent information that can be included in final Report. All data are highly secured, and results are available only appointed subjects. There is no limitation of variations what makes forwarding important information easy and smooth to different teams or sectors.

Any employee in a company with a suitable access level can use a smartphone to take pictures of the license plate of a car in the building and check what is in the pipeline, whether it is loaded, unloaded, or just a visit. If necessary, it can monitor the movement of the vehicle in the building, its condition and position. Table shown an example of data sheets generated from system.

Table

Example of CCSIPRO Report

CARPLATE	START	FINISH	COMPANY	NOTE	DELAY	C.W.P*
AA12345	20.04.2019 13:02:35	20.4.2019 15:48:38	COMP 1	*	167 minutes	OUT OF PLAN
BB98764	20.04.2019 07:02:30	20.4.2019 09:04:01	COMP 2	*	121 minutes	TOLERATED
YZ42042	20.04.2019 11:53:06	20.4.2019 13:53:29	COMP 3	*	120 minutes	OK
ZA08001	20.04.2019 13:06:11	20.4.2019 15:03:07	COMP 4	*	116 minutes	OK

*Compliance with the plan

System can generate direct statistics of time-effectivity inside object. Every vehicle position is automatically recorded on start/stop at every crucial point in object. Duration data are compared with tolerated value and can be used for fast identification of retardation.

4. Advantages of System Implementation

Logistics centers are extremely demanding on individual tasks. They require a detailed record of persons, vehicles, goods and other essentials associated with the transport of goods. Such a universal system is a suitable solution for logistics centers, as it represents a record of persons, vehicles, and goods, which are also a suitable security solution in the field of automated access control systems. It is important for any organization to optimize its costs and revenues. Security is no exception. Within the Faculty of Security Engineering, Kampová is more concerned with the issue of cost and revenue optimization [12].

The CCSIPRO system can bring several benefits to logistics centers as well as other entities. One of the main advantages is the simplification and time-saving of the entire process of monitoring the entry and exit of motor vehicles. Despite the initial financial costs, this system ultimately saves the organization's resources.

This system reduces the time required to identify and register motor vehicles to a minimum. As the system simplifies the work associated with records, it also reduces the needs of human resources.

A big advantage is also the automatic generation of reports. This helps to increase the clarity of the recorded data, and we can also monitor the statistics. Reports can be generated in the required format depending on who is the recipient of this information. The undeniable advantage of this system is also the possibility to connect it to other systems. One of the examples may be that in threat of COVID-19, it is possible to connect the system with thermal cameras measuring the temperature of people entering the building.

5. Conclusions

From the given example it is possible to identify opportunities in the development of SMART systems in the form of software to support logistics processes. No system is universal and is therefore suitable if they can be tailored directly to the customer. People, vehicles, and goods can have unique identifiers that can be tracked in the building. In the case of large logistics centers, it is necessary to choose a suitable communication method between the individual components (identifiers and reading devices) so that the system works flawlessly. When choosing a suitable system for monitoring processes in logistics centers, it is necessary to consider the certificates that the SMART technology supplier has and the references.

Of course, there should be a trial operation under various environmental influences that the system operates the most reliable.

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Validation of a Simple Multi-Body Head-and-Neck Model for Efficient Rear Impact Simulations

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Abstract

In this study, a 50th percentile male head-and-neck model which was developed using a 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 simple head-and-neck model was previously validated at a sled impact speed of 8 km/h. In this paper, the head-and-neck model is further validated at a sled impact speed of 6.2 km/h using recently published experimental data. The head-and-neck model can be used to simulate efficiently rear impacts and the resulting whiplash associated disorders in road traffic accidents. The results show that the model can represent successfully the rear impact response of a human head-and-neck system.
KEY WORDS: *head-and-neck model, whiplash, rear impact*

1. Introduction

Rear impacts in road-traffic accidents create a high risk of whiplash which is the sudden movement of the head with respect to the torso. This sudden movement typically produces discomfort and pain in the head-and-neck system. A common cause of whiplash is thought to be the formation of S-shape-like deformation in the neck due to the retraction of the head relative to the upper torso. In order to design safety systems against rear impacts, biofidelic human-body models are required.

There are various head-and-neck and human body models in the literature. These models can be classified as multi-body (MB) and finite-element (FE) models. MB models have fewer number of elements than FE models hence they are much more computationally efficient [1, 2, 4, 5, 9]. On the other hand, in FE models the geometry and the material properties of components and contacts of bodies are modelled in detail; local deformations and stress distributions can be studied and injury mechanisms in human-body parts can be investigated which can be hard to study experimentally [3, 7, 8]. However, MB models can predict successfully and cheaply the global responses (overall kinematics and resultant forces/moments) of the human body under impact loading; they are suitable for parameter variation, optimisation analyses and control system design, hence they can reduce the time required for the development of safety systems. MB models can be used as a supplementary and cheap tool to design safety systems which can be used together with more complex FE models.

There are mainly two state-of-the-art FE human body models used widely in the crash safety community, these are the Total Human Model for Safety (THUMS) and the Global Human Body Model Consortium (GHBMC) [7]. These models can be transformed to represent different postures, sizes, and age but this is a time demanding process. There are human-body models specifically designed for rear impact simulations including the BioRID II dummy [1-5]; one of these models was presented by Himmetoglu et al. [1, 2] 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 the further validation of the head-and-neck model by Himmetoglu et al. [1] using the recently published volunteer test data [6].

2. Rear Impact Volunteer Test Procedure

The experimental data to validate the 50th percentile head-and-neck model by Himmetoglu et al. [1] is obtained from Sato et al. [6]. The obtained data refers to Test Series 1 (with sled pulse 1). In these tests, a rigid seat having no head restraint and seatbelt, was attached to a sled which was allowed to slide down on inclined rails with an angle of 10 deg from the horizontal, as shown in Fig. 1. The seatback angle was 20 deg from the vertical The hydraulic damper at the lower end of the rails decelerated the sled and created a crash pulse typical of low speed rear impacts as shown in Fig. 3. The impact velocity of the sled was 6.2 km/h which resulted in a delta-V (change of velocity) of 8.1 km/h and a peak acceleration of 27 m/s^2 for the sled (see Fig. 3 and Fig. 4). In the figures, zero time corresponds to the first contact of the sled with the damper. The volunteers were asked to relax before the impact. In this Test Series 1 (with sled pulse 1), there were 12 male volunteers; they had 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.

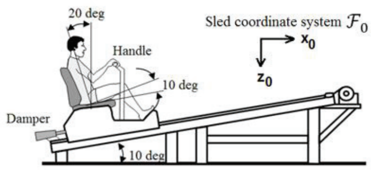

Fig. 1 Volunteer test setup [10]

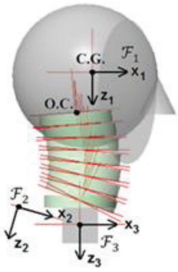

Fig. 2 Head-neck model and frames

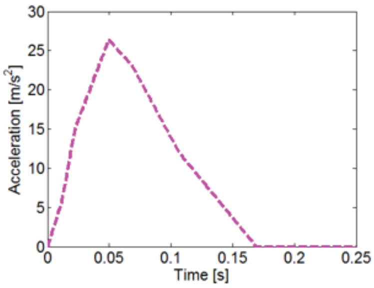

Fig. 3 Crash pulse

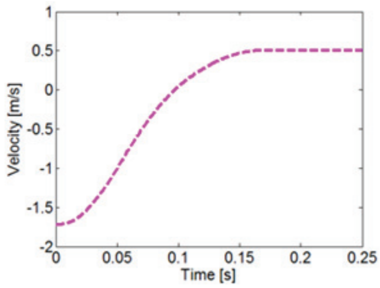

Fig. 4 Total sled velocity

Several target markers and accelerometers were attached to the head and T1 (the first thoracic vertebra) to record the displacements and accelerations. Four coordinate systems (i.e. frames) are used in the tests as shown in Fig. 1 and Fig. 2. The sled coordinate system (frame) which is attached to the sled, is denoted by $\mathcal{F}_0$ 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 $\mathcal{F}_1$ and its x_1 axis is parallel to the Frankfort line [6]. The T1 accelerometer frame is denoted by $\mathcal{F}_2$ 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 $\mathcal{F}_3$ 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 $\mathcal{F}_3$ passes through the occipital condyles (O.C.) at the initial posture of the head-and-neck. The frames $\mathcal{F}_2$ and $\mathcal{F}_3$ move almost together with T1.

3. The Properties of the Head-and-Neck Model

The 50th percentile head-and-neck model, shown in Fig. 2, was developed using the multi-body dynamics software MSC VisualNastran 4D [1]. The model is composed of a head, seven cervical vertebrae and T1; all of them being rigid bodies connected by rotational springs and dampers. The geometrical and inertial properties of the model are documented in detail in reference [1]. The initial posture of the head-and-neck model corresponds to a 50th percentile male occupant's head-and-neck in a standard automotive posture with the head looking forward [1].

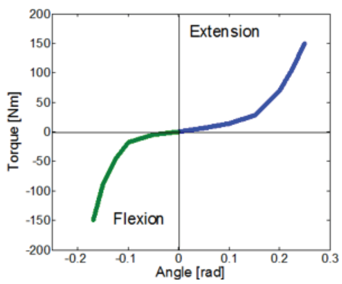

Fig. 5 Rotational stiffness [11]

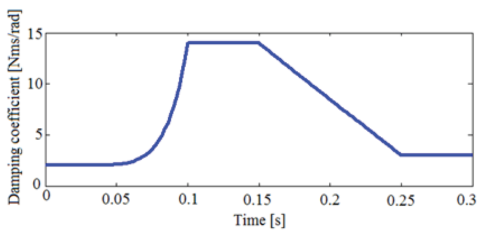

Fig. 6 Rotational viscous-damping coefficient

In this model, all intervertebral joints (i.e. the joints between each pair of vertebrae) consist of a rotational spring and damper connected in parallel. All intervertebral joints have the same stiffness and damping. The stiffness at the intervertebral joints is given by the function in Fig. 5 which shows the resistive torque for a given amount of intervertebral angular displacement. During the validation of the model, the torque values in Fig. 5 are multiplied by a factor of 0.75 to obtain good agreement with experimental data. The stiffness function in Fig. 5 does not incorporate muscle contraction effects. Muscle contraction, the viscoelastic nature and the dynamic stiffening behaviour of the soft tissues are simulated by applying a time varying rotational viscous-damping coefficient as shown in Fig. 6. This time varying damping coefficient follows in shape the variation of electromyography (EMG) measurements of the main neck muscles recorded during volunteer tests hence the time varying damping coefficient mimics muscle activity in the neck.

4. Validation of the Model

In order to validate the head-and-neck model against the experimental data, the recorded motion of T1 is used as an input to drive the head-and-neck system. For this purpose, the T1 accelerations recorded by the accelerometers in frame $\mathcal{F}_2$ are used as shown in Fig. 7 and Fig. 8. Additionally, the recorded angular displacement (with respect to sled) of T1 is used to specify the rotational motion of T1 in the model. In Fig. 7 and Fig. 8, the mean values of T1 x and z accelerations are shown along with the response corridors (mean $\pm$ one standard deviation (SD)) indicated by the dotted lines. The mean angular displacement of T1 (with respect to sled) which is presented in the published experimental data [6], was digitised to fit an 8th degree polynomial to the data by applying least-squares regression as shown in Fig. 9. This fitted polynomial is differentiated twice to estimate the mean angular acceleration of T1 as shown in Fig. 10. The mean T1-accelerations (both linear and angular accelerations) are used to specify the motion of T1 in the model. At the start of the impact (time equals zero), all bodies in the model have the same velocity as the sled.

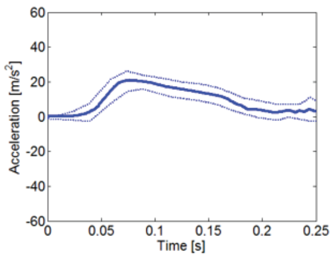

Fig. 7 T1 x-acceleration (mean ± SD)

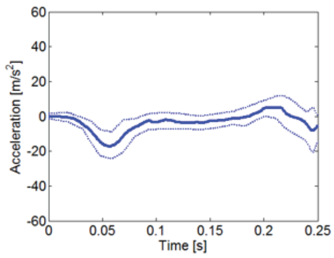

Fig. 8 T1 z-acceleration (mean ± SD)

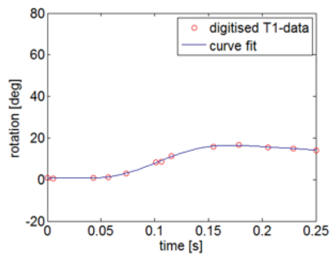

Fig. 9 Mean T1 angular displacement

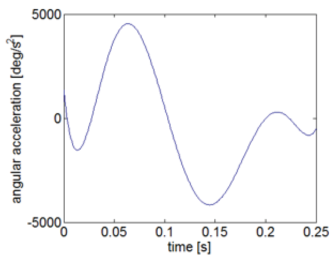

Fig. 10 Mean T1 angular acceleration

The responses of the head-and-neck 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 $\pm$ SD) are shown in blue and red colours, respectively. The response of the head-and-neck model is shown by dashed lines. Fig. 11 and Fig. 12 show the head C.G. displacements with respect to the sled expressed in the sled frame $\mathcal{F}_0$. Fig. 13 and Fig. 14 present the head C.G. accelerations (with respect to the ground) expressed in the head anatomical frame $\mathcal{F}_1$. Fig. 15 and Fig. 16 show the displacements of the centre of T1 with respect to the sled expressed in the sled frame $\mathcal{F}_0$. Fig. 17 and Fig. 18 present the angular displacements of the head and T1 with respect to the sled around the y_0-axis of the sled frame. Finally, Fig. 19 shows the head angular displacement with respect to T1 around the y_0-axis of the sled frame. The motion of the head-and-neck model at 50 ms intervals are given in Fig. 20.

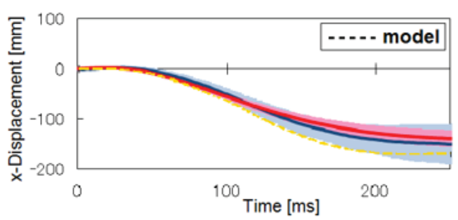

Fig. 11 Head C.G. x-displacement wrt sled

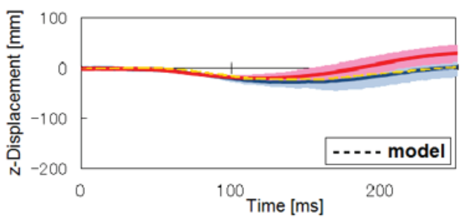

Fig. 12 Head C.G. z-displacement wrt sled

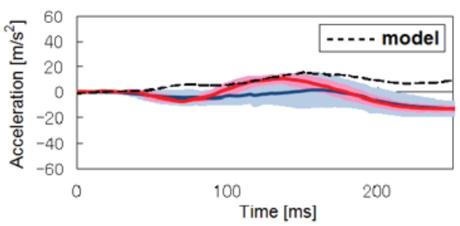

Fig. 13 Head C.G. x-acceleration

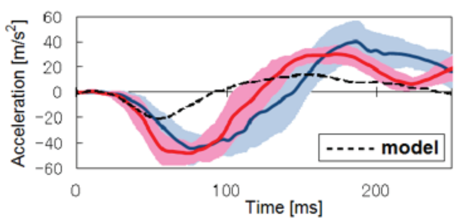

Fig. 14 Head C.G. z-acceleration

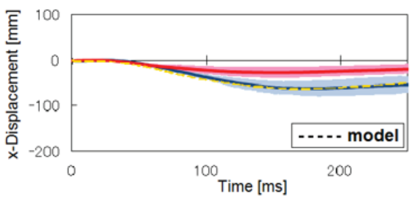

Fig. 15 T1 x-displacement wrt sled

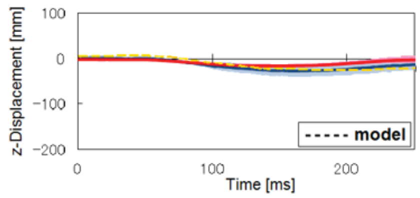

Fig. 16 T1 z-displacement wrt sled

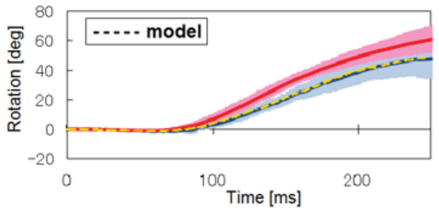

Fig. 17 Head rotation wrt sled

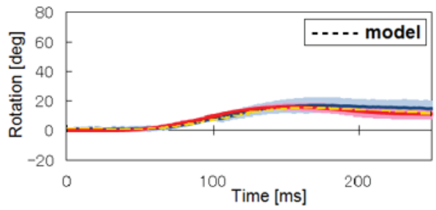

Fig. 18 T1 rotation wrt sled

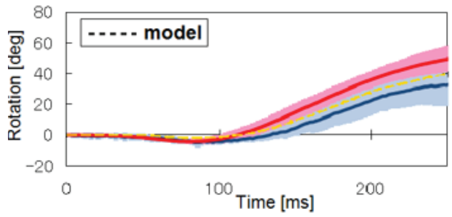

Fig. 19 Head wrt T1 rotation

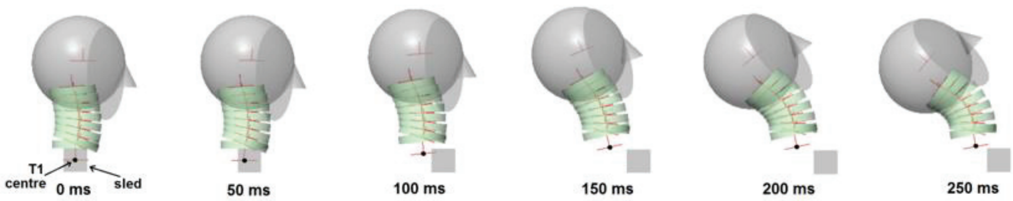

Fig. 20 The motion of the 50th percentile male head-and-neck model

5. Discussion and Conclusions

The presented figures indicate that there is a good agreement between the 50th percentile male model and the volunteer responses in terms of linear and angular displacements of the head and T1 (the first thoracic vertebra) since the model responses are within the response corridors ((mean $\pm$ one standard deviation (SD)) of male volunteers shown in blue colour. What's more, the shapes of the mean volunteer-response curves agree quite well with the model responses regarding the displacements. Considering head C.G. accelerations, there are some differences between the model and volunteer responses as the model response does not exactly follow the mean volunteer response. However, in the model the order of magnitude of head C.G. *x*-accelerations agrees well with that of volunteers but this is not exactly the case for head C.G. *z*-accelerations. It should be noted that generally it is not easy to estimate accelerations compared to displacements since the model is only an approximation for a real human and the small errors between the model and real human displacements are amplified during the calculation of accelerations knowing that accelerations are basically the derivatives of displacements. Another point is that the volunteer response corridors correspond to mean $\pm$ one standard deviation which means that there are other volunteer responses outside of the corridors. The upper neck (O.C.) forces and moments were also presented in the published data [6] but the calculation of these forces/moments was not expressed clearly hence they are omitted in this paper.

The 50th percentile male multi-body head-and-neck model presented in this paper is validated successfully using the responses of 12 male volunteers in rear impact sled tests. This head-and-neck model was also validated successfully at a higher sled impact velocity in a previous research [1]. This multi-body model is simple in architecture hence the required computation time is insignificant. The model is able to mimic muscle contraction without using separate muscle elements. This model is useful for researchers who need fast computation in their simulations.

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Error Formation in a Human Operator Decision-Making Process in Flight

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Abstract

Incorrect situation awareness may lead to an overestimation or underestimation of the state of a system, which is referred to as type I and II errors. Decision making might be regarded as the process of transition from the available information domain to the domain of possible solutions, thus depending on the estimated state of a system, the pilot forms his/her judgment and chooses a strategy for further actions. In this paper, a model of error formation in an aeronautical decision making is proposed as a confusion matrix of hypotheses along with an analysis of the two estimation error types. Furthermore, a possibility to quantify the total error of making wrong decisions, depending on the chosen number of the parameters under control is addressed. This determines the existence of a point corresponding to the optimal amount of available information, the threshold of the number of controlled parameters to estimate the condition of a system with a higher degree of accuracy.

KEY WORDS: *flight safety, mathematical modelling, human operator, decision making, situational awareness, human error formation*

1. Introduction

Improvement of aircraft design and automation technologies has changed the functions of the front-line human operators in the aviation industry, such as pilots, air traffic controllers and engineers, the main duties of which currently include more activities related to control and monitoring of aviation systems and components combined with decision making. The quality of a pilot's training and professional competency may be expressed in terms of the abilities to assess flight situations and make correct and timely decisions. As it is stated in the ICAO manual [1] situation awareness and problem solving with decision making are two of the core competencies indicating proficient performance. In a human-machine system interacting with external environment, in this case a pilot and the aircraft, the flaws present in the system may lead to incidents and serious accidents. According to Jensen and Benel [2] in general aviation, decision-making errors were the main cause in 35% of non-fatal aircraft accidents and 52% of accidents with fatalities. In commercial aviation, erroneous decision making caused 56% of accidents [3]. More recent analysis by Wen-Chin Li [4] using the Human Factors Analysis and Classification Systems framework [5] showed that 68% of the sampled accidents involved a decision error. Correct assessment of the condition of multiple systems, that are elements of the human-machine system and environment interaction, by the pilot defines successful outcomes of flights and the flight safety of the systems [6, 7].

The aforementioned allows to consider a human-operator's activities as a form of a complex universal control system. Such a comparison allows to make a basic analysis of the pilot's activity, specifically, the need to constantly evaluate the state of the entire "human-machine-environment" system using the readings of instruments that are indirect indicators of the state of the system under control. In case there is any deviation from the desired state of the system, the pilot's interference is required.

Since mental process, control and monitoring functions prevail over the functions of purely mechanical control, which are being progressively allocated to automatic control systems, the human operator has more time to concentrate on aeronautical decision-making (ADM). The pilot determines the degree of danger of a flight situation assessing the controlled parameters for compliance with a given set of values, and makes a decision on the choice of an optimal course of action. It is noted that the operation of any non-ideal controlling system is accompanied by type I and II errors, analogous to the errors present in statistical hypothesis testing. These errors appear as overestimation (type I error) or underestimation (type II error) of the condition of an aircraft system under control. A similar approach was adopted in studies by Karaush [8], Hazzauri and Shestakov [9]. Modelling ADM by the pilot, the principle of type I and II errors formation is represented as a result of hypotheses confusion, which allows to construct a confusion matrix of hypotheses. These hypotheses correspond to different state levels of a controlled system. It should be noted that the failure conditions classified in the methodology are according to [10], originally this classification is used for certification and approval of aviation equipment. This classification was chosen because of the distinct boundaries and definitions of failure conditions it provides.

2. Assessment of Failure Conditions and Flight Situation in ADM

The main task of any control system is an assessment and regulation, and therefore, the human operator, represented as a control system, must constantly evaluate the systems under control according to available information, in the present case an aircraft or any of its component, and based on this assessment classify failure conditions of the system. The classification of conditions in accordance with [10], is following:

1. No safety effect condition (NSE) – which corresponds to no effect on the operation of the airplane.
2. Minor failure condition (MN) – significantly reduces aircraft safety, however the crew actions that must be performed are well within their limits, including some physical discomfort to passengers or cabin crew. Minor failure does not require a change in the flight plan and does not obstruct further continuation of the flight, unless stated otherwise in the aircraft flight manual (AFM).
3. Major failure condition (MJ) – significantly reduces safety margins or functional capabilities, increasing crew workload, with possible flight crew discomfort and physical distress, including injury to passengers or cabin crew. Prevention of further transition into a hazardous or catastrophic condition must be ensured by timely and correct actions of crew members in accordance with the AFM, including the immediate change in the plan, profile or flight mode.
4. Hazardous failure condition (HF) – a large reduction in safety margins. With possibility of crew members being unable to perform their assigned tasks accurately or completely, including serious or fatal injury to a minor number of passengers or cabin crew.
5. Catastrophic failure condition (CF) – multiple fatalities and hull loss is almost inevitable.

The choice of the best course of action, that is ultimately supposed to prevent further escalation of a distressed condition, depends on the assessment of controlled systems by the pilot. This assessment process is indicated in Fig. 1. The horizontal axis represents the actual condition of a system, while the vertical axis indicates the perceived condition of the system by a human-operator. The line with a 100% grade slope represents the ideal pilot, whose evaluations always correspond to actual conditions. A real pilot operates with some errors, thus the slopes of the graphs which indicate a real pilot's assessment are different with the angle α being lower or higher than 45°. This leads to a mismatch between the actual state of the system and the assessment of the danger level of the situation by the value ΔE .

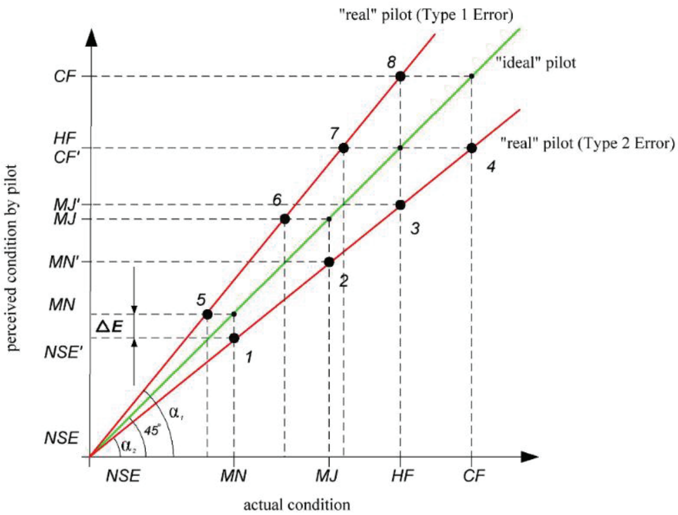

Fig. 1 Graphical representation of a situation assessment by the ideal and real pilots

Considering the real pilot graph of type II error, it can be seen at point 1 that s/he assesses the condition of the system as having no significant effect (NSE), while the actual condition of the system is in the state of a minor failure (MN). Furthermore, if the situation escalates to being catastrophic (CF) at point 4, the pilot would confidently assess the situation as hazardous (HF), which can lead to a conduct of inadequate procedures and further time consumption in the present time deficit. The opposite happens in the case when the real pilot makes type I errors in his/her assessment. As a result, some inadequate actions, as a response to mitigate the situation, are inevitable.

In real aircraft operations, emergency situations may escalate suddenly and the shape of the linear graphs presented will vary. Given that an emergency situation exacerbates gradually the pilot's assessment of the situation may be expressed as a certain algorithm in which the pilot monitors the information available through flight instruments and warning systems, and focuses on any changes of the indications that are outside the normal flight envelope. If the errors between the set parameters of the flight are within limits, the situation corresponds to normal flight conditions. If the errors are beyond the limits, then the current conditions are indicative of a failure and further events depend on the actions of the flight crew.

3. Type I and II Errors Formation in Decision Making

According to FAA the term ADM is described as 'a systematic approach to the mental process used by aircraft

pilots to consistently determine the best course of action in response to a given set of circumstances' [11]. In addition, it can be said that ADM is the process of transition from the information domain to the domain of possible solutions, thus depending on the information about the state of a system, the pilot forms his/her judgment and chooses a strategy for further actions.

The information the pilot works with is similar to sampling. To make inferences about the state of an aircraft system, the pilot needs to know a certain number of parameters that characterizes the system and its interaction with other systems onboard. Performance of ADM does not occur with all the necessary and/or all available information due to the scarcity or abundance of information on the flight instrument panel and the accuracy and reliability of that information, limited time available, the pilot's ability to perceive and process information. ADM is done with a sample of the available information [12].

The concept of optimal ADM includes the minimum time $\tau_{min}^{+}$of making the right decision and the maximum probability P_{DM}^{+} that is to say with a minimum deviation d from one. These values are possible only having the optimal amount of information I_{opt} necessary for the ADM [8].

The assessment of the current state of a system is based on observed parameters, which are a sample of M from the set of all parameters N. Those are necessary to accurately assign the system to a level corresponding to the true state.

The pilot making a decision assesses the compliance of the observed parameters with the specified operating limitations (OL) contained in the AFM. Let N number of parameters correspond to all available parameters. then there is an actual threshold of parameters N_0 ($N_0 \leq N$) such that if the number of parameters within the OL n ($n \geq N_0$), then it can be stated that the system functions normally, and the system is operating under normal operating conditions (NOC). If $n < N_0$, the system will be beyond the specified OL, meaning some action from the pilot is required.

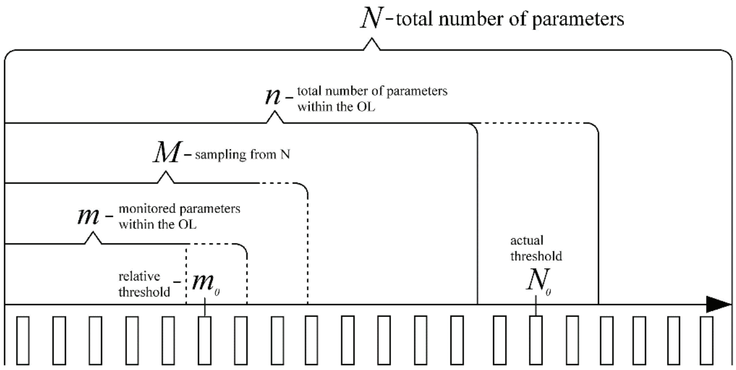

Fig. 2 Graphical representation of determining the state of the controlled system using sample *M* from *N*

The aforementioned is depicted schematically in Fig. 2. where N – the set of all available parameters describing the system; M – a sample of N, (parameters monitored by the pilot); m – the number of monitored parameters corresponding to the OL; m_0 – a relative minimum number of parameters that must be within the OL. In practice $N \ll M$, and m_0, allows the pilot to attribute the state of the system to one of the levels with a certain degree of accuracy.

Assessment of the level of the system state is based on the compliance of the parameters m from the set M with the specified OL. The number of parameters m can act as a quantitative measure in estimating the number of parameters n satisfying the OL from the total set N. Since this dependence is not well-determined, that approach leads to errors in overestimations and underestimations of the states of the system.

In order to construct a confusion matrix of hypotheses with five state levels of a controlled system, which correspond to the five failure conditions [10], it is necessary to introduce a series of probabilities related to confusion of hypotheses, as characteristics of the process of determining the current state of a system *X*. If $X \in \{X_i\}$ and it is assumed that $X \in \{X_j\}$, $(j \neq i)$, then the *i*-th and *j*-th hypotheses are mixed up, and the conditional probability of this event will be denoted P_{ij}. The probability of a correct evaluation with this approach will be P_{jj}[8]. The set of probabilities for the five condition levels is presented as a confusion matrix P (1).

The main diagonal corresponds to the probabilities of a correct assessment ($P_{11}, P_{22},\dots, P_{55}$), below the main diagonal are the probabilities related to type II errors, and above to type I errors. Since the probabilities in each of the rows of the matrix belong to a full group of events, their sum is $\sum_{j=1}^{5} P_{ij} = 1$.

Given a specific number of parameters *N* describing the system with the boundary at N_0, the following five probabilities corresponding to the five condition levels can be introduced: q_1 is the probability that $N_0 \leq n < N$ (NSE); q_2 is the probability that $N_1 \leq n < N_0$ (MN); q_3 is the probability that $N_2 \leq n < N_1$ (MJ); q_4 is the probability that $N_3 \leq n < N_2$ (HF); q_5 is the probability that $n < N_3$ (CF).

To determine the required $q_1, q_2, \dots q_5$, it is necessary to find the corresponding average values of probabilities in the specified intervals. These probabilities can be determined using statistical data available to aircraft operators and manufacturers. That would allow to construct a confusion matrix of hypotheses about the state of a controlled system

and to quantify the total error of making incorrect decisions, depending on the chosen value of m_0.

$$P = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} & P_{15} \\ P_{21} & P_{22} & P_{23} & P_{24} & P_{25} \\ P_{31} & P_{32} & P_{33} & P_{34} & P_{35} \\ P_{41} & P_{42} & P_{43} & P_{44} & P_{45} \\ P_{51} & P_{52} & P_{53} & P_{54} & P_{55} \end{bmatrix}. \quad (1)$$

4. Estimation of the Optimal Threshold of Monitored Parameters

For experimental purposes, it is assumed that the n value is static and the controlled system may be at two levels: normal and abnormal operation. In this case, the whole set of possible states is divided into two subsets: $\{X_1\}$ and $\{X_2\}$. Therefore the task is reduced to determining which set the actual state of the system X belongs to. In order to do this, M parameters are sampled from the set of parameters N.

If the state of the system $X \in \{X_1\}$, and the number $n \in \{N\}$ $(n \geq N_0)$, it is possible calculate the probability that the number of parameters m from the sample M comply with the OL using the formula [8]:

$$P^{+} = \frac{C_n^m C_{N-n}^{M-m}}{C_N^M}. \quad (2)$$

Similarly, P^{-} the likelihood that the state of the system $X \in \{X_2\}$, can be found.

When an assessment is made about the position of a system in either of the subsets $\{X_1\}$, and $\{X_2\}$, by estimating the parameters M, it is necessary to enter the threshold value m_0 $(0 < m_0 \leq M)$. Then, if the number of monitored parameters corresponding to the OL is more than the threshold, $m \geq m_0$, it is considered that the system is in the subset X_1, alternatively, if $m < m_0$, then the system is at X_2. At this point, type I and II errors occur, meaning either an overestimation or underestimation of the state of a system.

Considering that the controlled system can be at two levels (normal and abnormal operation), it is possible to construct a simplified confusion matrix of hypotheses. It takes the form as following:

$$P = \begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix}. \quad (3)$$

The diagonal of the matrix (P_{11} and P_{22}) represent the probabilities of correct assessment of the system conditions. Above the diagonal is P_{12} – the probability related to type II errors; below the diagonal, P_{21} – the probability related to type I errors. P_{12} and P_{21} are calculated using the following formulae:

$$P_{12} = \sum_{k=1}^{m_0} \frac{C_{m_0-k}^{n} \cdot C_{M-m_0+k}^{N-n}}{C_M^N}; \; P_{21} = \sum_{k=0}^{m_0} \frac{C_{m_0+k}^{n} \cdot C_{M-m_0-k}^{N-n}}{C_M^N}. \quad (4)$$

The probabilities of the correct assessment P_{11} and P_{22} can be found by the formulae:

$$P_{11} = 1 - P_{12}; \; P_{22} = 1 - P_{21}. \quad (5)$$

In the experiment, for the estimation of the optimal value of m_0, it was necessary to find such m_0 for each $M = \{1, 2, 3\ldots, 20\}$ where the sum of total error probabilities $P_{12} + P_{21}$ is minimal. Initial conditions were $N = 70$; $N_0 = 50$; $n = \{40, 49\}$; $M = \{1, 2, 3\ldots, 20\}$; $m_0 = \{1, 2, 3\ldots, 20\}$. Using the initial conditions four matrices were obtained: two matrices of P_{11} and P_{12} probabilities, two matrices of P_{21} and P_{22} probabilities. Consequently, the optimal values of m_0 for certain M values were derived, which are presented in Table.

Analyzing Table, it can be seen that it is highly probable to make an incorrect assessment with a limited number of parameters which indicate the state of a system. In addition, the total error decreases slightly from 0,99 to 0,93 with the increase in the value of the threshold m_0 from 1 to 15, when a failure condition is not very pronounced ($n = 49$). When a failure condition is more noticeable ($n = 40$), the total probability of making an error is reduced more significantly with the increase in m_0 from 1 to 13, specifically from 0,86 to 0,43.

The obtained results confirm the fact that all control systems operating with a sampling of information are prone to type 1 and 2 errors in their estimations, the severity of which depends on the threshold value of the sampling size and the extent of a failure condition.

Table

Optimal values of m_0, and the minimum sum of total error probability P_Σ

$n = 49$													
M	1	2	3	4	5	6	7	8	9	10	11	12	..	20
m_0	1	2	3	3	4	5	5	6	7	8	8	9	..	15
P_{11}	0.714	0.507	0.358	0.679	0.556	0.444	0.684	0.588	0.495	0.409	0.615	0.534	..	0.458
P_{12}	0.286	0.493	0.642	0.321	0.444	0.556	0.316	0.412	0.505	0.591	0.385	0.466	..	0.542
P_{21}	0.7	0.487	0.337	0.653	0.525	0.412	0.651	0.55	0.455	0.368	0.57	0.485	..	0.393
P_{22}	0.3	0.513	0.663	0.347	0.475	0.588	0.349	0.45	0.545	0.632	0.43	0.515	..	0.607
P_Σ	0.986	0.98	0.979	0.974	0.969	0.968	0.967	0.962	0.96	0.959	0.955	0.951	..	0.935
$n = 40$														
M	1	2	3	4	5	6	7	8	9	10	11	12	..	20
m_0	1	2	2	3	4	4	5	6	6	7	8	8	..	13
P_{11}	0.714	0.507	0.806	0.679	0.556	0.778	0.684	0.588	0.774	0.696	0.615	0.778	..	0.852
P_{12}	0.286	0.493	0.194	0.321	0.444	0.222	0.316	0.412	0.226	0.304	0.385	0.222	..	0.148
P_{21}	0.571	0.323	0.608	0.423	0.281	0.483	0.35	0.244	0.404	0.298	0.212	0.344	..	0.285
P_{22}	0.429	0.677	0.392	0.577	0.719	0.517	0.65	0.756	0.596	0.702	0.788	0.656	..	0.715
P_Σ	0.857	0.816	0.802	0.744	0.725	0.705	0.666	0.656	0.63	0.602	0.597	0.566	..	0.433

4. Conclusions

In this paper, the principle of error formation in aeronautical decision making was presented using a model, comparable in certain respects to statistical hypothesis testing, expressed in terms of the actual and perceived states of flight systems and the aircraft as a whole adopting the classification of failures set forth by the FAA [10]. For more accurate situation assessment, the calculation of the minimum sum of total error probabilities allows to determine objectively the threshold number of monitored parameters, in other words, the optimal amount of information I_{opt}. These results may be used for development and improvement of:

– Flight instrument panels, including the arrangement of information on multi-functional displays used in cockpits;

– Aircraft Flight Manual including references for the operation of an aircraft under abnormal, and emergency conditions;

– Company Operations Manual including subsidiary documents: Quick Reference Handbook (QRH) and Emergency and Abnormal Checklist (EAC);

– Flight training programs for pilots and instructors.

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Assessment of Partial Double-Tracked Railway Lines with Focus on Capacity

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Abstract

There is a relatively significant number of single-tracked railway lines in operation. Travel times can be improved because trains must wait on passing (crossing) with the other trains whereas capacity and quality level can be decreased due to this fact. On the other hand, the construction of the second track along the line can be expensive and should be considered only in cases of heavy traffic. Partial double-tracking can be an effective way of how to improve capacity and quality with limited costs. The paper is focused on the capacity assessment of partially double-tracked lines with an effort to find a process for determining which line segments should be upgraded to double-tracked and which should remain as single-tracked segments. Operational features, such as delay and delay propagation (timetable stability) are the main indicators for this process. These features are assessed with a microsimulation model created within the simulation tool OpenTrack.
KEY WORDS: *capacity, doubling of a railway line, model, railway, simulation*

1. Introduction

The issue is that train travel times on a single-tracked line can be extended due to the need of waiting at stations or passing loops on passing with trains running in the opposite direction. Most of the railway lines are single-tracked lines in the Czech Republic. It is about 79% of the total length [1]. A high ratio of these lines itself is not a problem because there is a number of lines where conversion into double-tracked line is ineffective due to the low volume of operation. On the other hand, there are also some lines which can be perspective for passengers as well as for freight transport and we focus on this type of line in the paper. Conversion of some selected segments (de facto creation of partial double-track railway line) can be an effective way of how to improve such lines. A similar discussion was registered also in Germany. Assessments in the field of passing on single-tracked lines are mentioned e.g. in the study of [2] following improvement of the railway for freight traffic. This illustrates that the issue is not a local issue of the railway network in the Czech Republic only and that similar problems are being resolved in many countries.

The aim of the paper is to create a base for new methodology focused on capacity assessment with the aim to select segments that should be converted despite the rest of the line will remain single-tracked.

The research hypothesis is that it is possible to apply some of the capacity indicators to identify which segments should be converted. The conducted research is based on microscopic simulation of a railway line in the software tool OpenTrack. Special focus is placed on stochastic effects influencing railway operation. Results are applied as a part of a complex methodology for the capacity assessment of railway lines.

2. The State-of-Art Situation in the Research Area

The capacity of railway infrastructure is a complex and important issue. Investments in railway infrastructure are high and usually on a long-term basis. Assessment of possible capacity extension is a scope of the paper [3] where a mathematical programming model is introduced for this evaluation. The increasing role of freight railway traffic is accented within the paper as well.

The capacity of Croatian double-tracked railway line Novska – Vinkovci – Tovarnik – State Border – (Šid) is assessed in [4]. Assessment is done also with the usage of OpenTrack simulation software. The research part is focused on the possibility to use both line tracks for trains going in the same direction at one moment and on the capacity effects of this way of operation. This makes evidence that the OpenTrack model can be effective for issues in the field of capacity assessment.

Specific measures of the degree of traffic balance of δ and delay tolerance level of λ for assessment of the capacity of a single-tracked railway line are presented in the paper [5]. A mixed integer linear problem equipped with a dichotomization-based heuristic method is applied for the solution. Capacity and train schedules are evaluated together with optimization of railway capacity utilization.

The coexistence of single-tracked and double-tracked railway lines is considered in the paper [6]. The mathematical model for timetable optimization (design) in network combining these types of railway lines is presented. A case study from Spain is added for the illustration of model application.

The optimization model of railway infrastructure capacity is presented in [7]. The possibility of converting some parts of the infrastructure to double-tracked is mentioned as well. This model is based on the concept of theoretical

capacity whereas theoretical (idealistic timetable) is followed with no regard on the volume of capacity itself.

Microsimulation is used in the paper [5] as well. Double-tracked lines for freight trains are considered in Spanish conditions. A customized simulation tool was created for the aim of the project (advice whether to lengthen some passing loops) with focus also on simulation of possible overtaking slower trains with faster trains at passing loops.

3. Simulation Model

The microscopic simulation model was applied as a base for the research. The model consists of a general railway line with a length of 50 km that is equipped with 6 railway stations (one per 10km). Stations have a suitable number of station tracks for all modelled trains so that there are eliminated bottlenecks in railway operation. This infrastructure is applied for simulation of different transport scenarios and for identification of effects between capacity indicators and stability of operation. It is true that this creates conditions for consideration, but this model is applied for setting up research. Different results can be obtained with regards to specific conditions of lines with the different topology of infrastructure.

The timetable of railway operation was placed into the model along with the transport infrastructure. The model represents a timetable with a duration of 4 hours. The timetable is not periodic, because of the illustration of some specific transport situations.

There are 20 trains modelled in the timetable. All these trains are passenger regional trains. The line and the operation can be characterized as a suburban railway with regional traffic. There are 7 trains in operation from station A to station F and vice versa (the whole line), 4 trains operate half of the line and the next 9 trains operate in the segment between stations E and F only. This is an example of a higher intensity of operation in close suburban areas (e.g. collective segment that is used by more lines).

The reverse way of the design of the timetable is applied. The timetable is designed for the case when the line is double-tracked line in all length and effects of the conversion of segments to single-tracked line is considered in the model. Consideration has been done for both situations, deterministic as well as stochastic. Naturally, occurred delays can be reduced thanks to the design of a timetable reflecting topology of a single-tracked line, but the effect of conversion to double-tracked segments is not so much clear visible as with this way of expression. Train delays are not expressing operational reliability, but difference from optimal (double-tracked) operation in this case.

Different specific effects are induced in each segment of a railway line. The list of segments, selected stations and the related effect is provided in Table 1, chapter 6. Stations are numbered 1 to 6 and named from A to F.

The line is equipped by an automatic block interlocking system. More trains can operate in one direction together. Application of such an interlocking system using line blocks, automatic block, ETCS L2 or L3 etc. is the reason why the requirement of 2 trains in the same direction to access the segment at one time moment is not considered as a conflict.

All involved trains have the same parameters. The basic speed of all trains is 80 km/h, it means travel time of 7.5 min in each line segment which is increased by 1 min for acceleration and 1 min for deceleration (9.5 min in total). There are 7 trains operated along all the lines, 4 in about half of line and 9 in the close suburban segment of E-F only.

4. Proposal of an Analytical Approach

Assessment based on simulation provides results with good resolution, but time and the organisational demands that are needed for simulation are high. This is the reason why it is needed to find also some more straightforward analytical methods although they usually provide results that are simplified and not that detailed. These approaches are not considered to be applied in a parallel way, but the simulation will follow analytic methods to get a more detailed assessments in complicated cases.

It is needed to find some indicators that are able to characterize the operation in each individual segment in a followed point of view with an ability to predict the final result, which segment or segments should be converted to double-tracked.

The approach can be named as an inverse approach. The ideal timetable is designed for the line as it would be a double-tracked line in total length (optimal case). It is done although not all line segments will be converted to double-tracked. The values of the following indicators are found for each individual line segment. These values correspond to the deterministic way of operation. Time is divided into time units according to the resolution of the timetable (0.5 min in this case). The following indicators (expressed by a line segment) can be assessed using this approach.

The total number of conflict time units. Conflict is identified when at least two trains of different directions of drive require occupation of the same line segment at the same time unit (0.5 min). This can reflect not only the conflict itself, but partially the time of waiting for passing as well (when the line segment is single-tracked).

The ratio of conflict time units in the assessed time frame. This indicator is defined as the ratio of the number of time units with identified conflict to the total number of time units in the assessed time frame.

Total conflict time. It is an analogical indicator to previous ones, but the volume of conflict time units is expressed by time in a direct way.

Indicators mentioned above are related to the approach when the conflict is identified with no regard for how many trains are in the conflict at the same time moment. The following indicators are taking the number of trains into account.

The total number of train-time units of conflict. Each time unit with identified conflict is plotted with the number of trains in that conflict. The first train is not involved in this number (practically this train is not needed to be stopped).

The maximal number of trains involved in the conflict. The last indicator is identifying how many trains are asking (are in the queue) for a given line segment when the segment is occupied (by the first train).

The meaning of applied indicators can be explained as follows. The number of time conflicts N_c expresses how many times the trains are passing in the segment. Time in conflict ΣT_c represents the amount of time when there is more than 1 train in the line segment. Total train conflict time ΣTCT stands for a sum of time values of TCT_i when a train is not only one going in the segment. In other words, T_c evaluates conflicts in a line segment point of view, TCT from the point of view of individual trains. These indicators are illustrated by the graphical timetable in Fig. 1.

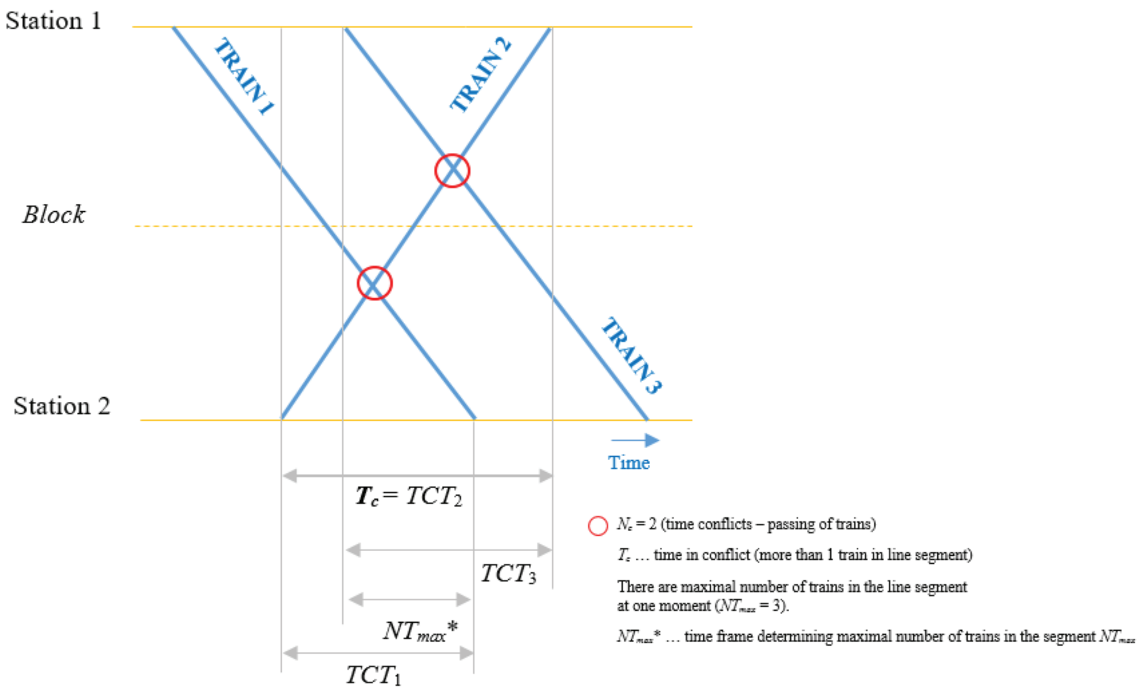

Fig. 1 Indicators for an analytical approach

5. Analytical Approach and Case Study

The proposed analytical approach was applied for the solved case study to be compared with the results of the microsimulation model.

The modelled railway line consists of 5 segments with a different volumes of operation and with different ways of passing trains. Each individual segment can illustrate the relation between the nature of the operation and the values of indicators. The values can be found in Table 1.

There is one difference between Fig. 1 and Table 1. Fig. 1 expresses one group of 3 trains. Table 1 contains generalized values valid for all trains (operational situations) that occurred in analysed time period with the length of 240 min.

6. The Importance of Microsimulation

The results of the analytical assessment (Table 1) can be applied for the statement of research hypotheses and for the definition of simulation scenarios. These hypotheses are examined in microscopic simulation together with characterisation of the railway operation itself.

Naturally, there is a very limited volume of cases in this case study to accept general conclusions, but we would like to present this as a case study-oriented research.

Simulation Scenario #1 (railway line is single-tracked in all segments)

The research starts with the scenario where the line is considered as single-tracked in all the segments. This is a base variant corresponding to the "state-of-art" topology of railway infrastructure. Application of the timetable designed for a double-tracked line can show what are the limits of such a line. High volume of delays can occur, but it evaluates the difference between ideal timetable and infrastructure limitations.

Simulation Scenario #2 (the segment of E–F is double-tracked only)

The busiest segment of modelled railway line is between stations 5 (E) and 6 (F) where additional trains operate. For illustration, these trains continue from E to another railway line.

Table 1

Values of indicators of an analytical approach

Line segments (stations)	Induced effects	Number of conflicts N_c	Time in conflict [min] ΣT_c	Ratio of time in conflict	(Total) train conflict time ΣTCT [min]	Max. number of trains in conflicts NT_{max}
1–2 (A–B)	1 passing close to the station 2 (B) (by one pair of trains)	1	1.5	0.63%	3	2
2–3 (B–C)	1 passing in the middle of segment (by one pair of trains)	1	9.5	3.96%	19	2
3–4 (C–D)	No passing	0	0	0.00%	0	0
4–5 (D–E)	Almost regular passing in the middle of segment (by most pairs of trains)	4	35	14.58%	70	2
5–6 (E–F)	Additional regional trains 9 passing situations.	9	48	20.00%	98.5	3

There are recorded the highest values of all indicators of capacity utilization in this segment (see Table 1). This simulation scenario #2 is based on the fact that only this segment is equipped with 2 tracks (is double-tracked).

Research hypothesis (related to this scenario) is that an important decrease of delays in comparison to scenario #1 will occur. In other words that converting this segment to double-tracked will be effective.

Simulation Scenario #3 (the segments of E–F and B–C are double-tracked)

This scenario is focused on the fact that there are 2 double-tracked segments on the line, each in a different parts of the line. On the other hand, the anticipated positive effect can be lower, because there is only one time conflict of 2 trains planned in this segment. It is the almost opposite situation than in E–F.

Simulation Scenario #4 (the segments of E–F, B–C and D–E are double-tracked)

This scenario is focused on the situation when all planned time conflicts (with only 1 exception in segment A–B) are located to double-tracked segments. It is anticipated that the results of the simulation will bring the minimal volume of delays because this situation corresponds to a timetable with an almost optimized passing of trains. Out of 15 total conflicts there are 14 time conflicts located on double-tracked line segments. In the case of stochastic simulation, we assess how the remaining single-tracked segments are limiting the capacity although only one passing is planned there. All the scenarios following infrastructure point-of-view can be compared one to another due to the application of the same timetable.

There are two approaches to simulate all scenarios – in the deterministic and stochastic manner. Deterministic simulation is usually applied for the validation of a timetable if it is "conflict-less". It is indicated by the fact that there is no delay recorded.

It was also tested another way - by a set of specific scenarios focused on conflicts of trains in individual segments. It is due to the fact, that (partially) single-tracked line is not suitable for the timetable using a double-tracked line. On the other hand, deterministic simulation provides important results as well. Limitations of a single-tracked line are assessed using this approach as it was mentioned above. Stochastic simulation is applied for the possibility to assess this situation not only in a theoretical point of view, but also regarding practical conditions. For example, an effect of two remaining single-tracked segments (A–B and C–D) in scenario #4 can be assessed because (with exception of one time conflict) these segments are not regularly applied for passing. This limitation is related to stochastic effects only.

There is only one time conflict in segment A–B. This passing is located very close to the station B. Time difference between the departure of one train and arrival of the second train is only 1.5 min so these trains may pass one another close to the switch area of the station B. This case can be applied for illustration how serious this situation can be in the point of view of operational stability as well as for research if this effect can be amplified or reduced with stochastic conditions – neighbour segment in the scenarios #3 and #4 is double-tracked, potentially allowing moving of passing to this double-tracked segments.

7. Discussion of Simulation Results

The main result of the paper is that the conversion of single tracked-line to a partial double-tracked line can be correctly measured when it is not possible to construct the second line in all segments of the considered line.

Our case study was evaluated with results that are available in Table 2. Individual lines in the table belong to individual modelled scenarios of double-tracked segments. Named segments of the line are double-tracked, the rest of the line remains single-tracked. The table is organized on the base of trains a train routes in the timetable. For that reason there are 20 trains in the stochastic simulation in spite of the fact that 16000 trains in total were taken into account by all 200 replications of 4 scenarios.

Table 2

Comparison of indicators for deterministic and stochastic simulation

Deterministic	Delayed Trains OUT	Avg. Delay OUT [s]	Max. Delay OUT [s]	Trains incr. delay	Trains decr. delay	Stable	Delayed Trains IN	Avg. Delay IN [s]	Avg. OUT/IN
Single-tracked #1	16	268.3	910	14	1	5	8	158.8	169.0%
F-E #2	6	80.4	438	5	1	14	1	10.35	776.8%
F-E, E-D #3a	5	146.9	1656	5	0	15	1	7.1	2069.0%
F-E, C-B #3	5	56.5	269	5	1	14	0	0	-
F-E, C-B, E-D #4	1	0.55	11	1	0	19	0	0	-

Stochastic	Delayed Trains OUT	Avg. Delay OUT [s]	Max. Delay OUT [s]	Trains incr. delay	Trains decr. delay	Stable	Delayed Trains IN	Avg. Delay IN [s]	Avg. OUT/IN
Single-tracked #1	20	364.9	541.2	17	1	2	20	287.1	127.1%
F-E #2	20	204.4	333.9	11	3	6	20	173.1	118.1%
F-E, E-D #3a	20	179	266.1	4	17	9	20	170.6	104.9%
F-E, C-B #3	20	135.7	265.2	3	11	6	20	170.2	79.7%

Indicator for the total number of delayed trains OUT means how many train routes have a delay value at arrival to the terminal station. It is important especially for deterministic simulation – only one replication without stochastically generated input delays. The possible positive value of Delay IN is caused by trains waiting on clear track between stations (from origin station), not by stochastic simulation in the case of deterministic assessment. Deterministic simulation is needed for evaluating how a timetable should be designed for a double-tracked line and how it will be applicable to such limited infrastructure. Naturally, practical punctuality of timetable can be improved with the design of a timetables for a specific composition of infrastructure. The case study is using an ideal timetable based on the "idealistic" operation concept for a given line with an effort to bring the infrastructure closer.

The values number of trains increasing, decreasing initial delay or of stable trains express how many trains tend to reduce or increase delays. Stabile trains are identified when the difference between input and output values of delay is less or equal to 3%.

The values representing stochastic simulation express average values obtained from all 200 replications of each individual scenario. For that reason, all 20 train routes indicate an initial delay. The ratio between output and input average value of delay plays a more important role in this case because it shows a tendency to reduce or increase the delay.

8. Conclusion

As a results document, it is not necessary to make all the railway lines double-tracked. It also can be seen that converting to double-tracked 3 out of 5 line segments (B-C, D-E and E-F) can allow applying this "ideal timetable" designed for 2 tracks along all the line without any time conflict in deterministic simulation. Results of stochastic simulation show that it is possible to obtain a reduction of initial delay with this composition of the single and double-tracked segments. The initial delay decreases by about 20%. Double-tracked version for 2 segments (C-B and E-F) allow "holding" the delay on a similar level as an initial (improved about 4%). It is simply quite clear that the segment with the most serious value of analytical indicators can bring an important effect when this segment will be converted to double-tracked as an individual (only one).

It can state as a result that proposed analytical indicators can help to select line segments to be converted to double-tracked, but it is not a strict result. When deterministic scenarios for converting to double-tracked segments E-D or C-B (by doubling of E-F) shows that the results are different from the very beginning. So, some other effects (maybe location of the segment on the line) are important as well. It can be concluded that this approach seems realistic but further research must be conducted in this filed for a greater level to generalize this conclusion as simulation assessment is still recommended, especially in ambiguous cases.

Acknowledgement

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Evaluation Methodology of Seaport Governance and Maritime Transport Attractiveness Dependence Based on Comparison of Seaports Governance on the Eastern Coast of Baltic Sea

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Abstract

Globalization of the global supply chain and the increasing emergence of international trade conditions challenge the complexity of maritime attractiveness because of numerous variable factors involved in the decision making of seaport selection from the perspective of seaport stakeholders. The complexity of the issue also relates to contingency in the market and it is therefore important to have some tools to evaluate the dependence between the decision making process at seaport governance level and its influence on maritime attractiveness from stakeholders' perspective. And this relation could be investigated by way of multilevel analysis of the seaport governance and multi-conceptional structure of maritime attractiveness; the dependence could be assessed via an expert survey by application of analytical hierarchical process (AHP) and grey relational analysis (GRA) combining methodology. The research established that legal structure has a direct impact on possible topmost effectiveness for seaport authority, what can be achieved through implementing an entrepreneurial business model based on the application of all determinant for the effective governance of state-owned enterprises, and these indicators may eventuate in uttermost maritime transport attractiveness.
KEY WORDS: *seaport governance, maritime attractiveness, governance effectiveness, attractiveness evaluation methodology*

1. Introduction

Global supply chain and seaport evolution in the emergent markets prompted the need to evaluate of how the seaport governance influences the attractiveness of the whole maritime transport sector in the region and to answer the question: which leading circumstances could increase or decrease the attractiveness of seaport as specialised modern logistic platform. Based on the trends of European seaports governance structure it is obvious that the majority of seaports (87%) are public bodies and more than half of them operate under a landlord management layout. Moreover, there are different public ownership forms such as national state-controlled enterprises or municipal facilities operating under different legislation. These conditions generate a high level of contingency around governance effectiveness because a lot of different governance frameworks could be found out in the combination of ownership and legislation forms. Some researchers found out that the state-owned companies are less effective because of the high bureaucracy hierarchic system of governance, other scientists maintain that less effective governance framework is on the municipal level. But both groups of scientists agree that the state-owned and municipal companies are especially important in the context of large scale investments, which are less attractive for private businesses due to the long term return on investment.

These circumstances prompted a wide range of criteria used by private companies for the evaluation of seaport attractiveness for setting up their business in the region or for selection of business location to the satisfaction of most seaport stakeholders. Further, these factors strongly relate to the seaport's spatial integration through a socio-economical perspective. Thus the key object of the research is the effectiveness of seaport governance in the maritime attractiveness context, and the focal idea of research is to compare different seaport governance modes, based on the formation of high regional maritime attractiveness.

2. Scientific Interpretation of Dependence Between the Seaport Governance and Maritime Transport Attractiveness

The interrelation between seaport governance and maritime attractiveness could be explained through the analysis of seaport governance structure. Partially this issue was investigated in the surveys of J. S. Lee Lam and D. W. Song [1] V. Bolevics [2], where the seaport governance efficiency was explored in the context of port performance. Because the seaport is generally a complex structure, as maintain the studies of G. R. Teisman and E. H. Klijn [3], T. Notteboom, P. de Langen and W. Jacobs [4], H. S. Cho [5], and X. Nguyen [6]. The outcome of the above studies finds the relation between seaport governance and maritime attractiveness to be dependent on the conceptual description of seaport under the emergence of internal and external circumstances. Firstly, the seaport per se is basically a specific

land and water territory owned by national governance. The exploration and management of this area is the key issue in the field of maritime attractiveness and seaport governance, because the whole seaport management including the recourses owned by the state or municipality, is subject to the seaport authority institution and its legal framework within the possible activities range [7, 8]. This managing body could be operating in varying relational modes and different legal forms within the differently structured management board, under diverse situations of uncertainty in the emergent market impacted by the global supply chain path development [3, 4]. This situation offers a lot of possible seaport governance models. Secondly, a seaport is managed by the Seaport Authority yet mostly in partnership with multiple different businesses and public facilities at the operational level of seaport business. And the overall governance effectiveness encompasses the efficiency of all these units [9]. Thirdly, seaport as the part of the national transport system and a part of the global supply chain, has been fully integrated into the supply chain and has unfailing logistical connectivity potential. Therefore, seaport governance is fully dependent on the national transport policies and legal seaport governance scheme that constitutes the seaport authority's operations in the field of exploitation the infrastructure and providing the business like conditions for businesses, also their integration to ensure the seaport's logistic connectivity [13].

Based on the theoretical principles of effective governance of state-owned enterprises [6] it was found that seaport governance effectiveness could be accounted for by these main determinants: financial and institutional autonomy within the polycentric governance control [6], strong competitive advantages [8], financial efficiency and operational productivity [7], clearance of the mission, strongly developed cooperation and partnership, leadership [6], the fulfilment of stakeholders' expectations [9]. And based on these findings and additionally including research results of V. Caldeirinha, J. A. Felicio, S. F. da Cunha, L. Machado da Luz [12] the main seaport criteria were identified for the survey: seaport governance's effectiveness (V), seaport authority's effectiveness (U), seaport authority business model's effectiveness (T) and maritime transport attractiveness (P) which are described in the researches of K. Ibrahimi on the maritime clusters [9], P. Verhoeven [8], P. de Langen and L. M. van der Lught [10] on seaport authority's performance. It can be assumed that maritime attractiveness P evaluation is based on the evaluation of seaport authority's performance P_{PA}, seaport performance P_{PP} and logistical connectivity performance P_{PL} [2, 9]:

$$P = P_{PA} + P_{PP} + P_{PL} . \tag{1}$$

Because the complexity of maritime transport sector attractiveness [9] establishes the link between seaport governance efficiency and maritime transport sector attractiveness [8], it can be defined by the seaport governance matrix model (Fig. 1), which generated the scope of cumulative maritime attractiveness [9]. For the evaluation of the relation between seaport governance and maritime attractiveness the different governance levels could be identified as shown in Fig. 1. Firstly, the policy of maritime and seaport governance is regulated based on the legal framework, also including the national transport policy and transport system integration into one unit working for the global supply chain connectivity. And the results of the highest level of governance enable management functions and activities on other levels. Strategical management level enables the processes and operations of the whole seaport and thus produces the attractiveness of a seaport business environment where the tactical and operational management could be applied [6, 10].

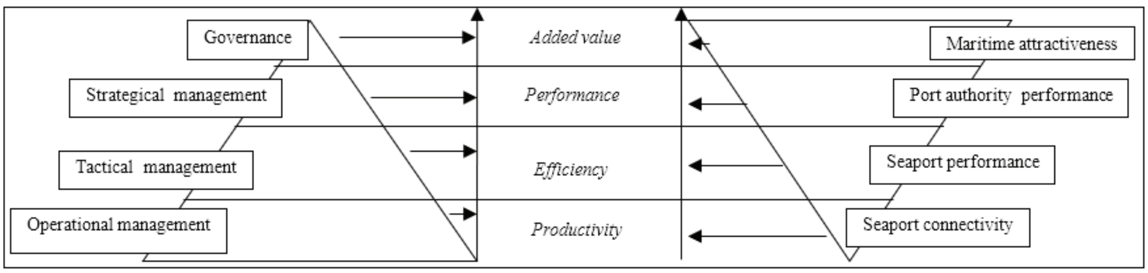

Fig. 1 Complexity of effective seaport governance concept in the context of the maritime transport sector attractiveness [6, 10]

Based on the findings of P. W. Langen and M. van der Lught [10], P. Verhoeven [8], K. Ibrahimi [9], V. Bolevics [2], J. S. Lee Lam and D. W. Song [1], the sum of seaport governance could be expressed as the seaport and maritime transport connectivity which is created by the seaport authority and governance integration. Another dimension of attractiveness is the seaport performance, and this determinant enables operational performance in the context of integrational connectivity within the hinterland transport systems [1, 9]. Another determinant of attractiveness - seaport authority performance which could be measured based on the implemented business model of seaport authority. The business model of a port authority explains the capacity of business processes. As found in the researches of P. Verhoeven [8], the three dimensions of seaport authority's business model exist:

- the conservative local business model based on the local operational level;
- the co-operative business model, expanded by improving financial and infrastructure development activities, based on the regional corporation level;

- and the entrepreneurial business model, expanded by enhancing investment activities, social and economic spatial integration, based on the global enterprise level.

It is important to explain, that these three types of business models are constructed on the base of cumulativeness and it means that the conservative business model is set up in a legal framework and defines the main seaport authority functions that enable seaport activities at all. But these functions and activities are not enough facilities for the formation of maximal maritime attractiveness and attractive advantages in the global supply chain. Based on the research results P. Verhoeven [8] found that the regional and global port authorities could survive in the globalization of the supply chain, and these types of port authorities could create the uttermost attractive seaport business environment and maximise the attractiveness of the whole maritime transport sector.

In summarizing it could be noted, that the maritime transport sector attractiveness depends on the performance of the seaport authority business model, which is provided for in the legal framework of seaport governance.

3. The Methodological Approach to the Evaluation of Dependence Between Seaport Governance and Maritime Attractiveness

For the assessment of indexes of attractiveness (P), governance effectiveness (V) and seaport authority attractiveness (U, T) the combined multi–criterial decision–making methodology based on the analytical hierarchical process (AHP) and grey relational analysis (GRA) methods were applied as it was approved in the analytical researches of J. Chen, Z. Wang, F. Zhang, N. K. Park and A. Zheng [11]:

- AHP method was applied for the calculation of significances of governance effectiveness (w_V), seaport authority performance, expressed through the seaport functional performance (w_U) and seaport authority operational performance (w_T), maritime transport sector attractiveness criteria (w_P) based on the applying the pairwise comparison methodology;
- GRA method was applied for the calculation of the comparative index, expressed through grey relational grade GRG, of governance effectiveness (GRG_V), seaport authority performance (GRG_U, GRG_T) and maritime transport sector attractiveness (GRG_P) at the seaport of the eastern coast of Baltic Sea – Tallinn, Riga and Klaipeda seaports, based on the expert's criteria assessment by the Likert scale where 1- weakest position, 5- strongest position;
- combination of AHP and GRA methods were applied for the weighted comparative grey relational grade (w_VGRG_V, w_UGRG_U, w_TGRG_T, w_PGRG_P) calculation used for substantiation of the relationship between seaport governance efficiency and maritime transport sector attractiveness, and establishment of strengths and weaknesses in compared seaports.

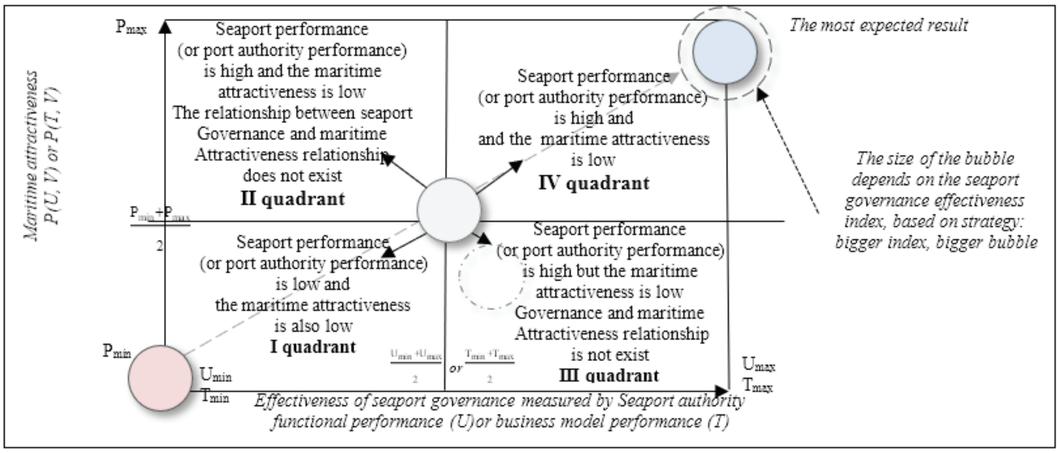

Fig. 2 Three-dimensional matrix model for the visualization of maritime attractiveness relation with the seaport governance effectiveness [13].

Based on the said methodology's principles the expert survey was conducted for the evaluation of the significance of each governance and attractiveness criteria and for assessment of these criteria in different maritime transport sectors on the eastern coast of Baltic Sea, actually the case studies of Riga, Tallinn and Klaipeda seaports. For the evaluation of these signs and comparative coefficients the expert survey was applied: 81 experts from Lithuania, Latvia and Estonia participated in the research, by 27 experts from each country. The set of experts were formed based on these assumptions:

- the experts' set must be adequate on the structure of stakeholders: 1 national, 1 municipality, 1 seaport authority, 1 seaport management board representatives, and 4 representatives of public organizations operating in the seaport (governance group – 15%); 2 shipbrokers, 5 stevedores, 3 expeditors, and 2 hinterland logistics representatives (direct seaport's actors 44%); 1 passenger shipping companies, 12 shipbuilders, 1 industry, and 1 IT company involved in IT projects development in forelands and hinterlands representatives (indirect seaport's actors 15%); and 3 scientists and researchers' representatives (11%);
- experts must be practiced at least 5 years in the presented position;

- experts should be managers at the governance or strategical, tactical, and operational level;
- scientists must prepare at least 3 scientific publications in the related scientific area and to have a Doctor of Science degree in management or technological sciences.

Based on the theoretical and methodological approach of the assessment on the dependence between seaport governance effectiveness and the maritime transport sector attractiveness the three-dimensional visualisation was prepared based on the chart presented in Figure 2. If the calculation results will appear in II or III quadrants, it will mean that the relationship does not exist and the governance framework in these seaports is neither balanced nor effective.

In another case, it will be assumed that relation will exist and the recommendations will be constructed based on the quadrants: I quadrant means, that governance framework is not effective and should be improved, at III quadrant – the seaport governance have potential to grow maximal effective and maritime attractiveness to be upped to maximal. Additional analysis of comparable weighted criteria makes it possible to fulfil recommendations by identification of the weaknesses and strengths in the context of improving maritime attractiveness.

4. Analytical Approach to the Evaluation of the Relation Between Seaport Governance and Maritime Attractiveness

Based on the effective governance criteria significances in the context of maritime attractiveness the following management criteria for the improving maritime attractiveness were established as most significant:

- the most effective seaport governance framework shall outline these criteria: the national seaport within the management body operating under corporative law in the background of landlord seaport type including the private and public partnership based on the concession agreements (see the bubble size in Figs. 3 and 4);
- the most effective port authority functions in the context of maritime attractiveness involve the essential authority functions as management of infrastructure and ensuring seaport activities including safety and security, further including the elements of sustainable infrastructure development and attracting of large scale national and international investment through the effective management of public and private cooperation in the seaport cluster;
- the most effective port authority functions relate to a strongly developed conservative business model of the port authority, however, for increasing the maritime attractiveness it is important to develop port authority's business model which should encompass the worldwide financial investment into the port and hinterland terminals, spatial integration through the social and economic dimension within the stakeholder's expectations fulfilment, and creating added value, which all refer to the operations of entrepreneurial business model.

The research results presented below in Figs. 3 and 4, gives the possibility to summarize that maritime attractiveness has more flexible relation within the port authority business model, because the attractiveness dependence on functions are very strongly related and the modelling process could be too vulnerable for changes of functional parameters and this result could be explained by the strongly functional dependence on legal governance framework. Based on these assumptions, for the evaluation it is preferable to use attractiveness dependence on the port authority's business model.

Research results found out that the highest attractiveness index was that of Tallinn maritime transport sector which is built on the high level of seaport authority business performance: strongly developed basic conservative business operation, and widely developed and developing entrepreneurial business operation shape the high index of seaport governance effectiveness (Fig. 4).

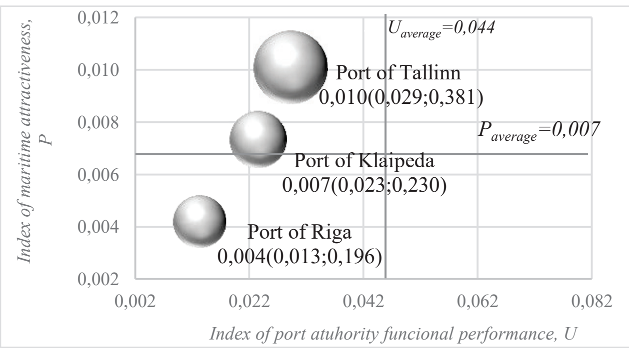

Fig. 3 Attractiveness index dependence on port authority functional performance

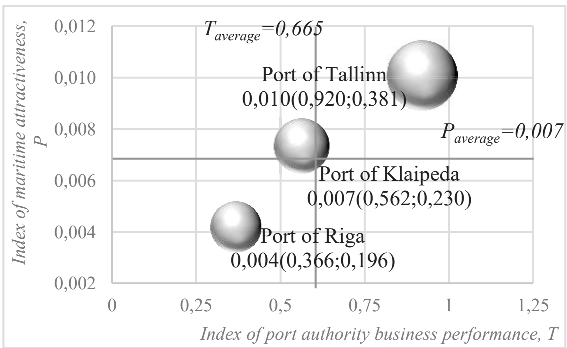

Fig. 4 Attractiveness index dependence on port authority business performance

Port of Klaipeda governance effectiveness and maritime attractiveness is in the middle range: the strongly developed conservative business model of port authority creates a high level of possibilities to develop entrepreneurial business activities, but the legal status of the port authority in the range of state-owned enterprise limits this potential. Therefore, at the time of research certain improvement in maritime attractiveness could be observed, based on the partially improving the activities of the co-operative model (Fig. 4). The research found that port of Riga governance effectiveness is based on the strongly developed some of the co-operative model's activities of the port authority, but

the low level of implemented conservative and basic functions generate the low level of maritime attractiveness, and a most effective way to increase maritime attractiveness could be achieved by improving the basic port authority functions as provided in legal governance framework, including continuity to develop co-operative model's activities. However, the entrepreneurial functions at the research time were not possible because of the legal status of the port authority – a municipality owned institution.

Based on the results, presented above, the main outcome recommendation could be formulated based on research findings presented in Figs. 5-7. As shown in Fig. 5, it is not enough to develop the basic significant operation of Port authority business in the context of maritime attractiveness, it is equally important to maintain a cooperative business model, which has the cumulative effect on the increase of maritime attractiveness (Fig. 6). And lastly, the maximal effect could be gained through developing entrepreneurial business activities (Fig. 7), operated however under the corporatized governance framework which is adequate for the effective governance framework index.

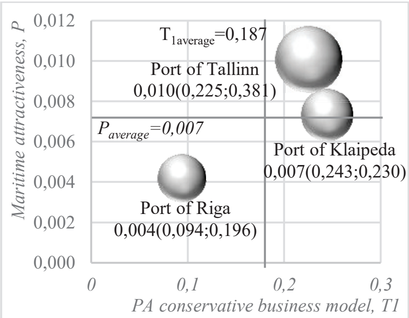

Fig. 5 Maritime attractiveness dependence on the conservative busi-ness model of the port autho-rity

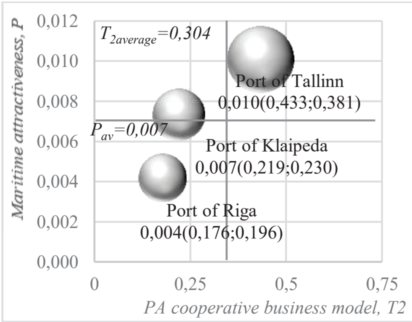

Fig. 6 Maritime attractiveness dependence on the cooperative business model of the port authority

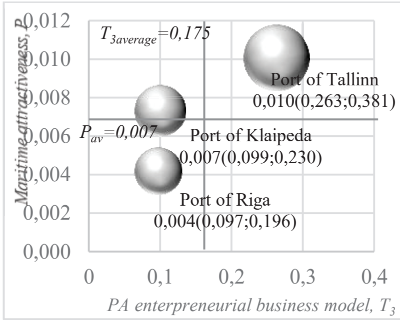

Fig. 7 Maritime attractiveness dependence on the entrepreneurial business model of the port authority

Based on the research results it is important to note that maritime attractiveness in all seaports could be increased by way of improving the financial incomes from infrastructure management, sustainable infrastructure projects implementation and also increasing social and economic spatial integration through digitalization, and positioning regional seaports as environmental friendly logistic platforms. Recommendations for increasing maritime attractiveness at Riga seaport are based on the improving fundamental port authority functions such as diversification of port duties and increasing the transparency of port regulation, also increasing port connectivity within the best developed hinterland infrastructure consolidation in the region. Recommendation for Klaipeda seaport is to develop spatial social and economic integration through the added value creation and enhancing financial investment activities, and upkeeping strongest positions in infrastructure management.

5. Conclusions

Based on the scientific research and theoretical approaches the dependence between seaport governance and maritime transport sector attractiveness could be interpreted through the theoretical principles of state-owned companies governance, which insist that the main influence factor for increasing the maritime attractiveness is the effectiveness of governance denoted through these effectiveness determinants: financial and institutional autonomy, high operational productivity and financial efficiency, leadership and partnership, expectations of stakeholders and clarity of mission, which presume creation of high value added services. Scientific research found that effective governance based on the legal framework of seaport enables the performance of port authority and port connectivity, which directly shifts the maritime attractiveness to the higher level dependent on the seaport authority business model and range of functions. The upgrade of the port authority's performance is the precondition for a more attractive business environment that may result in the boosted performance of seaport.

Based on the scientific research of seaport governance influence on maritime transport attractiveness issues, the research methodology was conducted by combining two multicriteria decision-making methods AHP and GRA. The limitations of methodology - the geographical dependence of experts due to which application of the methodology worldwide is restricted. Further, it would be more appropriate to calculate index in the combination of quantitative and qualitative data, but this requires creating additionally a balanced comparable indication system, which was not the object of the present research. For more significance and consistency of research, the additional criteria were considered such as consistency ratio and the competence index of experts. The application of prepared methodology bears the result – a method of how to evaluate maritime transport attractiveness based on governance effectiveness, and the method was put to test through the comparison of Klaipeda, Riga and Tallinn seaports governance performance and maritime transport sector attractiveness.

The research results found that the highest maritime transport sector attractiveness' index established at Tallinn maritime transport sector, because the Tallinn seaport authority operates under the corporatized governance framework and has strongly developed basic significant functions and the port authority runs the entrepreneurial business model.

The second-rated seaport of the eastern coast of the Baltic sea is Klaipeda seaport, with Lithuanian maritime transport sector attractiveness based on the strongest developed conservative business model as well as the implementation of most significant functions pertaining to the infrastructure upgrade and established safety and security. The main attractiveness advantage in Riga seaport is the outstanding port entrance navigation services and implemented numerous activities of the co-operative model, however weak development of main significant port authority functions gives the lowest index of attractiveness in the region.

Recommendation of increasing maritime attractiveness at Tallinn, Riga and Klaipeda is based on the improving the business model of seaport authorities of Tallinn, Riga and Klaipeda seaports by the implementation as much as possible co-operative and entrepreneurial facilities, but firstly the legal framework of Riga and Klaipeda seaports governance should be revised, because the existing governance schemes limit the entrepreneurial activities of Riga and Klaipeda seaport authorities.

The main attractiveness of the produced methodology is a possibility to be applied not only in the scientific research in the field of seaport management and governance, but this methodology can be applied in other fields of maritime transportation such as performance of logistical and technological systems, the performance of seaport technological connectivity where the qualitative and quantitative indicators could be combined to derive the best results in the decision–making processes of seaport governance.

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Preventive Measures to Gain Optimal Surface Quality to Mitigate the Outcomes of Runway Excursions

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Abstract

The paper deals with the efficiency of regular measures of airport maintenance to gain optimal surface quality of unpaved areas to help to prevent the effects of runway excursions. The authors investigated the practical application of the theory of soil mechanics, specifically of the compactor efficiency at adjacent areas to paved surfaces. These are to come with the needs of safety, so to meet with two contradictory requirements. On one hand, the surface should provide sufficient bearing capacity to carry an aircraft without intolerable damage, and on the other hand, in contrast, it should ensure satisfactory drag to stop an aircraft within designated limits far from air traffic obstacles. The results from exhibited experiments are due to be applied as a base in the refinement of current methodology in airport maintenance practice.
KEY WORDS: *runway, runway excursions, unpaved airport surfaces, runway end safety area, runway strip, rolling efficiency, soil moisture measurements*

1. Introduction

The runway design may come well enough with aircraft operated at a specific airport to fulfill the highest standards in air traffic safety. However, the conditions for severing incidents and accidents associated with an aircraft running off a runway are still in place. Having conducted a brisk survey of aircraft accidents, roughly a half (approximately 50 percent) is associated with runway excursions [1, 2]. Suppose these accidents cannot be entirely reduced, the outcomes could be certainly mitigated through the thorough design of unpaved transition areas such as runway strips and runway end safety areas. It is recognized that it should be predominantly enduring over the full range of weather conditions. In order to tackle this, generally, the aviation authorities require that the maximal sinking limit of an aircraft tire in these areas is 15 cm ensuring sufficient drag to stop the aircraft safely. In doing so, the major aircraft manufacturers claim that such a drag cannot pose any danger of aircraft damage. If left in the natural state, the adjacent areas are necessary to maintain regularly. Especially dynamic compaction is highly efficient in doing so. However, despite the extent of the theory over the soil compaction, a field experiment at a particular airport is highly needed to gain appreciated results.

2. Applicability of Soil Compaction at Airfield Maintenance Practice

Despite being an intrinsic part of common building practice, the compaction is highly needed in the maintenance of unpaved and unprepared airport surfaces for economic reasons. Runways with taxiways and aprons are always the focal point. Their physical characteristics are retained by a thorough design and maintenance requiring a great deal of effort and investment. On the other hand, the safety, transition areas being extremely spacious are left in a natural state, if it conforms to the specific traffic requirements. Nevertheless, the design of these areas is often associated with specific conditions of soil being in a certain range of soil density giving the final soil properties such as bearing strength. The real state is extremely vulnerable, dependable mainly upon the meteorological and seasonal changes. In order to mitigate them a regular maintenance practice covering above all the compaction should be ensured.

Firstly, to clarify the compaction as a term, mechanical densification of soil with the particles being pressed into closer contact whereupon the air being expelled. In contrast to consolidation when the static force is implied, the compaction involves the dynamic force by moving loads often carried out by rollers. As a result, it implicates settlement, changes in shear resistance, volume changes and movements of water. From practical experience, particularly the shear resistance of some soils can be even doubled. Despite being an extreme example, even the smallest changes can be worth considering. Seeking the quantification, the process is normally formalized in the building practice by dry density respectively dry unit weight. Despite requiring insignificant elaboration in the field, it should be considered for airport practice too.

Secondly, the relationship between soil moisture and density is extremely important in the field while conducting the compaction. That is to say, the moisture content should be at the level at which the soil becomes sufficiently workable with soil particles closely pressed and the air is mostly expelled (see Figs. 1 and 2). This tendency at most soils is analogous. However, the moisture and density ranges vary upon specific soil content. In general, less moisture out of the Optimal Moisture Content (OMC) more difficult it is to compact whereas more moisture out of the OMC is

present in the soil, less density can be gradually attained. To support appropriate information relevant to a particular soil condition, usually, laboratory tests such as the Standard or the Modified Proctor are essential to deploy [3]. It is worth noting that the resulting characteristics are valid for one single compactive effort. From hand on experience, more efforts are known to have increasing effects on maximal density and decrease on the OMC. On account of this, in practice, the compactor characteristics such as the weight and the number of passes can be roughly estimated according to the maximum density and the OMC of a specific soil. However well the machinery is chosen, the actual compaction is vital to be tested in the close proximity of a real surface having the same soil conditions [4]. (see Fig. 3) As mentioned, the density and the OMC vary for different soils. On one hand, the moisture content is less critical for soils with greater clayey content, and on the other hand, it is rather critical for granular soils with good grading [5]. As a result, these soils require rather thorough moisture control, which is, by and large, recommended to be approximately 5 % of the soil density and 4 % of the OMC. In short, a variety of soils possesses different compactive characteristics, which are highly associated with the moisture interval in which the soils are workable.

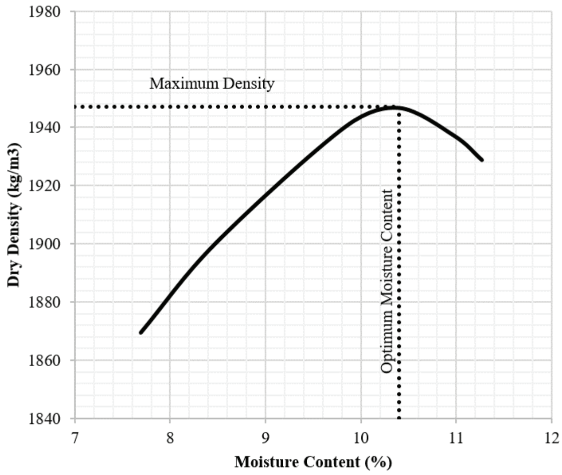

Fig. 1 Example of the relationship between moisture and density at Airport 1

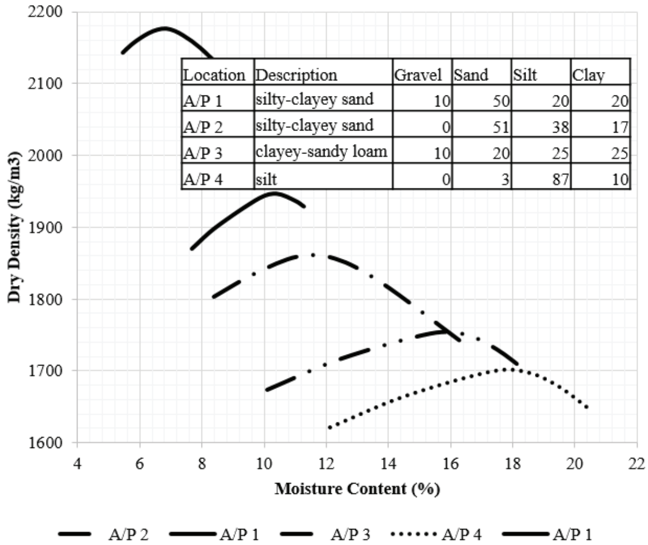

Fig. 2 Compaction effort of various soils representing the average condition at the tested airports

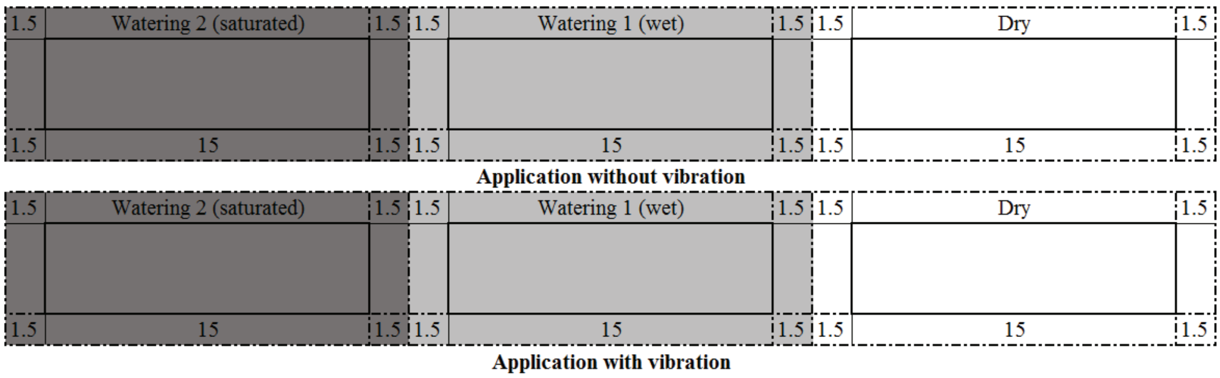

Fig. 3 Site proposal for a number of compactive efforts at airfields [4]

Thirdly, while testing a number of roller passes, it is necessary to evaluate the soil density. A number of devices can be applied whether for laboratory or field applications. Considering airfield maintenance practice, only those with rapid deployment and appropriate accuracy are vital for this kind of experiment. In reality, the aim is to ascertain the value of actual unit dry weight respectively dry density. Even in the field, the unit wet weight can be easily ascertained by taking a sample of known volume and weight from the soil layer. Then the unit wet weight equals to the wet weight of the sample divided by its volume. Having known the soil moisture, a simple formula can be easily applied to calculate the expected unit dry weight.

3. Machinery Selection for Application in Airport Maintenance Practice

The compactor application and selection in the airfield operation have always been dependable on the local availability of machinery as this sort of maintenance can be perceived as supplementary actions. In 1970's highly specialized self-propelled pneumatic-tired rollers were designed targeting the specific use at airfields. The design

seemed to be ideal for grass and soil surfaces, having the capacity enabling the roller to be adjusted for different soil conditions and required compaction. Being applied a week or so per a season, the concept proved to be highly economically inefficient. As a consequence, other more universal rollers took over its role.

Firstly, from economical and rational reasons the machinery, which was chosen for this study, was supposed to be available at all four airports. That is to say, the two-axle steel-wheeled and the self-propelled, smooth-drum vibratory rollers were tested. The reason was to figure out the optimal compacting procedures in the local conditions and to compare the results achieved by both of them with characteristics declared by the self-propelled, pneumatic-tired roller, which was commonly applied at airfields in 1970's. The scope of the basic information associated with compactions is displayed in Table 1.

Table 1

Basic compactor characteristics of selected compactors associated with soil compaction [6, 7]

Device	Weight (kg)	Width (mm)	Compaction pressure (MPa)	Vibration frequency (Hz)	Centrifugal force (kN)	Static linear load (kg/cm)
Self-Propelled, Smooth-Drum Vibratory Roller JCB VM 135	14550	2100		31/36	282/173	34.3
Two-axle, Tandem-Steel Wheeled Vibratory Roller VSH 100	5000/5200 (front/rear drum)	1600		30/42	80	24.5/28.4
Self-Propelled, Pneumatic-Tired Roller PV-25	12000 – 25000	2500	0.18 - 1	-	-	n/a

Secondly, with regards to the testing locations, the testing sites were selected in the close vicinity of the runways at all four airports tested. The designed dimensions were 15 times 4 m ensuring two moves, one next to the other for a total of three areas per roller at each airport. The first area was designated for moves without vibrations whereas the second and the third area were picked for moves with vibration frequency one and two. The site which was supposed to be wetted was not applied as the tests were launched in the springtime and after the snow thawing (see Fig. 3). The commence of experiments was sensitively pinpointed up to the point when the ground had roughly the optimal moisture content for the compaction.

Thirdly, to evaluate the effectivity of the compaction process, a number of characteristics were supposed to be ascertained including the number of passes, bearing strength, soil moisture, wet and dry density. The most vital characteristic to ensure the operability of unpaved airport surfaces is the bearing strength. To come with the current needs of aviation regulations, it should be obtained in the California Bearing Ratio (CBR) [8]. Despite gaining the CBR estimate, the Dynamic Cone Penetrometer was applied due to its speed and comfort of deployment [9-12]. The soil moisture content was calculated based upon a measurement of bulk soil permittivity (εb) and electrical conductivity (σb or ECb). These were used to calculate pore water conductivity (ECp), porous soil permittivity (εp) from soil temperature into the volumetric water content (θ). Extensive studies have displayed that the volumetric water content (θ) relates to an equivalent of the square root of the soil dielectric constant (ε) [13-15] (see Eq. (1)). Initially, the coefficients ($x1$, $x2$) were obtained experimentally, however, due to slight diversity in the soil content over the vast movement areas, the device default values were considered as the optimal solution [16].

$$\sqrt{\Sigma} = x_0^2 + x_1\theta \,. \tag{1}$$

Fourthly, having investigated the theory over the compactor efficiency concerning to the soil depth, the compaction should be conducted in layers to achieve reasonable outcomes in greater depths. In other words, the soil profile requiring densification is necessary to separate into layers from 15 to 20 cm thick. The level depends on soil composition and moisture content. This supports the idea to launch the tests at specially designed testing sites. On top of this, it was found that in the example of granular soils with good grading, which seems to be rather common at tested airports, it is necessary to retain the moisture level in the interval of roughly ±2% of the OMC to achieve reasonable compaction regardless the type of the compactor. As a consequence, special attention has to be dedicated to moisture measurements specifically at the Airport 1 and 2. Furthermore, having investigated the applicability of the soils for these constructions, nearly any soils, except for highly organic soils, can be theoretically retained in the transition areas if properly maintained. That is to say, despite being extensive, the range of tested soils provides sufficient compaction characteristics to come with the needs of the tested airports. It supports the theory as the coarse grained are highly desirable whereas the fine grained are less being more difficult to compact and requiring more careful moisture control. As testing machinery, two axles, tandem steel wheeled and self-propelled, smooth drum vibratory rollers with different weights were available and applied (see Table 1).

Finally, as mentioned, the water content during densification should be somewhat around the OMC. The construction work being conducted in the field, the soil condition and therefore the moisture is strongly dependent on the weather condition, specifically on the precipitation rate. Suppose the example when the actual soil moisture is below the allowable range, the water should be added whilst when above the OMC the field drying should be executed. Both

activities is expected to be done thoroughly, mixing the soil with water is necessary for a common construction practice. However efficient this appears, it can hardly ever be done in common airport maintenance practice. Only the irrigation appears to be feasible which may involve the water sprinkling only. The amount of water required to be added could be easily calculated by the use of a simple formula. Nevertheless, it has been proven that the specific condition, when the compaction is effective, happens a few times during a season. As a result, the full advantage of this period should be taken. This, however, requires continuous soil moisture monitoring in the vicinity of the airport movement area.

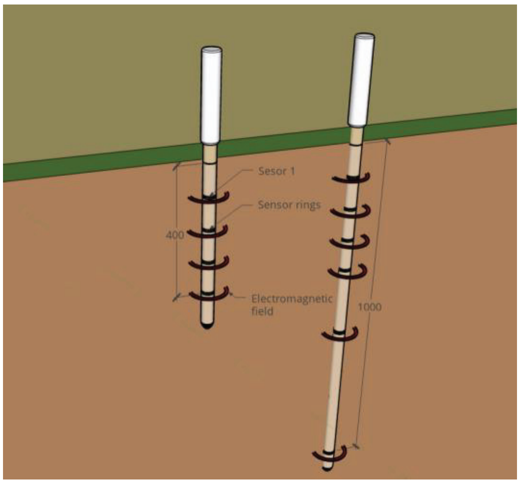

Fig. 4 Application of profile probes in a soil

3. Results and Comments to the Experiments

Having tested a wide range of soil characteristics in the specific conditions of the particular airports, the results should be formalized for practical applications. That is to say, specifically, compact lift respectively thicknesses and an effective number of compactor passes seem to be reasonable and sufficient in the airfield practice. In order to fulfil the aim of this study all of these were calculated with the aid of soil moisture, density and strength measurements for each roller pass. The total of passes varied from airport to airport, but, by and large, at least ten were conducted per a site. With regards to the measuring locations, the specific testing sites were sensitively selected in the close proximity of live runways, so some of the measurements requiring physical presence were conducted when the air traffic was suspended. Focusing on the specific airports which locations are characterized by diverse soil conditions, the advantage of the wide variance was taken and they were split into three overall soil groups being comprised of coarse-grained, mixed-grained and fine grained soil conditions. Particularly, Airport 1 and 2 were categorized into the coarse-grained group according to the prevailing soil content, whereas Airport 3 into the mix-grained and the airport 4 into the fine-grained group.

Firstly, the compact lift plummeted with the decreasing grain size at variance for the different equipment. The best outcomes were achieved by the smooth-drum vibratory roller represented by 0.4 m for the coarse grained, 0.3 for the mix-grained and 0.2 for the fine-grained materials whereas the worse in efficiency was displayed by the tandem-steel wheeled roller with the range from 0.3 for the coarse grained soils down to 0.15 for the fine grained. (see Table 2) The numbers characterizing the pneumatic-tired roller were gained from theoretical calculations based upon measurements a few decades old. Nevertheless, it was added to give greater overview over level of efficiency of the tested rollers.

Table 2

The results formalized in the table with the vital information for practical application

Airport	Soil classification	Self-Propelled, Smooth-Drum Vibratory Roller		Two-axle, Tandem-Steel Wheeled Vibratory Roller		Self-Propelled, Pneumatic-Tired Roller	
		Compact lift / thickness (m)	Number of passes (1)	Compact lift / thickness (m)	Number of passes (1)	Compact lift / thickness (m)	Number of passes (1)
A/P 1	Coarse-grained	0.4	8	0.3	8	0.4	10
A/P 2		0.3	6	0.2	8	0.3	7
A/P 3	Mix-grained	0.3	6	0.2	8	0.3	7
A/P 4	Fine-grained	0.2	6-7	0.15	10	0.2	6-7

Secondly, the number of passes was attained by calculation of the dry density and the bearing strength measurements after each roller pass. Although the strength is crucial for the operation, the final values were calculated with the aid of the density. The measured strength in average increased up to three passes and then with the following

passes it either remained at the same level or slightly decreased (see Figs. 5-8).

Finally, as mentioned in the previous text the assessment of the compaction effectivity was based on acquiring an actual soil density. It could be ascertained through various means, the theory accounts on with the soil moisture measurements which in fact were in the beginning measured in the limited soil profile down to 5 cm. Despite measuring continuously, it proved to be extremely restrictive and obstructive. By the end, the moisture measurement had been successfully tested by the application of a profiled probe measuring the moisture in the entire profile down to 40 resp. 100 cm in 10 cm increments. (see Fig. 4) Providing this, the practical experiments showed that the control of moisture can be easily controlled and therefore retained in great deal smaller margins. Previously the 4% limits were hardly retained whereas the application of the profile probe helped to shrink this interval into roughly 2%. This supports the idea that the profile soil measurement is vital in the effective maintenance of unpaved areas by compaction, specifically for airport unpaved areas.

To sum up, as shown in the chapter, the best performance with regards to the soil compaction was achieved by the smooth-drum vibratory roller regardless of the material being compacted. While gaining the essential soil characteristics, it was found that the effective moisture controlled can be achieved by the application of probes based on electrical soil properties measurements. Particularly, the comprehensive information over the soil moisture in the entire soil profile down to at least 60 cm provides sufficient accuracy for launching effective maintenance.

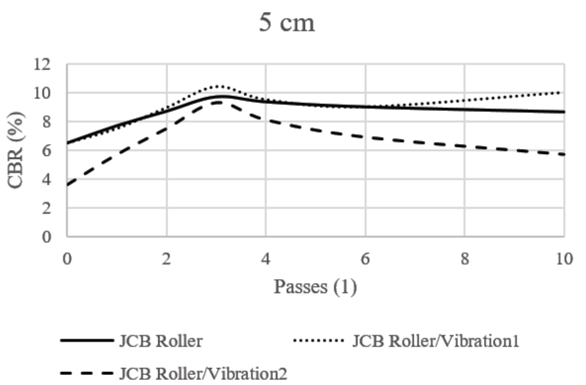

Fig. 5 Example of the bearing strength measurements for the depth of 5 cm for the roller without vibrations, vibration speed 1 and 2

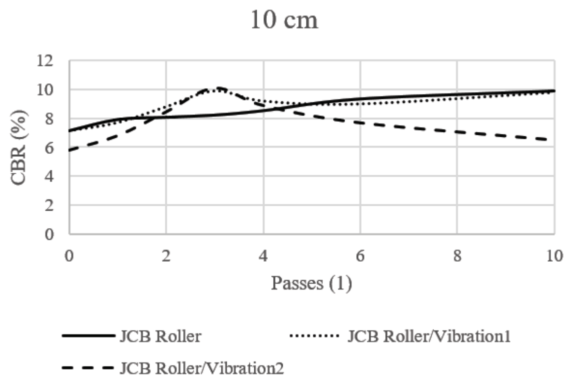

Fig. 6 Example of the bearing strength measurements for the depth of 5 cm for the roller without vibrations, vibration speed 1 and 2

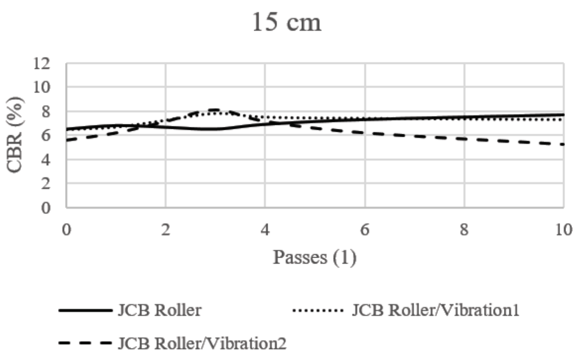

Fig. 7 Example of the bearing strength measurements for the depth of 5 cm for the roller without vibrations, vibration speed 1 and 2

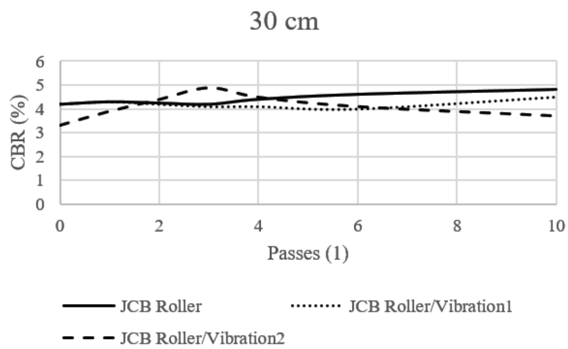

Fig. 8 Example of the bearing strength measurements for the depth of 5 cm for the roller without vibrations, vibration speed 1 and 2

4. Conclusions

In closing, the formal, theoretical principles of soil mechanics aimed at the maintenance of unpaved airport areas were formalized and supported by experiments at the real airport practice. To support the repeatability and practical applicability, the tests were executed at four airports characterized by diverse soil conditions representing three important soil groups comprising the coarse grained, mix-grained and fine-grained conditions. Not only was the compaction equipment and procedures assessed based on the efficiency in real conditions, but also the necessity of constant monitoring of soil condition was stressed. The experiments comprised in the paper display the importance of the availability of the soil moisture which should be ensured for a full soil profile. On top of this, practical examples of the specific application of the probes measuring electric properties of soils have shown the suitability and feasibility for the field practice. The constant monitoring proved to provide vital aid in retaining the designed surface quality over its

lifetime. On account of this, the highest safety standards issued by the aviation authorities may be effectively maintained in airport operations.

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Challenges and Development of Gas Fuel Storage Systems in Means of Transport

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Abstract

An overview of contemporary solutions for gaseous fuel storage systems in high-pressure tanks in means of transport is included in this article. Development in this area is currently very intensive due to the increasing use of gaseous fuels to power internal combustion engines. The variety of solutions used is the answer to the challenge of reducing global carbon dioxide emissions and reducing toxic emissions. The development of new tank designs as well as the tests carried out allow for the improvement of systems in terms of functionality and safety. The study presents solutions used in the storage of hydrogen and natural gas. The results of testing these solutions in the light of the requirements of applicable standards and legal provisions are also presented.
The high level of sophistication of modern technologies for the production of high-pressure tanks (cylinders) allows to increase working pressures to 70 MPa. The main purpose of the presented research is to verify the tank structure and applied security systems. The basic test methods are checking the tank and the functioning of the safety devices in open fire conditions (Bonfire test). In addition, CNG and hydrogen storage tanks undergo a penetration test. During this test, it is important to properly empty the tank after shooting through a rifle bullet.
KEY WORDS: *gaseous fuel, storage systems, CNG, Hydrogen*

1. Introduction

Limiting CO_2 emissions is currently the most frequently cited argument in global economic development. The EU energy transformation assumes achieving full decarbonisation of fuels in 2050, and in 2030 the number of registered trucks powered by CNG/LNG should constitute 25% [1]. Initiatives are also being undertaken towards the intensive development of infrastructure enabling a significant concentration of NG refueling points network, and its availability at multi-fuel stations. Observing the development of the automotive market, there is a continuous increase in the number of vehicles powered by gas and electricity (Fig. 1). As published in the report of the European Automobile Manufacturers' Association (ACEA), the share of vehicles powered by these energy sources, registered in 2019, was 10.6% (in the 4th quarter of 2019 - 13.2%), while in 2018 only 7.5% [3]. These data do not fully reflect the share of vehicles fueled with gaseous fuels, since a significant part of them is adapted to gas supply on the secondary market. As regards gaseous fuels, upward trends persist for several decades. This is due to the fact that these fuels significantly reduce carbon emissions. When using biomethane, this balance in the WTW area can be even negative in some cases [2]. At the same time, the costs associated with their use are often lower than for traditional fuels.

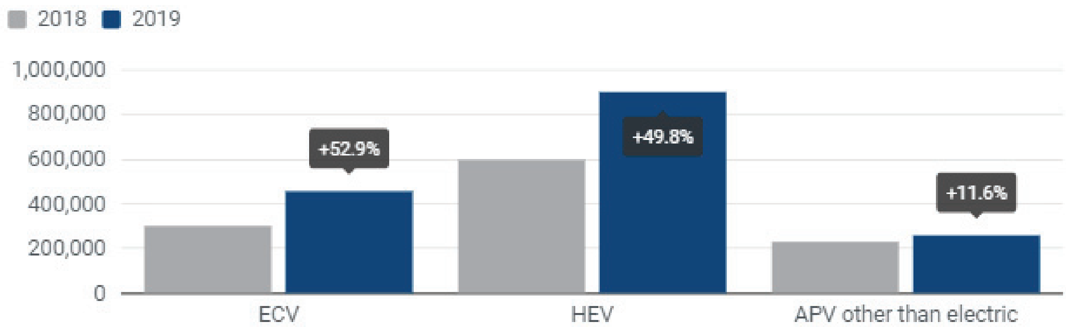

Fig. 1 Number of new registered electric and alternative fuel powered vehicles in the European Union

A similar recovery is observed in the use of hydrogen in motor vehicles. The basic group here are vehicles (cars and buses) powered by electricity generated in fuel cells, where hydrogen is an energy carrier. These vehicles are included in the zero-emission category because they do not emit CO_2. Therefore, their development makes a significant contribution to the said energy decarbonisation program. Additional advantages include shortening refueling time and increasing range. Currently, the main restrictions on the development of this solution are: high cost of fuel and a poorly developed network of hydrogen refueling stations [4].

From a technical point of view, the storage of gaseous fuels is a challenge to ensure proper energy density. This is a very important factor for the comfort of using the vehicle. Comparison of the energy density of the fuels used shows that, compared to traditional fuels, natural gas despite a similar calorific value (about 50 MJ/kg) offers a much smaller amount of energy in the same volume, even in liquefied form. The problem of hydrogen storage is similar. It has about 2.5 times higher energy per unit of mass; however, its low density results in low energy per unit volume, which translates into tank dimensions. In addition, the storage of gaseous fuels under high pressure or in the liquid phase requires the use of tanks with significant mass, which is an additional challenge. To put the problem as a whole, the widespread use of hydrogen and natural gas depends, among others from the development of technology of storage systems for these fuels on the vehicle. Challenges to be met are not only satisfactory user comfort and functionality, but also safety criteria set out in relevant regulations.

2. Basic Legal Acts

Listed below are the directives and ordinances most commonly used in the process of obtaining approval / certification of gaseous fuel storage systems. The application of a given legal act depends on the place of use (continent, country, region, etc. ...) and the intended use of the element. The basic legal acts that specify the requirements that must be met by the described storage systems in terms of their safety of use are:

1) Regulation No 134 The United Nations Economic Commission for Europe (UNECE) - Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen-fuelled vehicles (HFCV).
2) Regulation No 110 The United Nations Economic Commission for Europe (UNECE) - Uniform provisions concerning the approval of:
   I. Specific components of motor vehicles using compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system.
   II. Vehicles with regard to the installation of specific components of an approved type for the use of compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system.
3) European Standard EN12245 – Transportable gas cylinders - Fully wrapped composite cylinders - European Standard specifying minimum requirements for materials, design, construction, prototype testing and routine production control of composite cylinders for compressed, liquefied and dissolved gases. The standard covers transport pressure cylinders, seamless, with a water capacity exceeding 150 liters and not more than 3,000 liters.
4) REGULATION (EC) No 79/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 January 2009 on type-approval of hydrogen-powered motor vehicles. Commonly called the EC79 directive; contains basic provisions regarding the type-approval requirements for hydrogen installations and their components.
5) ISO 11119-3: 2013 standard specifies the requirements for composite gas cylinders with a capacity of up to 150 l and composite tanks with a capacity above 150 l and capacity up to 450 l for storage and transport of compressed or liquefied gases.
6) CSA / ANSI NGV 2-2019 - Compressed Natural Gas Vehicle Fuel Containers - The standard contains requirements for the material, design, production and testing of serially produced refillable containers of type NGV 2 (all 4 types) intended exclusively for the storage of compressed natural gas, for operation in the vehicle. Applies to tanks up to and including 1000 liters, permanently attached to the vehicle.

3. Gaseous Fuel Storage Systems in Vehicles

Pressure tanks used for storing natural gas and hydrogen in vehicles are divided into 5 types depending on the design:

- Type I - all metal tanks;
- Type II - tanks with metal liner (steel or aluminum) and fiberglass, aramid or carbon fiber winding;
- Type III - tanks with metal liner (steel or aluminum) and full winding of glass, aramid or carbon fiber;
- Type IV - composite tanks with non-metallic (polymer) liner in full fiber winding;
- Type V (new one, not included in standards) - composite tanks without liner, made in CTD technology (Fig. 5).

The main determinants in the production and development of tank structures are:

- ability to store the amount of fuel that ensures the achievement of the assumed range, which depends on the type of vehicle;
- reducing the cost of manufacturing the tank;
- reducing the weight of the tank;
- dimensions of the tank do not affect the comfort of use.

Fig. 2 CNG-1 cylinders

Fig. 3 Cryogenic LNG tank in the truck [6]

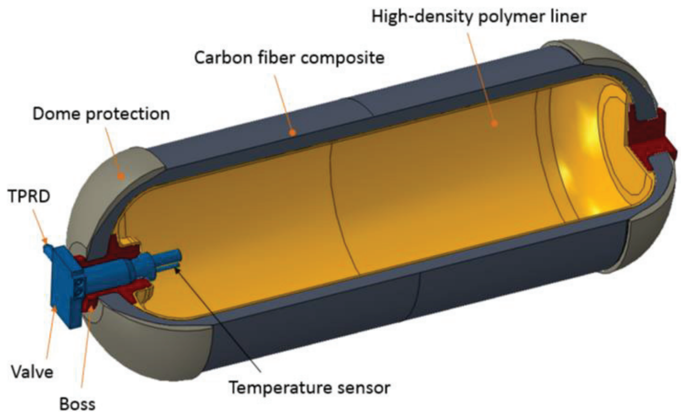

Fig. 4 Cross section of tank type IV [5]

Fig. 5 Composite tanks without liner - Type V [7]

In modern literature, you can find a lot of materials describing hydrogen storage methods. However, commercial vehicles are dominated by the method of using pressure vessels. Depending on the design of the tank, the hydrogen is stored at a pressure of 50 to 70MPa. Type IV composite tanks dominate (Fig. 4). Also known is the LH2 liquid hydrogen storage system, which was used in the BMW Hydrogen 7 test series. Hydrogen is stored in a 170-liter cryogenic tank at a pressure of 70MPa. To remain in the liquid phase a temperature of −253°C is required. Despite the very good insulation of the inner tank (high vacuum), when the vehicle is not in use, the fuel evaporates and the tank is gradually emptied by the security system.

Storage of natural gas in vehicles develops in two directions. The constructions of CNG pressure tanks and LNG cryogenic tanks (Fig. 3) are being improved in parallel. The storage conditions for natural gas differ from those for hydrogen. In CNG systems, nominal pressures in the range 20-30 MPa are usually used. In LNG tanks, on the other hand, the fuel temperature is −162°C and the pressure does not exceed 2MPa. Among the CNG tanks, both steel tanks (type CNG 1) (Fig. 2) are produced, due to the lower price, and composite tanks, due to the reduced weight. Among the composite tanks, currently the most popular are tanks with a polymer insert, type CNG 4.

Equipment used in tank safety systems is known as PRD (Pressure Relief Device). Their operation is to protect the system against damage due to excessive pressure. These devices are activated under certain conditions and allow fuel to flow to the environment, thereby reducing pressure. There is also a TPRD version where the device is thermally activated. In the case of PRD/TPRD devices operating in parallel in one system, the gas flow channels to the environment must be separate.

4. Tank Strength Tests in Extreme Conditions

4.1. Selected research methods

The factor that is potentially the greatest threat is the physical and chemical energy of the fuel stored in the tank. The required pressure resistance of the tanks depends on their purpose, construction and nominal working pressure NWP. The burst pressure values for CNG tanks according to ECE Regulation No. 110 are shown in Table 1. For hydrogen containers, ECE Regulation No. 134 also specifies a minimum burst pressure of 225% NWP. The exception are composite fiberglass tanks, which must withstand 350% NWP [8].

Table 1

Minimum actual burst values and stress ratios

Construction material	CNG-1	CNG-2		CNG-3		CNG-4	
	Burst pressure [MPa]	Stress ratio [MPa]	Burst pressure [MPa]	Stress ratio [MPa]	Burst pressure [MPa]	Stress ratio [MPa]	Burst pressure [MPa]
All metal	45						
Glass fiber		2.75	50	3.65	70	3.65	73
Aramid fiber		2.35	47	3.10	60	3.10	62
Carbon fiber		2.35	47	2.35	47	2.35	47

The final test procedures in the approval process are intended to verify the construction of the tank and the protective system used in extreme operating conditions. One test determines the resistance of the storage system to open fire - a bonfire test, and the other involves shooting a filled tank with a rifle bullet to observe how the disturbed structure will behave when emptying the tank.

4.2. Filling of the tank

Tanks intended for research must be equipped with appropriate equipment that allows filling/emptying the tank and safety valve. Preparation of the test tanks consists in filling them with appropriate compressed gas to the required working pressure NWP. Depending on the requirements set out in the regulations, it can be: hydrogen, natural gas, nitrogen or air.

In the presented tests, the tank intended for hydrogen storage was filled with nitrogen, compressed to a pressure of 70 MPa. To this end, a filling system has been developed that ensures a maximum pressure of 100 MPa.

The pressure increase in the tank depends on its capacity and the Booster supply pressure. The tested tank had a water volume of 80 dm3. In the first filling phase, the empty tank can be connected directly to the nitrogen tank, which allows free flow of gas for pressure equalization. In the second phase, nitrogen from the reservoir fed to the Booster is injected into the tank until the required pressure is obtained. The booster works on the principle of a pneumatic motor and is supplied with compressed air from a compressor. For proper operation of the Booster, supply pressure in the range of 1-10 bar should be ensured. The tank filling process is shown in the graph (Fig. 6).

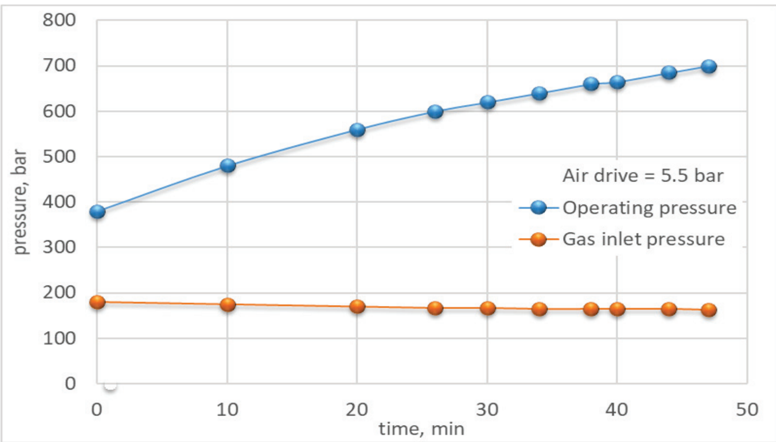

Fig. 6 The filling process of the 80-liter tank

4.3. The penetration test

The tank should be positioned at the required distance from the rifle so that the tank wall forms a 45 ° angle with the bullet track (Fig. 7). A 12.7 mm rifle with an electro-trigger was used. A positive test result is obtained when, after launching, the bullet penetrates the tank wall, causing it to unseal. After emptying, the tank should remain completely. That means it can't explode. The permeation test of the 80 liters tank was successful. The next photos show the tank after emptying to atmospheric pressure (Fig. 8).

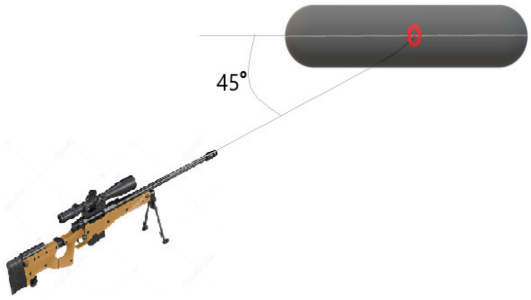

Fig. 7 Correct tank positioning

Fig. 8 View of the tank after the test with the hole marked

4.4. The bonfire test

The purpose of the bonfire test is to check the resistance of open fire to the entire gaseous fuel storage system. Requirements may vary depending on the regulations/directive under which the system is tested. In most bonfire tests, the tank should be emptied by PRD devices. In some cases, the strength of a container exposed to open flame is tested for the required period of time.

The presented, exemplary results were obtained during tests of a CNG - 4 tank tested for compliance with the requirements of UNECE Regulation 110 [9]. According to these regulations, two tank samples are tested. In the first tank, natural gas is compressed to a pressure of 100% WP. In such conditions, during the test the PRD device activated by increasing pressure should work. In the second case, the tank is refueled to 25% WP. In this case, the PRD device activated by increasing temperature should work.

The tank is placed about 100 mm above the fire source, which ensures a minimum flame temperature of 590°C. The most commonly used is gasoline or kerosene. After lighting the fire, the temperature should rise to the required value within 5 minutes. The pressure relief device should not allow pressure to rise above 34MPa. The temperature fuse PRD should open at a temperature of 110 ± 10°C. Gas should flow out of the tank through PRD equipment until it is completely empty. During the test, the tank should not leak or explode.

Parameter measurements should be made max. every 30 seconds. During the bonfire test, the pressure inside the tank and the flame temperature over the fireplace length should be monitored at points 0.75 m apart. The results obtained during tests of the 82-liter CNG-4 tank are shown in the graph (Fig. 9).

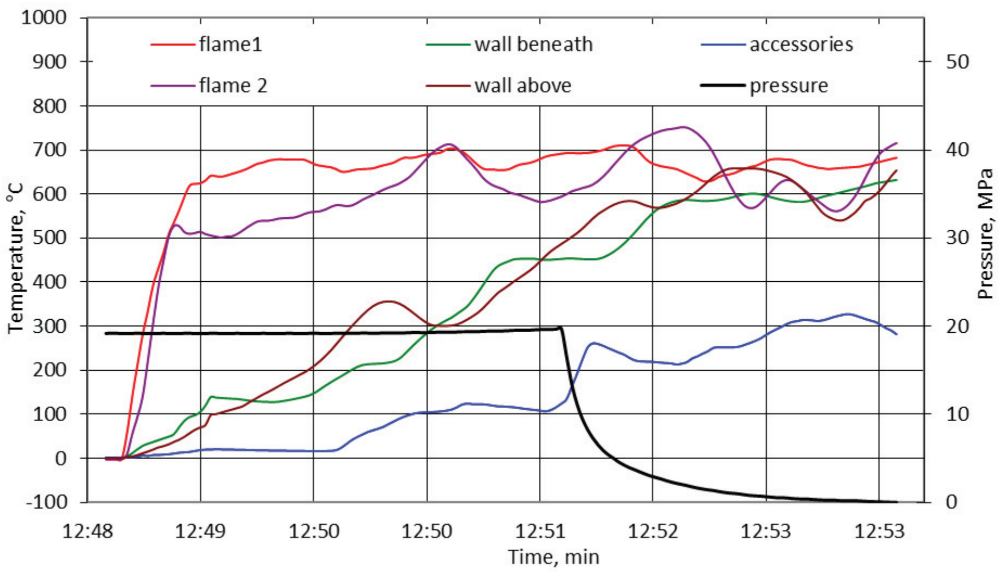

Fig. 9 The results of the pressure in the tank and temperatures during the fire test of the 82 liters tank CNG-4

5. Conclusions

Summing up the main aspects presented in this study, it can be stated that:

1. Due to the adopted goal of limiting global GHG emissions, a very intensive development of gaseous fuel storage systems (in particular natural gas and hydrogen) is currently observed in means of transport. The development

of new tank designs as well as the tests carried out allow for the improvement of systems in terms of functionality and safety.

2. Among the solutions produced on an industrial scale, pressure and cryogenic tanks dominate. The state of advancement of modern technologies for producing high-pressure tanks (cylinders) in means of transport allows the use of working pressures up to 70 MPa.

3. The utilitarian aspect has the strongest impact on stimulating development in this area, where the main factors are: installation and operating costs of the system, safety and comfort of use. One of the most important problems is the underdeveloped network of refueling stations in most countries.

4. The applicable regulations force manufacturers to ensure a high level of security of their systems. The test methods used also take into account the behavior of the tank in extreme situations, such as a fire or a shot through the tank. Their purpose is to limit the hazards that may result from the release of a combustible/explosive medium stored under high pressure.

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    I. Specific components of motor vehicles using compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system
    II. Vehicles with regard to the installation of specific components of an approved type for the use of compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system

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Streamlining Assembly of a Compressor to a Car Chassis with an Air Suspension System

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Abstract

The main objective of the solution of the presented problem is the engineering design of a manipulator, which will serve for mounting a compressor to the Porsche Cayenne chassis. The manipulator will be controlled pneumatically and it will be a part of the assembly line. The solution of the presented task also contains the design of a pneumatic circuit including pneumatic logic and individual components. The main effort is to reach an accurate three-dimensional model, which will be the basis for the creation of production drawings of the designed device, for its production and its commissioning. The designed handling device will facilitate human work and becomes the car production process more efficient.
KEY WORDS: *a chassis, manipulation, a compressor, engineering design*

1. Introduction

The main purpose of the article is to present a streamlining assembly of a workplace, where air compressors will be mounted to a car chassis.

The main demand is, that the mounting process of a compressor will be solved from below of a chassis, namely from the right rear part of a chassis. Since the manufacturer of cars has already created a steel structure of a suspender for the designed engineering solution, possible concepts of schematic variant solutions of necessary kinematics of the solution needed for the proper working of the manipulator are designed (Fig. 1).

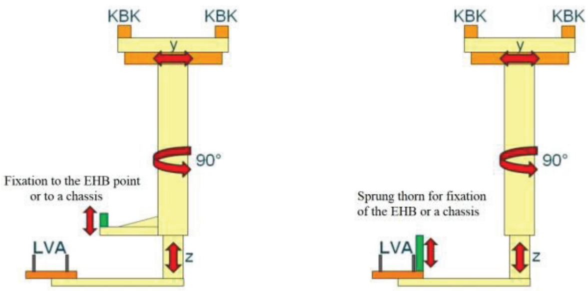

Fig. 1 Possible concepts of a manipulator

2. Description of a Problem

Basic parts of the manipulator are a rail system in x direction (front view in Fig. 1), a travelling gear, a rail system in y direction, a vertical telescopic column with a guidance in z direction and rotating about this axis of 90^{O}, a fixation point serving for arrestment of the manipulator to a EHB – a hanger carrying a chassis, which allows to move a chassis in the assembly line movement, a horizontal arm with a holder of the air compressor (LVA). Assembly of the compressor has to be performed in running of the assembly line and it can be divided to following assembly steps:

- inserting of an air compressor on a manipulator;
- performing of mounting of a magnetic valve;
- rotation of a manipulator of 90° to the assembly line;
- pushing out of a thorn and fixation to the EHB or to a chassis;
- waftage of the manipulator by a hinge or by a chassis;
- lift of the manipulator and mounting of a compressor to a vehicle by screwing (Fig. 2 left);
- movement of the manipulator downwards and lock-off of the fixing element from the EHB or from a chassis;
- rotation of the manipulator of 90° out of the assembly line;
- shutdown of the manipulator to the staring position.

From the given technical specifications, it has followed, that all movements of the device except of the lift have to be controlled manually and thus, they are fully dependent on physical predisposition of an operator. Because of this reason, the device had to be designed with regard to the magnitude of the actuating force, which an operator has to perform during manipulation with the device.

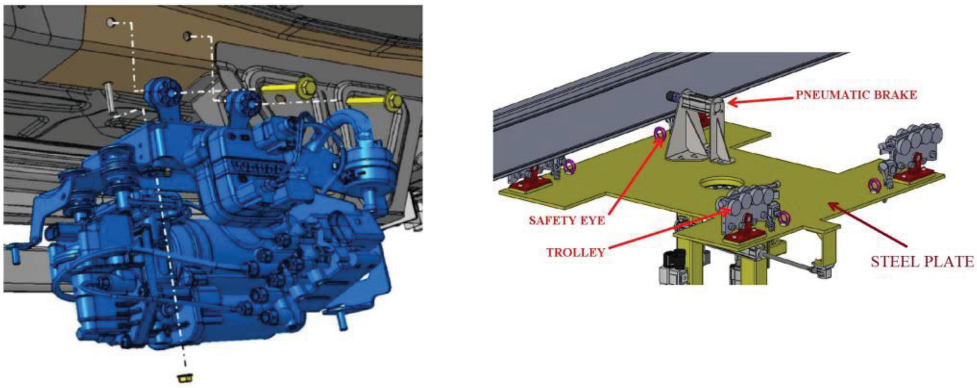

Fig. 2 Process of mounting of an air compressor to a car chassis (left), main parts of the manipulator (right)

3. Requirements for the Designed Manipulator

The design has to be controlled only by one operator, which at the same time performs also a montage of an air compressor to a chassis. Control elements have to be located in such positions, that the operator will be able to handle this device fully manually. The lift of the device has to be pneumatic, because the assembly line is equipped with compressed air distribution. The operator should control the lift by means of two bottoms two-handed operation. The rotary arm of the manipulator should be stopped in the end positions by the automatic locking system, i. e. braking the arm in its extreme position. Rotating the arm of 90° again will require activation of the release mechanism, i. e. releasing by means the control bottom. When designing the manipulator, it will also be necessary to observe various safety and ergonomic regulations according to prescribed standards, which deal with construction guidelines, safety distances, protective elements etc. It is also necessary to adhere to the standard STN EN 614-1 [7], which deals with the principles of ergonomic design [1, 3, 4]. Furthermore, geometric factors, physical limitations, maintainability conditions, general principles of manual operation, visual, acoustic, mechanical and electrical safety elements were taken into account in the design. For the possibility of creating a structural design of the manipulator, the authors of the article were provided with a scheme of the workplace with the input geometric parameters of the workplace of the device (Fig. 3 left).

Figure 3 left shows the relevant chassis section of a car (blue) located in the position, which corresponds with the real position of the chassis on the appropriate assembly line section. At the same time, the compressor is placed on the chassis in the mounted position (Fig. 3 right, yellow) together with the RPS point (red point), which is taken as accurate, i. e. the reference point for individual parts of the structure. There are several such points on the vehicle and they have both structural and assembly significances. They are unnecessary for the function of the car. The model also showed the exact positions of the rail system used for hanging of a handling equipment. The dimensions provided by the company concerned might seem authoritative because the hinges carrying the individual parts of the chassis are precisely calibrated and therefore the resulting deviations in the mounting of the chassis on the hinge will be at least. However, many years of experience in the field of practice suggest that in reality, with such large components, tolerance zones with a size of sometimes up to 20-30 mm are created, especially in the horizontal directions. It is also necessary to consider the rotation of the chassis around its vertical axis (Fig. 4) and also other deviations.

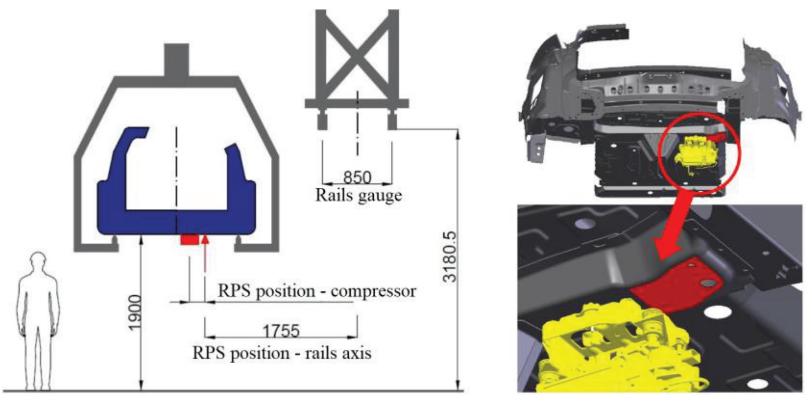

Fig. 3 A scheme of the workplace with input data (left) and a three-dimensional model of the relevant chassis section (right) with the exact position of the compressor (yellow) and the RPS point (red)

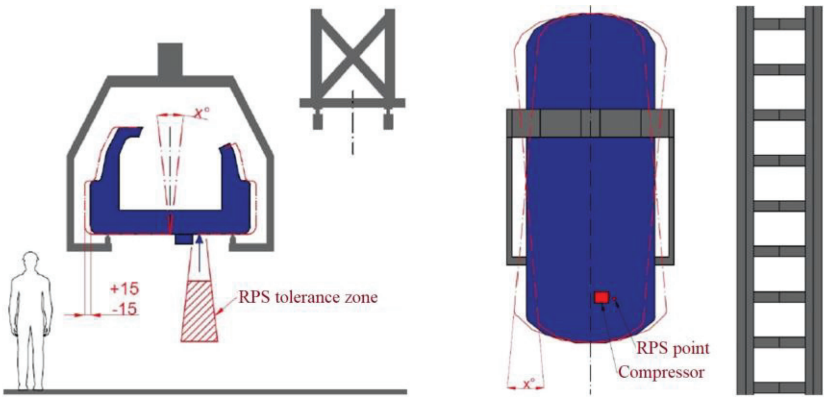

Fig. 4 Method of attaching of an air compressor to a chassis

Theoretical aspects of the manipulator engineering design include:
- a schematic proposal of the entire manipulator structure;
- proposal of tolerances of the manipulator during operation;
- proposal of mechanisms, which serve for setting of the manipulator before operation;
- proposal of a pneumatic system and control logic;
- choice of pneumatic components of the pneumatic system;
- proposal of control elements, verification of the manipulator in term of ergonomic and safety [3].

The entire structure of the manipulator consists of several individual structural units:
- a moving mounting system of a compressor with an integrated RPS point, which is able to move in *y* axis within tolerance limits;
- supporting beams together with a setting mechanism, which enables to set the rotation inclination about *y* axis;
- a linear guidance of a manipulator arm in *z* axis;
- radial-axial bearing for possibility of rotation of the manipulator towards and outwards of the assembly line about *z* axis;
- a plate, which serves for carrying and guiding of the manipulator by means of rail trolleys in *x* axis, i. e. in the direction of the assembly line movement.

A mounting system of a compressor serves for ensuring it in the proper position against a car chassis. It must not damage the compressor during operation. The mounting system of a compressor is located on an aluminum plate, which is mounted on a moving supporting beam. The entire mounting system of a compressor is movable because of needs of tolerances of dimensions in *y* axis. Rail trolleys are located on the manipulator arm and a guiding system serves for proper positioning of the compressor on the manipulator.

The manipulator arm ensures the compressor lift in *z* axis and it consists of a vertical and a horizontal part. The horizontal part of the arm comprises the linear guidance of the compressor.

4. Stress Analysis of a Steel Plate of the Manipulator

Stress analysis of a steel plate (Fig. 3 right) of the manipulator was another step in designing of the manipulator for mounting an air compressor to a car chassis. It was carried out by means of Ansys software [2, 5] working based on the finite element method [6-9] and these analyses are important to verify, weather this main carrying part of the manipulator meets all requirements in term of carrying capacity in term of strength. Simulations were focused on obtaining of values of stresses and deformations after loading by real forces values.

During designing of the manipulator there was supposed, the steel plate carrying the whole weight of the manipulator will be one of the most loaded element. Therefore, the thickness of the plate has been chosen of 10 mm and it will be made of S235JR steel. The yield of strength of this material is of 235 MPa and the ultimate strength is of 360 MPa.

For better accuracy of calculation, there was necessary to define all welded elements. Contact surfaces of welds and welded parts were defined by means of the “Connections” function. Welds and welded surfaces in contacts were defined using the “Bounded” function. It resulted to solid joints of selected elements. On the contrary, contacts between surfaces, which have been just in contact without welded joints, were defined as “Friction” function. It means that they behaved during calculation as surfaces with a friction contact [3, 9]. In this case, it is a steel-steel contact. Boundary conditions have been chosen as following: a rotation coupling has been defined on four surfaces, in which the steel plate in connected with trolleys (Fig. 2 right). It allows rotating about all axes and also translation movement in the *x* direction. The rotation coupling defines a joint coupling the trolley and the plate. The translation in the *x* direction defines movement of the trolley on a rail.

The loading force acts on the mounting surface of a bearing in the vertical direction. Its value represents the gravitational force of the device hanging on the plate. The manipulator weight has been determined of 150 kg. The loading force has been rounded on the value of 2,000 N taking into account the gravitational acceleration and the safety

coefficient.

Results of stresses calculated in compliance with the von-Misses theory are shown in Fig. 5.

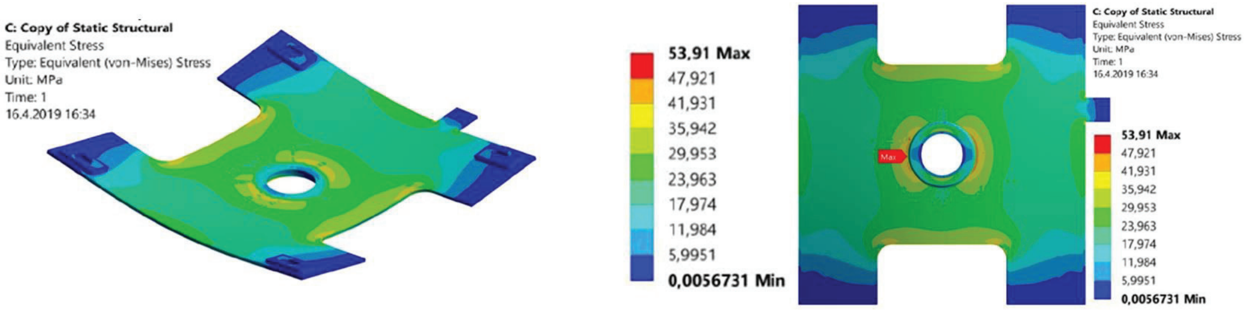

Fig. 5 Distribution of stresses evaluated based on the von-Misses stresses theory: 3D view (left), 2D view (right)

From this figure we can conclude, that the maximal calculated value of the stress is of 53.91 MPa. It means that we have chosen the proper construction material as well as its utilization is optimal. Moreover, the safety in term of strength of the designed device is fulfilled. As it was supposed, maximal values of stresses are reached in locations of welded joints, where they connect the working area of the bearing with the plate. Stresses have greater values in plate edges. Just for this reason, edges are rounded. Despite this fact, these locations show higher, however acceptable values of stresses. We suppose to verify the visual check of these exposed welds during auditing inspections of the device.

5. Conclusions

The presented article includes a description of the designed manipulator for mounting a compressor to a car chassis. It will be part of an assembly line. The designed manipulator is constructed in such manner, that it meets all requirements of the assembly line producer in terms of safety, ergonomic, functionality. The part of the design is also the stress analysis of the steel plate as one of the main carrying parts of the manipulator. Based on simulation computations, the structure of the plate can operate safely for a long time.

Acknowledgements

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Research of the Flow Around the Steam Turbines Blades of Biconvex Profile

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Abstract

The article presents the results of computer simulation of the working fluid flow in the lattices of low pressure turbines last stages, which are composed of biconvex profile blades. A special design (biconvex profile) of solid state blades for modeling CFD is used. The CFD model includes a package of three blades that are similar to real blades. An analysis of the working fluid flow in the model made it possible to determine the rational thickness of the wave-like protrusion, which provides an uninterrupted flow. The developed CFD model can be used as an element in larger models of energy and vessels steam turbines.
KEY WORDS: *turbines, steam turbine blades, solid-state turbine models, aerodynamics at supersonic speeds*

1. Introduction

It is necessary to use working blades with high bending resistance to some turbine stage high-power steam turbines (both marine and stationary), due to considerable bending effort. The use of the ordinary turbine blade profile (Fig. 1, profile *IV*) leads to flow separation and increases energy loss [1]. It was proposed to change the design of the blade in order to reduce energy losses and ensure flow without separation. Blade made with a biconvex profile was developed (Fig. 1, profiles *I – III*) [1]. The set of such profiles allows to provide their optimum aerodynamic flow while providing the necessary resistance bending moment.

High resistance to bending moment is achieved by moving the maximum bending moment from the input edge of the blade to the top of the protrusion located on the pressure side (point A, Fig. 1).

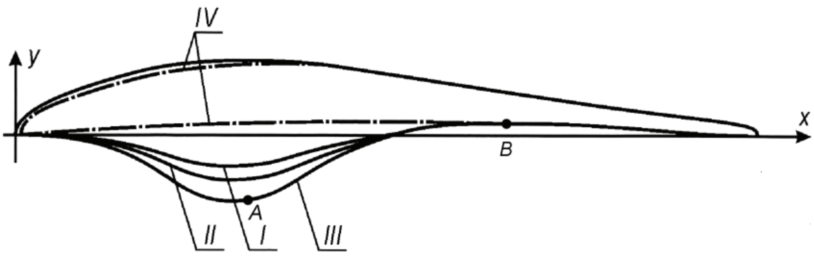

Fig. 1 Turbine blades [1]: *I*, *II*, *III* – biconvex profile: *I* – 0,14; *II* – 0,16; *III* – 0,19; *IV* – normal profile

Since the shape of the pressure side in the biconvex (*I* - *III*) profiles (Fig. 1) and shape the gas stream in the channel between the blades differs significantly from the ordinary (concave, profile *IV*), it is necessary to study the stream profile on the profiles, and determine the most rational shape of the blade profile. A particular interest for the study is the section of the profile located between the top of the protrusion (point *A*, Fig. 1) and the middle of the concave side (point *B*, Fig. 1) [1]. This area is characterized by an aerodynamic regime in which a separation of the flow can occur. Theoretical calculations showed that separation is possible for relative radius $R \geq 0,19$ [2].

The conducted experimental research confirmed that the biconvex profile has good aerodynamic characteristics in the speed range from 0,5 *M* to 1,35 *M* (where *M* is the Mach number), in which the energy loss on biconvex profiles (Fig. 1 – profiles *I* – *III*) almost 2 times less than in the traditional profile (Fig. 1 – profile *IV*) [1].

In order to select the optimal shape of the biconvex profile and to develop recommendations for the manufacture ship and stationary steam turbines blades, it is advisable to perform computer simulations of the process of flow through the blades. The latter allows to increase significantly the vibration reliability of steam turbines and reduce the level of energy loss [3].

A series of three profile blades were selected for the research (Fig. 1 – biconvex profiles *I* – *III*). As can be seen from Fig. 1, the profiles differ only in the shape of the pressure side: with a protrusion of variable magnitude, with a relative radius R = 0,14; 0,16; 0,19 – biconvex profiles *I* - *III*.

2. Fluidic Muscle Parameters Research

We took samples from three blades (similarly studied in the experiment [1] and shown in Fig. 1 in order to develop solid-state models. The blade is made of steel.

The research cycle included the following steps:

- at the first stage, solid-state models of biconvex blades were created (Fig. 2), these solid-state models are elements that are embedded in the computational domain of the mathematical model to determine flow parameters;
- the second stage is an aerodynamic study for various modes of operation of the blades for speeds of 0,5 *M* and 1,35 *M* (where *M* is the Mach number), for two types of gas flows (air and steam).

The model was introduced into the CFD (Computational Fluid Dynamics) software package [4], which includes a wide range of technical data, material assignment, input parameters, boundary conditions, setting goals for research, saving the project for analysis, and others. The last step is to prepare a project for calculation is to set the parameters that control the calculation. These parameters include: a time step, a choice of a scheme for approximating equations in space and time, the frequency of autosave, etc.

CFD modeling aim at reproducing numerically the 3D flow around the turbine blades, resulting in key information about the model or full scale forces acting on the blades, power loss and hydrodynamic performance in general.

The flow simulation was carried out as an "external aerodynamic task". As a result of the calculations, it is necessary to find the distribution of gas velocities and pressures when flowing around the turbine blades at various operating modes, and also to check the strength of the selected profile under the influence of flow pressure.

For calculations for of High Mach number flow, the following energy equation is used [5]:

$$\frac{\partial \rho E}{\partial t} + \frac{\partial \rho u_i \left(E + \frac{p}{\rho} \right)}{\partial x_i} = \frac{\partial}{\partial x_i} \left(u_i \left(\tau_{ij} + \tau_{ij}^R \right) + q_i \right) - \tau_{ij}^R \frac{\partial u_i}{\partial x_j} + \rho \varepsilon + S_i u_i + Q_H \cdot \tag{1}$$

where u_i – is the fluid velocity; ρ – is the fluid density; E – sum of internal and kinetic energy; S_i – is a mass-distributed external force per unit mass; Q_H – is a heat source or sink per unit volume, τ^R_{ij} – is the Reynolds-stress tensor, q_i – is the diffusive heat flux; ε – the turbulent dissipation. The subscripts are used to denote summation over the three coordinate directions.

The visualization of the pressure distribution on the blade surface is one of the test solution, which allows you to determine the pressure change in certain areas of the blade, and also gives a general picture of the force acting on the surface of the blades.

Comparison and analysis of experimental data [1] and the results obtained during CFD modeling, allows us to more fully investigate and justify the patterns of flows in turbine blades, and choose the most rational design of the blades.

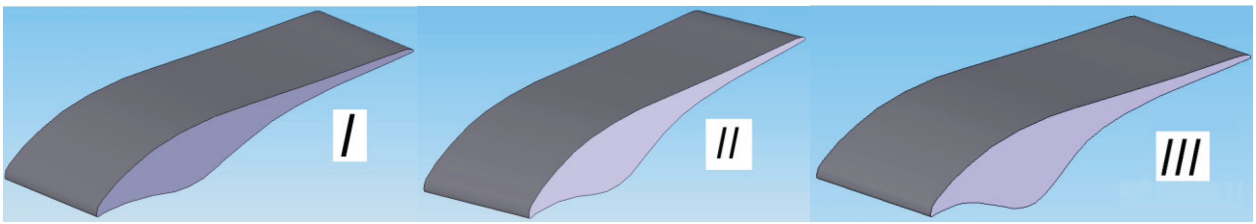

Fig. 2 Solid state models of biconvex blades turbine: *I* – *R* =0,14; *II* – *R* = 0,16; *III* – *R* = 0,19

In Fig. 3 shows the velocity distribution in the cut of the biconvex blades (flow direction from left to right). The studies were carried out for profile blades when flowing around them with air at a speed of 0,5*M*. It is shown that the deviation from the initial velocity in the zone between points *A* – *B* at the blade *I* – *R* = 0,14.

In Fig. 4 shows models of steam flow rate that blows a biconvex blades at a speed of 0,5 *M*. An analysis of the flows shows that the deviation of the flow velocity in the zone between points A – B is not significantly different from all the studied blade designs. This flow structure is explained by a lower vapor density (compared with air density). Therefore, it is possible to use any of the investigated blades (in the range of tested speeds) for steam turbines. In this case, the main indicator when choosing the shape of the scapula should be the required bending resistance of the scapula. However, at a flow rate of 0,5 M, the yield strength of the blade material is not exceeded for any of the investigated blade designs.

Fig. 5 shows the air flow change in the study of biconvex blades that are blown at a speed of 1,35 *M*. From the presented flow patterns, it can be seen that in the zone between points *A* – *B*, blade *III* – *R* = 0,19 has the largest region of sharp inhibition of flow. For profiles with a smaller protrusion radius, this region decreases. And accordingly, the smallest area of braking (and possible flow separation) has a blade *I* – *R* = 0,14.

Fig. 6 presents a simulation of the steam flow which is blowing a biconvex blades at a speed of 1,35 M.

The presented pictures in cross section, the smallest region between points A – B, in which there is a sharp decrease in flow velocity, has a blade I – R = 0,14.

Based on the patterns examined in computational experiments in cross section show the blade has the best aerodynamic characteristics - I – R = 0,14. However, for its justified use as the main option biconvex blades for steam ship turbines, it is necessary to simulate the strength under the influence of flow pressure at a maximum flow velocity of 1,35 M.

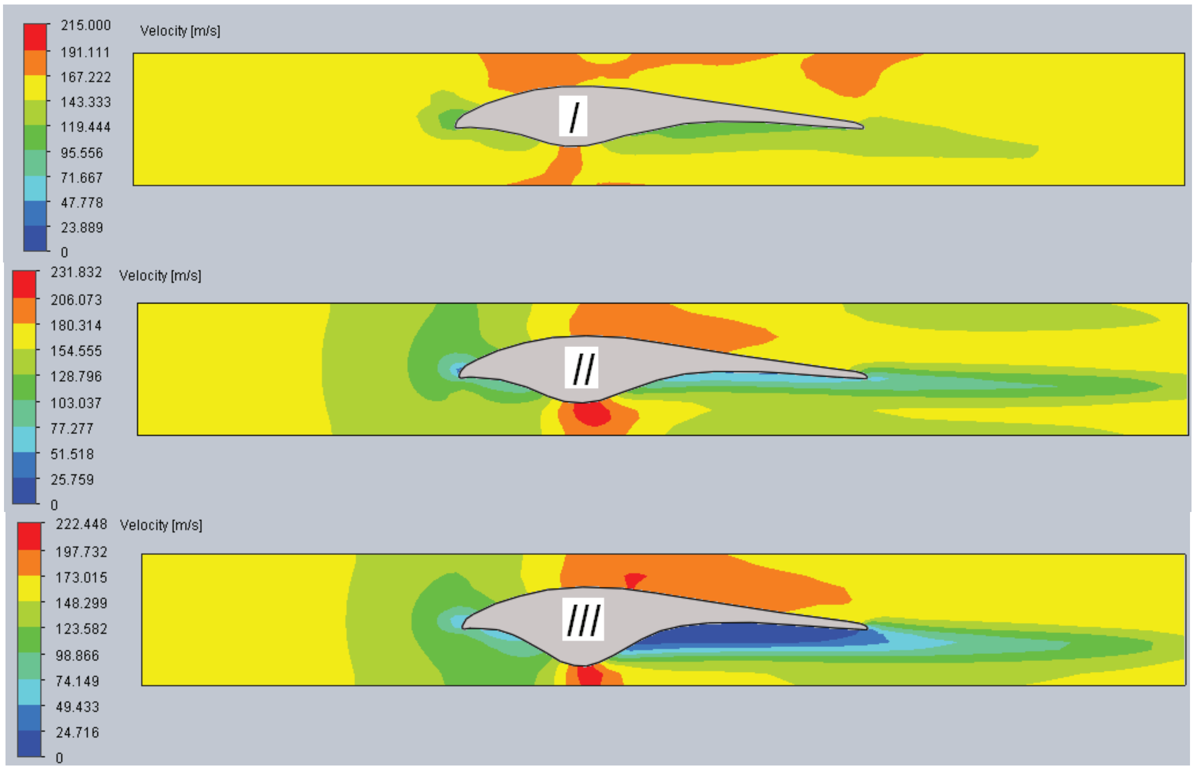

Fig. 3 Model of air flow around biconvex blades at speed 0,5 M: I – R = 0,14; II – R = 0,16; III – R = 0,19

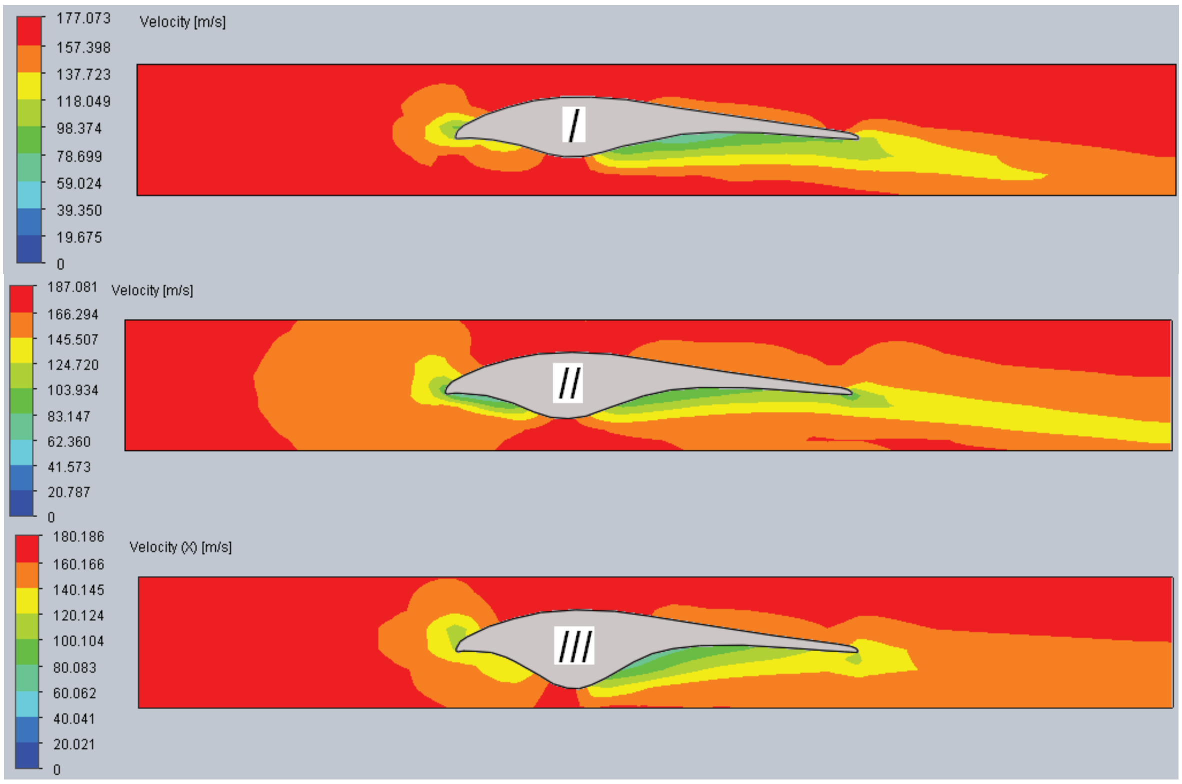

Fig. 4 Steam flow around biconvex blades at a speed of 0,5 M: I – R = 0,14; II – R = 0,16; III – R = 0,19

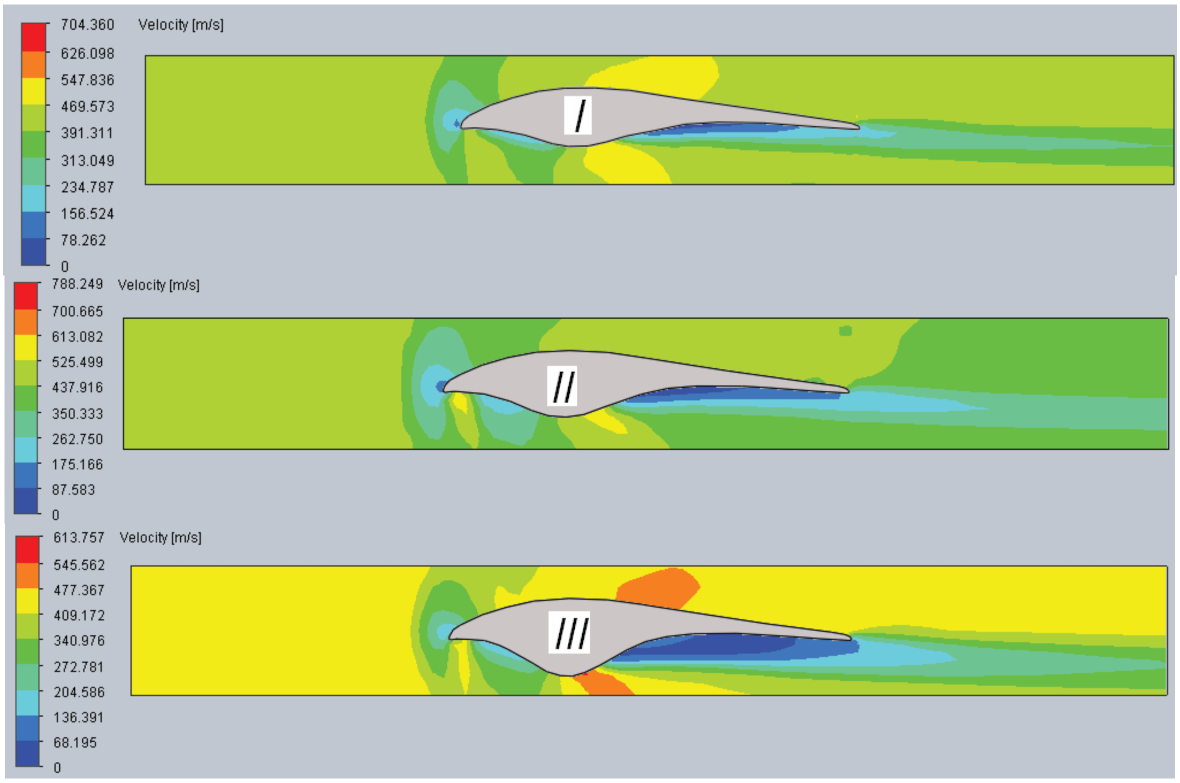

Fig. 5 Model of air flow around biconvex blades at speed 1,35 *M*: *I* – *R* = 0,14; *II* – *R* = 0,16; *III* – *R* = 0,19

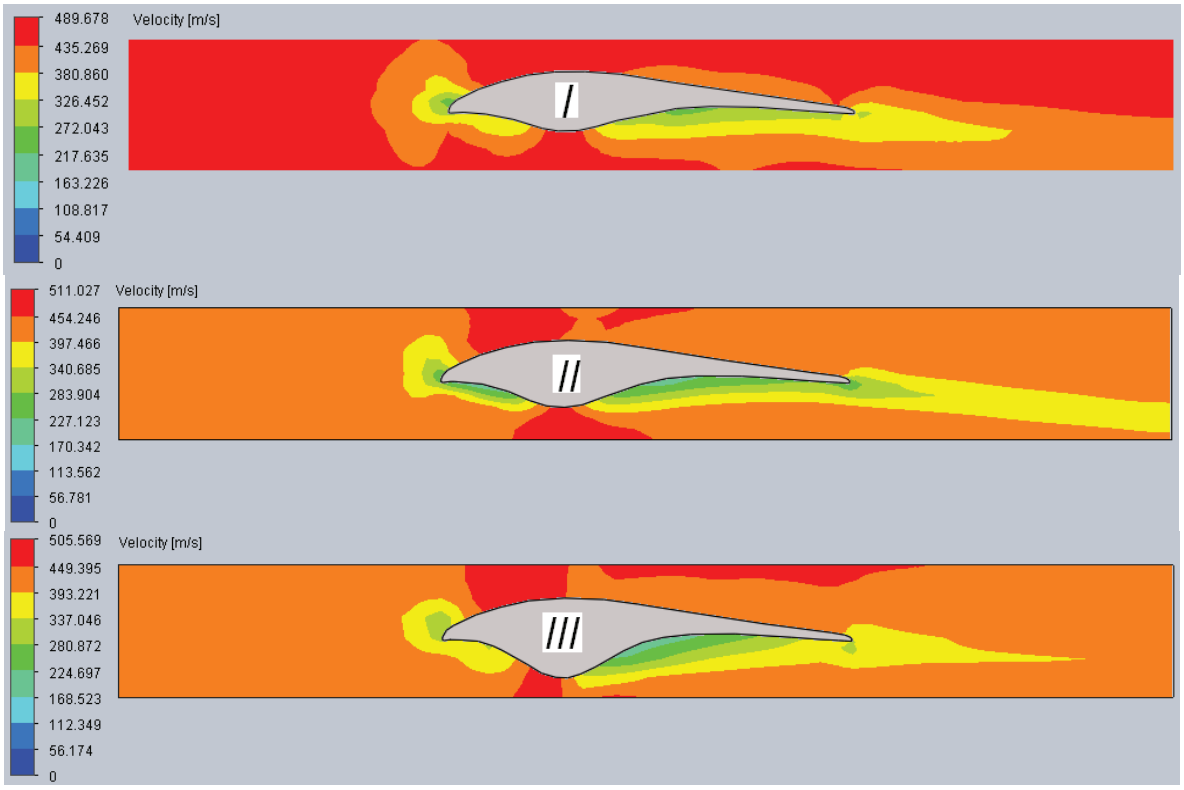

Fig. 6 Steam flow around biconvex vanes at a speed of 1,35 *M*: *I* – *R* = 0,14; *II* – *R* = 0,16; *III* – *R* = 0,19

To check the strength of the selected profile under the influence of flow pressure, an analysis we carried out of the deformation of the blade. The results of the analysis of the stress-strain state are based on linear static analysis, and anisotropic material is assumed. Linear static analysis suggests that: the behavior of the material is linear according to Hooke's law, the induced displacements are small enough to ignore changes in stiffness due to loading, and loads are applied slowly to ignore dynamic effects [5]. The simulation results are shown in Fig. 7.

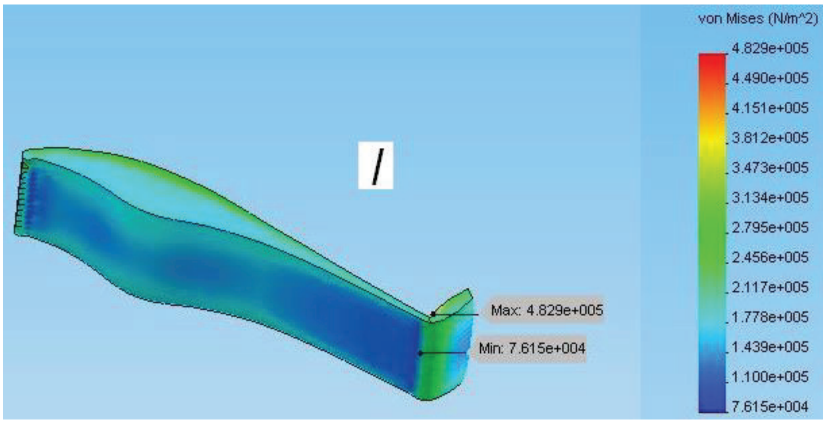

Fig. 7 Deformation model of biconvex profiles *I* – *R* = 0,14

3. Conclusions

Solid-state models of biconvex blades that can improve the reliability of steam turbines have been developed using the experience of experimental research of steam turbine blades [1]. The distribution of air and steam flows is obtained based on numerical modeling in the operating speed range. Computer-based visualization of flows makes it possible to select a rational blade design in which the possibility of flow separation on the inside of the blade (pressure side) is minimized.

The simulation results analyses show that an increase in the profile thickness from *R* = 0,14 to *R* = 0,19 leads to an increase in the zone of reduced velocities and increased pressure, in which flow separation and increase in resistance are possible (in the area between the apex of the protrusion, point *A*, and the middle of the concave side point *B*, Fig. 1).

A comparison of the three options for biconvex blades (*I* – *III*, Fig. 1) shows that the decrease in the hydraulic resistance coefficient due to the improved flow around is 6% for the blades *I* – *R* = 0,14 (compared with the blade *III* – *R* = 0,19).

A computer analysis of the blade stress-strain state *I* - *R* = 0,14 showed that the resistance to bending forces does not exceed the yield strengths for alloy steel (Fig. 7).

We can recommend a biconvex blade *I* – *R* = 0,14 as a basic version of the blade, which has the smallest possible separation zone in section *A* – *B*, the least hydraulic resistance compared to profiles (*II* and *III*, Fig. 1), and provides structural strength.

The calculations performed on the CFD model show that the use of CFD modeling methods allows, at the early stages of designing turbine blades, to select the most optimal (in terms of energy losses) forms of profiles for specific modes of operation of the ship's turbine.

Further improvement of the profiles that have passed the preliminary calculation check is advisable to conduct on the basis of more detailed experimental tests to obtain dependences of losses in the lattice, the exit angle of the flow from the parameters of the lattice and the angle of gas flow.

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Meeting Digitalization Challenges to Future Specialists: Development of Educational Environment at Lithuanian Maritime Academy to Ensure Effectiveness of Studies in Shipping and Logistics Information Systems

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Abstract

Trends in the development of digital shipping and logistics processes provide an insight that automation of the global supply chain is evolving; that the process leads to the qualitative changes in skills and competencies of specialists working in maritime industry. Educational institutions have to be ready for recent changes and present the solutions of the development of students' respective knowledge and practical skills meeting labour market needs. In this paper, the notion of the effectiveness of studies from the perspective of study result definition in terms of competences, learning outcomes, and learning achievements is discussed. Fundamental ideas of the concept of study results are presented; the content of studies, focusing on cognitive and psychomotor domains of learning, of the Shipping and Logistics Information Systems study programme are described; specific characteristics of the development of practical skills using different simulators with respect to the defined learning outcomes from the psychomotor viewpoint at three levels (general, professional, and research skills) of the said mentioned study programme are explained in detail; and the means of achieving them are presented by describing the case study of practical application of specific educational environment at Lithuanian Maritime Academy.
KEY WORDS: *learning outcomes, effectiveness of studies, educational environment*

1. Introduction

The phenomenon of the effectiveness of studies has been a widely discussed issue for a couple of decades due to its close connection to the quality of studies. The effectiveness of studies can be defined as a feature of the learning process indicating the achievement of the intended learning outcomes, which have to be related to recent changes in labour market needs. The effectiveness of studies depends on a variety of factors in the internal and external environment, including national legal framework conditions and international partnership. Understanding of the concept of study results from three perspectives (labour market, learning outcomes, student learning achievement) and emphasising their special characteristics in the Shipping and Logistics Information Systems (SLIS) study programme also in ensuring the effectiveness of studies.

The demand for SLIS specialists is influenced by the global strategic revolution of innovations and technologies Industry 4.0. This tendency describes how new technologies and machine learning algorithms could be used in the different fields of national, regional and worldwide industries. Increasingly more automated autonomous systems are integrated into the global supply chains, which means that the increasing data stream from sensorial systems creates the demand for contemporary competencies of specialists working with automated systems in usage and interpretation of special data engineering and analysis algorithms, open source accessible tools for the modelling optimised solutions in the shipping and logistics.

The capability to prepare such specialists at specific educational institutions and to ensure the quality of their education, including the possibility of their quick adaptation to changes in the labour market, needs special attention: the contemporary educational environment with functional possibilities to develop psychomotor skills according to the learning outcomes matching recent industry demand has to be in place, the teaching staff needs to have proper qualification and ability to use study methods including methodological study materials, and practical tasks have to be worked out. The case study of different simulators installed at Lithuanian Maritime Academy (LMA) proves coherence of properly developed learning outcomes and adequate means in achieving them in order to ensure the effectiveness of studies.

2. Notion of the Effectiveness of Studies from the Study Result Perspective

Researchers have been interested in various aspects of the effectiveness of studies in recent decades; as a result, their ideas have enriched the evolving concept of educational effectiveness. Considerable attention has been paid to the justification of the study results as an outcome of the study process, e.g., to revealing the factors influencing the study results, e.g. [7, 13, 14], to the identification of the problems in the assessment of study results and learning outcomes, e.g. [3, 5, 8, 11], and to the investigation of the impact of usage of contemporary educational facilities, i.e. simulators, for

better study results [2]. However, so far, a clear and systematic presentation of fundamental ideas of the concept of study results in maritime education and training is missing. These considerations have inspired the authors to analyse relevant scientific literature and documents in order to clarify and systematize the fundamental ideas of the concept of the study results and apply those ideas in the case of maritime studies, specifically to SLIS study programme. In the analysis of the scientific information on the study results and learning outcomes, a number of essential ideas of the study results have been revealed. While analysing the essence of the effectiveness of studies, the following question arises: what is the relation between the effectiveness of studies, study results, learning outcomes, student achievements, and their competencies? How can study results be defined through dividing them into three domains of learning: cognitive, psychomotor, and affective meaning the knowledge, skills, and attitudes of respective students?

The answer to those questions is based on a modern definition of study results. From the formal point of view, the study results can be described as statements. It is possible to agree with T. McMahon and H. Thakore [10] that the study results are the statements to the effect what students have to be able to do after finishing the study program or its part (e.g. a specific course). Despite a large number of study result definitions in use, the definition of the learning outcomes as one of the forms of study results presented by Adam (2000) [6, p. 53] seems particularly apt as summarizing different views: "*learning outcomes* can be defined as the content of what a successful student will know, understand and be able to demonstrate at the end of the study process or a certain phase of the study process. Learning outcomes are the specific evaluated student achievements, the description of students' acquired competencies after finishing a certain phase of the study process". Although this definition reveals the essence of the notion of learning outcomes, it can also be applied to clarify the concept of study results, since the study process is, in fact, the process of learning and teaching at the institution of higher education.

The aforementioned Adam definition shows that there are three essential aspects defining the study results:

1. Study results: knowledge, skills, and attitude which students have to acquire (intended learning outcomes).
2. Study results: student learning achievements.
3. Study results: acquired competencies.

The definition implies that the content of study results as a form of learning outcomes consists of knowledge, skills, and values/attitudes. However, this aspect of study results is the most problematic, as there the opinions of scholars and educational politicians differ substantially. In scientific literature and documents regulating educational process, the definition of learning outcomes as a form of study results involves knowledge, abilities, competencies, skills, attitudes, approaches, etc. For a better understanding of these issues, the concepts of learning outcomes and learning objectives should be linked. The content of learning objectives and learning outcomes is identical because, in general, any imaginary activity outcome can be called its objective. It means that the learning objectives are, in fact, the intended and expected learning outcomes or study results. In order to understand the content of learning outcomes, it is important to classify learning objectives. Educational theory and practice is widely based on Bloom's taxonomy of educational objectives [4]. Bloom classifies objectives in accordance with the individual cognitive (knowledge), affective (emotional), and the psychomotor (skills) areas. Cognitive areas of learning describe knowledge, affective areas of learning describe attitude/values, and psychomotor areas of learning describe physical movement, coordination, and motor skills. Based on the objectives of the taxonomy, scholars offer to include assessment into student's cognitive, psychomotor, and attitude-behaviour domains, and to evaluate the learning outcomes according to the transformations in students' knowledge, attitude, and behaviour (reflecting the abilities which cover skills) [1]. In compliance with this concept, the learning outcomes as a form of study results should be considered as knowledge, abilities (i.e. skills), and attitudes acquired in the study process.

Another aspect defining study results is student learning achievements. One can agree that the learning achievements have a lot in common with the learning outcomes, however, the learning outcome is defined as "a statement describing what and how a student is expected to learn" [3, p.113], whereas the learning achievements is the effect of student's learning activity, showing what he/she has achieved in the study process. Learning outcomes as a form of study results, presented in the study program as statements, reveal the objective side of the phenomenon, i.e. the requirements of public and labour market, which reflect the competencies to be acquired in the study process which are necessary for recognition of graduate's qualification. Meanwhile, student learning achievements demonstrate the subjective side, i.e. what an individual acquires in the study process. Consequently, student learning achievements can be assessed according to the changes in their individual knowledge, attitudes, and behaviour (reflecting abilities and skills) which occurred in the study process. According to Pukelis [12], student achievements may either exceed the defined learning outcomes as a form of study results or not to reach them, since that depends on student's efforts, abilities, and talents as well as lecturer's qualifications, the institution's material resources, and other factors. The third aspect of the study results is the competencies which are required for the specialists from the labour market. A conceptual connection exists between the key competencies and study results [12]. These concepts are similar, however, there is an essential difference between them: "competency is the category of labour market, while learning or study results is the category of vocational training and higher education" [12, p. 199].

It can be noted that the core content of competencies, study results, and learning outcomes as well as student learning achievements consists of knowledge, skills, and attitudes, however, this core content can be analysed in different contexts, e.g. in terms of competencies, combining knowledge, skills and attitudes with regard to labour market positions, that is, the knowledge, skills and attitudes a graduate needs to acquire to become a highly-qualified professional demanded in the industry. Given the employment context, the institution of higher education develops a study program, in which the learning objectives of the program and/or intended learning outcomes (in other words, the knowledge, skills,

and attitudes) a graduate has to acquire in the study process in order to be prepared for the professional activity are formulated. Student learning achievements indicate an individual student's performance in the study process in order to achieve the intended and expected objectives (learning outcomes) of the program, thus the knowledge, skills, and attitudes are considered in the subjective context. Thus, the learning outcomes as a form of study results can be understood as theoretical knowledge, skills, and attitudes which are formulated as study objectives and competencies to be achieved, the assessment of which helps to determine a student's individual learning achievements at the institution of higher education (Fig. 1).

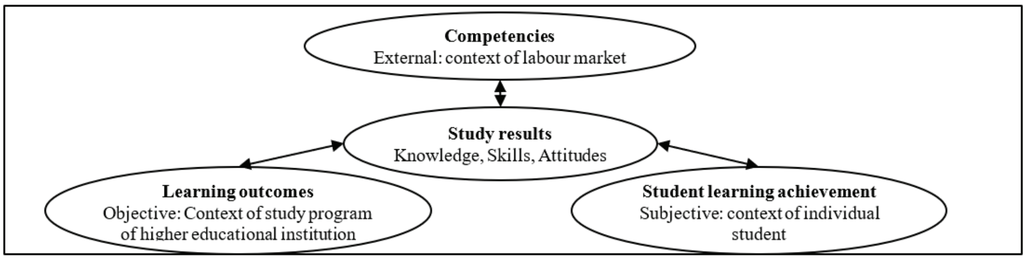

Fig. 1 Logical connection of three aspects of study results

To sum up, it can be stated that the content of study results includes knowledge, skills, and attitudes which can be understood in three aspects: external context of studies – competencies oriented to the requirements of society and the labour market; subjective context - the aforementioned knowledge, skills, and attitude to be regarded as a student learning achievement, demonstrating what a student has acquired in the study process; and objective context of study results, which depends on the knowledge, skills, and attitudes defined in the study program of a particular higher educational institution. In order to ensure the effectiveness of studies, all three aspects have to be in strong coherence.

3. Special Characteristics of Defining the Learning Outcomes in the SLIS Study Programme

Trends in the development of digital shipping and logistics processes suggest that the global supply chain is evolving and leading to qualitative changes in the skills and competencies of specialists working in shipping and logistics. Although the need for a human in automated global supply chain systems and processes is not completely ruled out, there is no doubt that the number of the staff directly participating in some processes will decrease, while the remotely-based jobs will be in demand [9]. The shipping and logistics business field is complex and multidimensional, therefore the data flows collected from integrated sensorial systems are multi-layered and scattered between different actors of global supply chain. Usually forecasting and decision-making processes in the development of the global supply chain are based on data analysis, where the first step is most difficult due to the need for knowledge and skills required to collect the scattered data: some data collections are located at the operational level, other data are distributed at the tactical managerial level, and the biggest part of open sourced data are located at the national and regional levels. Therefore, the whole possible data set could be described as a scattered and not sorted database, which leads to specific requirements for the competencies of data analysis algorithms and specific tools, based on the sufficient skills in the field of shipping and logistic business processes.

As a result, the automation in shipping and logistics in the process of implementation of fully autonomous ships and partially autonomous systems, generates unstructured and unsorted data sets, stored in different physical and cloud locations; those data will increase with each subsequent step of automation, so the professional skills in data analysis will be highly required in the global supply chain. With the introduction of autonomous shipping systems and an increasing role of artificial intelligence in maritime sector, some seafarers will eventually move to land-based workplaces and change they work specifics from immediate troubleshooting to the operational data engineering and analysis. Thus, the new working conditions will create the demand for specialists with the competencies to manage data generated from autonomous or partially autonomous systems equipped on-board with the aim to prevent engineering incidents and prepare the guidelines for decision makers. Such prospects in the shipping allow to justify the need for data analysis competencies in this field of activities and to describe the learning outcomes of the SLIS study program, corresponding to recent changes in industries oriented to specific knowledge and skills, such as ship navigation processes and operations, ship power plant operations, freight operations, etc. These conditions in the shipping and supply chain logistic processes also influence the demand of skills not only how to work with data analysis tools by implementing valid methods of mathematical analysis, apply machine learning algorithms, but also how to operate and use sensorial systems. So, the main competencies in the field of IT are required, such as knowledge and understanding of principles of operation of database management systems, understanding of architecture of hardware and software of automated systems, their standardization and interaction principles and etc.

In this context the main learning outcomes of the study program were developed, as shown in Table. The fundamental background of knowledge is based on the mathematics and informatics theories and methodology, strongly related within the changes in shipping and logistics operations in the maritime sector. General skills of such specialists have to combine mathematics and IT areas and shift to the maritime sector level. As shown in Table, combining mathematics and IT knowledge leads to the possibilities of acquiring modelling and optimization, imitations, and

simulation skills, including data processing for a methodology integrated in these methods. In the maritime transport sector, general skills are acquired in the identification of the main data sources, in accessibility of open sourced data bases, including the data from the implemented automated processes and sensor systems.

Table

Relationships between specific fields and learning outcomes in the SLIS study program

	Target scientific fields and related learning outcomes			
Types of learning outcomes' groups	***Mathematics***	***IT***	***Maritime transportation (seaborne transportation)***	
			Shipping	***Logistics***
Knowledge	Mathematical analysis methodology Statistics methodology Validations methodology	Algorithms Programming Data bases Systems infrastructure	Ship navigation operations Ship engine room operations	Port operations Cargo operations Warehouse operations
			Geographical information systems	
General skills	Modelling and optimization, imitations and simulations, data processing methodology		Identification of data sources, accessibility of open sourced data bases, automation processes and sensor systems	
Professional (or specific) skills	Spec.software: R Studio, Python, ArcGIS	Basics of artificial intelligence and machine learning, Big data technologies, Internet of things technologies		
Researchable skills	Research methodology: data analysis methods and tools			

Professional or specific competencies require the skills in the area of latest technologies applied in the maritime transportation, such as artificial intelligence solutions. These solutions are based on the internet of things and big data technologies, which specificity influences the increasing of data streams. Meanwhile, data processing with the analytical aims requires more machine learning algorithms in the area of decision making in shipping and logistics management processes.

Professional or specific competencies require the skills in the area of the technologies applied in the maritime transportation, such as artificial intelligence solutions. Meanwhile, data processing with the analytical aims requires more machine learning algorithms in the area of decision making in shipping and logistics management processes. The other significant part of skills is data analysis and their interpretation which belongs to the group of research technologies. Based on this pyramid of learning outcomes, it could be argued that knowledge in the specifically related to data analysis areas of global supply chain and maritime transport sector influence the combinations of general, professional, and research skills, dependent on the applied complex methodologies and specific software tools. The knowledge of shipping and logistics processes in combination together with the programming and mathematics methodologies lead to the possibilities of acquiring the knowledge of modelling and optimization, imitation and simulation on the basis of applying programming tools at the general skills level. However, in the area of professional specific skills, the latest data analysis technologies and tools could be applied to the deep data analysis and forecasts of processes and operations in the maritime transport sector. This model also identifies the possibility to substantiate the importance of intersectoral specialists for the improving of processes and operations in the context of the brokering role between human and artificial intelligence.

The recent changes in maritime sector related to introduction of artificial intelligence and autonomous shipping create a need in the labour market of the specialists having specific data processing and IT knowledge and skills [16]. In order to meet the described challenges, SLIS study program was developed at LMA. The learning outcomes in this study program were formulated focusing on the cognitive (knowledge of main principles used in mathematics, IT, shipping and logistics) and psychomotor (skills in respective disciplines) domains of learning. The skills were divided into three main groups: *general,* including abilities to collect data from accessible automated sensor and open sourced data bases, apply mathematic modelling and optimization, imitate and simulate processes, analyse and interpret data; *professional,* such as skills in application of special software for data processing, usage of machine learning algorithms and big data technologies, exploration of automated sensor systems; and *research* skills, pointing out the ability of graduates to apply data analysis methodology in practice.

4. Case Study of Practical Application of a Specific Learning Environment at Lithuanian Maritime Academy in Order to Achieve the Defined Learning Outcomes

In order to ensure the effectiveness of SLIS studies, the coherence of the formulated learning outcomes with student learning achievements has to be achieved. This can be achieved by ensuring proper educational environment, enabling the development of student practical skills. Based on the specifically formulated learning outcomes and the need for students to acquire proper practical skills, the educational environment with specific simulators was applied at LMA. The usage of different simulators was aimed to reach two main objectives: one of them was to get acquainted with specific shipping and logistics operations, and another, to be able to collect and use specific data during the execution of tasks, including imitation of real life situations, with the aim o achieve and explain the obtained results. For the explanation of

the usage of a set of simulators by the students of the SLIS program, the target research field of not structured data could be drawn as shown in Fig. 2. It is important to say that the maritime sector, consisting of foreland and hinterland, is connected into a whole ecosystem on the basis of seaport. Port operators and foreland and hinterland operators work at the seaport in strong connection and create a set of general and added-value services for customers and for the seaport itself. However, at the level of the global supply chain, the seaport connects not only different types of transportation modes but also the whole seaborne trade logistics chain, including shipping and logistics environment, technologies, and conditions.

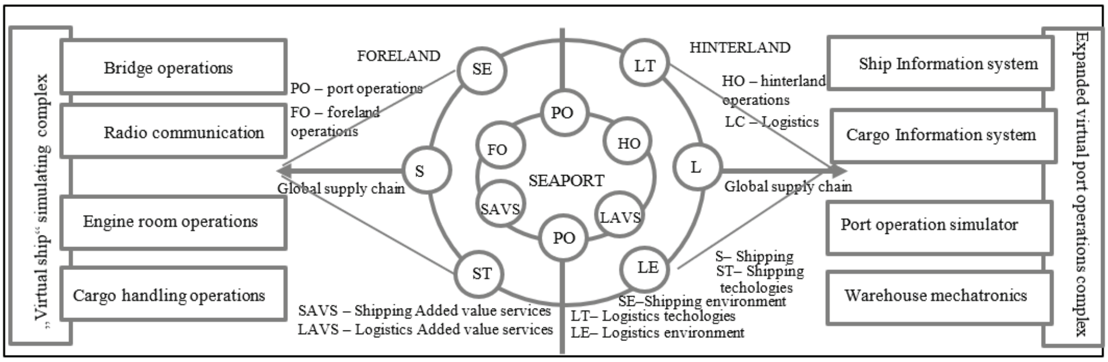

Fig. 2 Relation of LMA specific educational environment with the maritime transport sector organizational ecosystem

LMA has well equipped simulation-based training environment consisting of several functional parts imitating the whole or partial maritime navigation and engineering and shipping and logistics processes [15]. This simulation-based educational environment is logically divided into separate parts: foreland simulators for seafarers training and hinterland simulators for seaport specialists training. This simulator-based educational environment allows one to simulate real foreland and hinterland processes, and this specificity leads to the possibilities of using simulators for experiments and also of collecting multiple data for the imitation of random probable real life situations, in order to make proper decisions. This means that all specialized simulators are integrated into SLIS study program for increasing the effectiveness of studies by training general, specific, and research skills by introducing the experimental imitations method to the study process.

With respect to the learning outcomes, the bridge operation simulator creates the opportunities to get the required knowledge about navigation operations onboard and technological autonomous navigation technologies and the remote management of them. The same situation is in the engine room operations. These simulators have a wide range of experimental activities, and such types of problems can be solved: optimal route finding, optimizing of vessel resources, findings of an optimal set of sensors and equipment for the solution of an identified problem in the engine room; these activities are related to the problem identification, experimental activities, and finding the required data as well as their processing and interpretation.

Ship information system and Cargo information system simulators are used on the hinterland side providing an opportunity to acquire the knowledge of document management at the cargo handling operational level and also influence knowledge transformation to specific skills through experimental practice: this simulator creates opportunities for financial and managerial analysis of cargo operations, and the experimental data can be used as the material for data processing, analysis, and imitative modelling. In describing the process of organizing simulation processes, it can be mentioned that, firstly, simulators are used to collect the knowledge and data about the ongoing processes, and finally, to form an experimental set of data, needed for data analysis and decision making. In addition, simulators are used not only as an instrument to simulate the effect of already taken decisions, but also as a tool to predict the consequences of every taken action. In this case, simulators are used for a double purpose: as a source to acquire the appropriate knowledge and as an instrument to plan experiments and simulate specific situations.

To sum up, the educational environment developed at LMA consisting of foreland and hinterland simulators provides an opportunity to develop practical skills at the generic, specific, and research levels by applying Mathematics, IT, Shipping and Logistics knowledge defined in SLIS study program by respective learning outcomes. Combination of properly developed learning outcomes corresponding to needed competencies of specialist according to recent changes in the maritime sector and labour market which are developed during study process by using modern educational environment facilities in means of different simulators provide possibility to acquire practical skills in the form of students learning achievement. This ensures coherence of the three aspects of study results which are reflected in the cognitive and psychomotor domains of learning.

5. Conclusions

The content of study results includes knowledge, skills, and attitudes which can be understood in three aspects: the external context of studies – competencies oriented to the requirements of the society and labour market; subjective context - the aforementioned knowledge, skills, and attitudes to be considered as a student learning achievement, demonstrating what a student has acquired in the study process; and the objective context of study results, which depends

on the knowledge skills and attitudes defined in the study program of a particular higher educational institution. In order to ensure the effectiveness of studies, all three aspects have to be in strong coherence.

The recent changes in maritime sector related to the introduction of artificial intelligence and autonomous shipping create a need in the labour market for specialists having specific data processing and IT knowledge and skills. In order to meet the described challenges, SLIS study program was developed at LMA. The learning outcomes in this study program were formulated focusing on the cognitive (knowledge of main principles used in mathematics, IT, shipping and logistics) and psychomotor (skills in respective disciplines) domains of learning. The skills were divided into three main groups: *general,* including abilities to collect data from accessible automated sensor and open sourced data bases, apply mathematic modelling and optimization, imitate and simulate processes, analyse and interpret data; *professional,* such as skills in application of special software for data processing, usage of machine learning algorithms and big data technologies, exploration of automated sensor systems; and *research* skills, pointing out the ability of graduates to apply data analysis methodology in practice.

The educational environment developed at LMA consisting of foreland and hinterland simulators provides an opportunity to develop practical skills at the generic, specific, and research levels by applying Mathematics, IT, Shipping and Logistics knowledge defined in SLIS study program by respective learning outcomes. Combination of properly developed learning outcomes corresponding to needed competencies of specialist according to recent changes in the maritime sector and labour market which are developed during study process by using modern educational environment facilities in means of different simulators provide possibility to acquire practical skills in the form of students learning achievement. This ensures coherence of the three aspects of study results which are reflected in the cognitive and psychomotor domains of learning.

The case study of the use of educational environment consisting of a set of different simulators at LMA illustrates the practical implementation of reaching coherence of theoretically defined three aspects of study results (external, objective, and subjective) to ensure study effectiveness in SLIS study program.

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Effect of Current-Conducting Coating of Copper and Titanium Alloy on the Service Durability of a Composite Material

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Abstract

This paper provides the experimentally set characteristics of durability of the polymer composite material HEXPLY 8552S / 37% / AGP280/C (hereinafter – HEXPLY) (laying +/- 90°, number of layers – 8) on the basis of carbon fiber with an applied coating of copper and titanium alloy. The sputtering of copper and titanium alloy is current conducting, thus allowing to apply power to it and heating the surface this way. It can be used for heating the surface of aircraft components by using the simplest method possible that does not require complex additional equipment, which also makes the aircraft construction heavier. Components of HEXPLY material are used to manufacture fuselage shell, primary elements of aircraft structure, as well as helicopter rotors. The continuous struggle for reducing weight of aircraft has resulted in the increasing use of composite materials in the structure of an airframe and its elements. Less studied properties of new composite materials require additional research of their characteristics. This paper provides estimates of structural characteristics of the studied composite material with an applied current-conducting coating.
KEY WORDS: *composite material, copper and titanium alloy sputtering, current-conducting coating of structural components of aircraft, strength characteristics*

1. Introduction

Most airlines that perform flights in winter conditions have to treat aircraft components with a deicing liquid. Such liquid prevents from initial icing on high lift devices and other components. In case of ice appearing on high lift devices, a pilot loses control of aircraft partially or fully, which results in occurrence of abnormal or emergency situations during a flight.

By introducing the technology of sputtering a current-conducting coating on the surface of aircraft components, airlines will no longer need to treat their aircraft with a deicing liquid to secure safety of flights, this way saving financial and human resources. Besides, such liquids are of a toxic nature and contaminate the environment.

This article provides results of tests of a composite material with the applied copper and titanium alloy sputtering. The testing purpose is to evaluate and compare the longevity and fatigue characteristics of specimens of the studied material with the applied current-conducting sputtering thickness <0.25 mm and without it. All tests have been performed in accordance with ASTM D2344. [1]

Composite material HEXPLY has been chosen as a reference material. This composite material is not current conducting as such and, thus, is not capable of heating according to a resistor principle when electric current passes through it. In recent years, this composite material has been used quite extensively in aviation.

2. Materials and Methods

To perform the tests, 21 elementary specimens with the size of 140 × 12 × 2 mm have been used. All specimens have been cut out of the same panel of HEXPLY material (laying +/- 90˚, number of layers – 8).

Copper-titanium sputtering has been applied to the specimens with the help of the vacuum unit NNV-6.6-I1. The process of applying a coating presents sputtering of the specimen surface with a resistive alloy of copper and titanium (with increased concentration of titanium) [10, 11].

Following the sputtering, a visual inspection has been performed and instrumental control with the help of a certified multimeter for any kind of damages, uniformity and conductivity of the coating.

During the control procedures after the sputtering, damages have not been detected and conductivity was present.

All tests have been performed on the certified servo-hydraulic testing machine Instron 8801 with the use of the test instrumentation described in [1].

To estimate the destructive deadweight loading (the static capacity limit), first, in accordance with [1], three specimens have been tested until destruction, according to Fig. 2, and, based on the obtained results, maximum alternate-stress loads of the cycle have been chosen for low-cycle fatigue equal to P_{vmax1} = 0.8 Pst, P_{vmax2} = 0.7 Pst and P_{vmax3} = 0.6 Pst from the average value of the destructive deadweight loading P_{st}.

Table 1

The geometrical characteristics of specimens are following

Nr.	Spaceman Identification number (SIN)	Thickness, mm	Width, mm	Cross-sectional area, mm^2	Weight, g
1	PT1-1	12.73	2.02	6.52	3.229
2	PT1-2	12.83	2.01	6.51	3.241
3	PT1-3	12.85	2.00	6.46	3.232
4	PT1-4	12.86	2.00	6.43	3.215
5	PT1-5	12.84	1.98	6.30	3.182
6	PT1-6	12.85	1.95	6.14	3.151
7	PT1-7	12.85	1.92	5.98	3.113
8	PT1-8	12.81	1.89	5.79	3.062
9	PT1-9	12.84	2.01	6.53	3.251
10	PT1-10	12.83	2.00	6.46	3.23
11	PT1-11	12.86	2.00	6.43	3.215
12	PT1-12	12.84	1.98	6.30	3.182
13	PT1-13	12.85	1.99	6.42	3.225
14	PT1-14	12.83	1.96	6.25	3.19
15	PT1-15	12.85	1.93	6.09	3.154
16	PT1-16	12.84	1.90	5.91	3.108
17	PT1-17	12.78	1.87	5.72	3.058
18	PT1-18	12.81	1.99	6.38	3.205
19	PT1-19	12.84	1.95	6.15	3.152
20	PT1-20	12.83	1.93	5.99	3.103
21	PT1-21	12.75	1.86	5.65	3.037
Average		12.83	1.96	6.21	3.17
Standard deviation		0.03	0.05	0.28	0.07
Coefficient of variation		0.27%	2.49%	4.50%	2.07%

Table 2

Technological Parameters of the Coating Application Process

Current of the evaporator (titanium)	J1-70A
Focusing current of the evaporator	J1fok.-0.6A
Current of the magnetron (copper)	Jm – 4A
Voltage of the magnetron	Um-420 V
Base voltage	Ubas-0V
Argon pressure in the evaporation chamber	Par-1x10-1 Pa
Time of applying the coating	T- 40 min
Table rotation	3 rev/min
Composition of the received coating	Cu-86%,Ti-14%

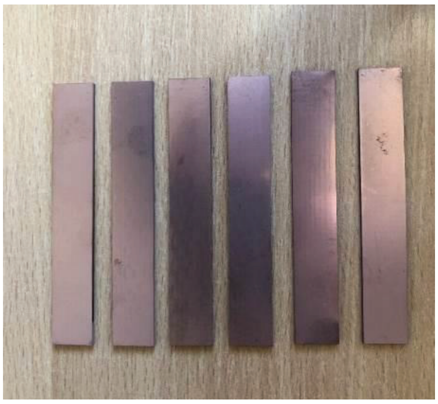

Fig. 1 Specimens following the application of a copper-titanium coating

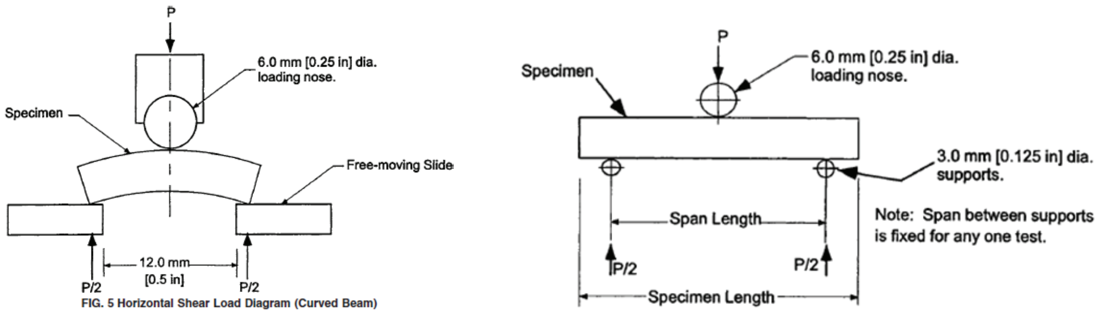

Fig. 2 Specimen testing according to the following method: Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates

3. Results and Discussion

When analysing data of Table 3, it can be noted that the spread of values of the coefficient of variation of the breakdown voltage logarithm is over ten times bigger than the spread of values of the destructive loading logarithm, which is caused by the additional effect of the cross-section area on the general error of determining the static strength characteristics. It is well-known that the spread of fatigue endurance largely depends on the endurance curve parameter *m* and is very sensitive to the applied load [2].

As this article does not analyse a quantitative estimate of the effect of loading (stress) on fatigue endurance of the specimens when building the fatigue curve, but only a qualitative estimate of this effect, further on we will use values of destructive loadings.

Table 3

Results of deadweight loading of specimens without sputtering

Specimen identification number	Destructive loading P_{st}, N	Cross-section area F, mm²	Breakdown voltage σ, MPa
PT1-1	2571.00	6.52	386.83
PT1-2	2608.00	6.51	393.00
PT1-3	2632.00	6.46	399.69
Average	2603.67	6.50	393.17
Standard deviation	30.73	0.03215	6.42982
Coefficient of variation	1.18%	0.49%	1.64%

As this article does not analyse a quantitative estimate of the effect of loading (stress) on fatigue endurance of the specimens when building the fatigue curve, but only a qualitative estimate of this effect, further on we will use values of destructive loadings.

Thus, a variable cycle has been used for fatigue tests with the following maximum and minimum loads of a constant sign cycle with a similar stress ratio $R = P_{vmini} / P_{vmaxi} = 0.1$ [3]:

for the first group of specimens: $P_{vmax1} = 2082.94$ N; $P_{vmin1} = 208.3$ N

for the second group of specimens: $P_{vmax2} = 1822.57$ N; $P_{min2} = 182.6$ N

for the third group of specimens: $P_{vmax3} = 1562.20$ N; $P_{vmin3} = 156.2$ N

It is well known that when estimating fatigue curves, different types of curves are used [4, 9], but the most preferred is the fatigue curve in the system of double logarithmic coordinates $lg\ \sigma - lg\ N$, where σ is stress or load [5], N – the number of cycles until the failure criterion.

Table 4

Provides the results of fatigue tests of specimens without sputtering

Max. load (N)	2082.9		1822.6			1562		
SIN	Cycles	Log	SIN	Cycles	Log	SIN	Cycles	Log
PT1-4	3052	8.02	PT1-7	6150	8.72	PT1-10	13096	9.48
PT1-5	624	6.44	PT1-8	6876	8.84	PT1-11	13425	9.5
PT1-6	1358	7.21	PT1-9	7320	8.9	PT1-12	12844	9.46
Average	1678	7.22		6782	8.82		13121.67	9.48
St.Deviation	1245.23	0.79		590.64	0.09		291.35	0.02
Coef.of Var.	74.21%	10.99%		8.71%	1.00%		2.22%	0.23%

Table 5

Provides the results of fatigue tests of specimens with sputtering

Max. load (N)	2082.9		1822.6			1562		
SIN	Cycles	Log	SIN	Cycles	Log	SIN	Cycles	Log
PT1-13	171	5.14	PT1-16	1916	7.56	PT1-19	13749	9.53
PT1-14	144	4.97	PT1-17	1856	7.53	PT1-20	12866	9.46
PT1-15	203	5.31	PT1-18	2027	7.61	PT1-21	12054	9.4
Average	172.67	5.14		1933	7.57		12889.67	9.46
St.Deviation	29.54	0.17		86.76	0.04		847.75	0.07
Coef.of Var.	17.11%	3.34%		4.49%	0.59%		6.58%	0.70%

When considering the results of fatigue tests of specimens, it can be noted that the value of fatigue endurance of the specimen PT-5 sharply contrasts to the general values of the selection. As there are only by three specimens used for the testing, we apply robust (steady) methods for analysing the data. One of the characteristics of such analysis is a median of selection that we apply to our data [6].

Table 6 provides comparative data of fatigue endurance for two batches of specimens, with and without sputtering.

Table 6

Comparison of fatigue endurance medians for two batches of specimens

Loading, H	2082.9	1822.6	1562.2
without sputtering	1358	6876	13122
with sputtering	173	1933	12890

When comparing the data provided in Tables 4 and 5, it can be noted that median values of fatigue endurances practically coincide with their average values, especially for mean logarithms. This can be regarded as confirmation of absence of discards and the potentially symmetric distribution of logarithms [7].

To illustrate changes from fatigue endurance caused by a stress condition, let us provide on Fig. 3 mean fatigue curves in double logarithmic coordinates for both batches.

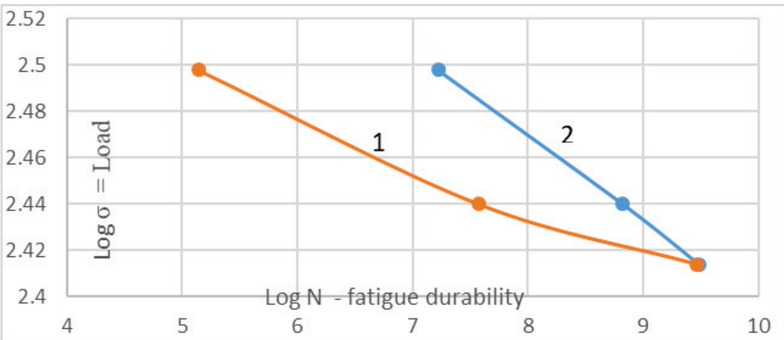

Fig. 3 Comparison of fatigue curves of the specimens: *1* – with sputtering and *2* – without sputtering

The comparison of fatigue curves shows that the reduction of loading in the area of maximum operational loads accepted in aviation (less than 0.67 of destructive deadweight loading) practically does not cause any effect on fatigue endurance of the specimens with the applied coating compared to conventional specimens with no coating. Still, at high levels of stress, close to destructive ones, fatigue endurance of the specimens with the coating decreases sharply compared to conventional specimens.

It can be expected that for lower levels of loading, endurance of the specimens with the coating can exceed that of conventional specimens, as the applied coating of the current-conducting coating can play the role of an inhibitory coating smoothening micro damages (stress raisers) on the surface of the specimen [3].

Such property of current-conducting coatings can be used not only for deicing systems, but also for monitoring the technical condition of Structural Significant Elements (SSE) included in the Structural Health Monitoring (SHM) Health Usage Monitoring Systems (HUMS) [8] in the online mode, when changes of current-conducting properties of the coating can signal about the appearance of micro damages on the surface of SSE.

4. Conclusions

1. Comparison of characteristics of fatigue endurance has been performed for two batches of specimens from

the same batch of aviation polymer composite material HEXPLY 8552S / 37% / AGP280/C (laying +/- 90˚, number of layers – 8) on the basis of carbon fiber.

2. Static tests of three specimens and fatigue tests of 18 flat specimens with the size of 140 × 12 × 2 have been performed in the conditions of three-point bending on the test machine Instron 8801 in accordance with the requirements of ASTM D2344/D2344M Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates.

3. The comparative fatigue tests have been performed on three levels at maximum loads of a constant sign cycle for specimens without an applied coating and specimens with sputtering of a current conducting copper-titanium layer thick < 0.25 mm by means of a vacuum unit NNV-6.6-I1**.**

4. The results of static tests of specimens without coating demonstrated the destructive load (stress) equal to 2.6 kN (393 MPa). The obtained result has been used for setting the following parameters of a constant sign cyclic loading:

- maximum loads of the cycle for each batch of specimens 2.08 kN, 1.82 kN and 1.56 kN;
- cycle ratio 0.1.

5. The tests have demonstrated that the specimens with sputtering in the areas of high loads (70%...80% of the destructive load) have less fatigue endurance than the specimens with no sputtering.

6. At low levels of loading (stresses), i.e. in the area of maximum operational loads, fatigue endurance for both batches is practically identical. Besides, the observed reduction of difference in endurance between different batches at reduced loads is decreasing, thus, allowing one to conclude about a positive effect of the coating on the surface of the specimen.

7. It is practical to apply current-conducting coatings to be included in the systems of technical condition diagnostics of structural elements in the online mode.

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The Issue of Improving of the Design of a Railway Wheelset

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Abstract

The article analyses one of the significant drawbacks of traditional wheelsets of rail vehicles, which consists in the occurrence of elastic deformations of bending of its axis in operation. It has been established that this is due to the irrational scheme of transferring vertical loads from the topsides of the rail vehicle. The magnitudes of these angles determine the additional (elastic or plastic) displacements of the points of the contact of wheels with the rails transversely of the rail gauge when the wheelset is subjected to the static and dynamic loads during the movement. A possible way to eliminate this disadvantage of the traditional wheel pair is to change the loading scheme of its wheels with vertical loads. This is possible to perform by changing the traditional design of a wheelset and abandoning its traditional axis using independently rotating wheels (IRW). The use of wheel pairs with IRW eliminates another significant disadvantage of traditional wheelsets. It is associated with high torsion stiffness of the axles of such structures, which does not allow the wheels to rotate relatively to each other. This causes increasing of wheel slip on rails when moving in curved sections of the track and it also limits the speed of steady movement of rail vehicles in straight tracks. However, when using wheel pairs with the IRW, they are not centred in the rail gauge. At the same time there is long contacting of a flange of one of the wheels on the rail with a high level of wear. Improving the dynamics of rail vehicles with IRW and reducing wear of wheels and rails is possible by means of mechatronic systems to control the position of wheelsets in the track gauge.
KEY WORDS: *a wheel, a load scheme, a wheelset, independently rotating wheels (IRW)*

1. Introduction

When rail vehicles are moving in a track, the safety of this movement and acceptable levels of force and wear processes of interaction between a bogie and the rails should be ensured. The showing of these processes is influenced by a significant number of factors. The main ones are the construction and condition of the crew and the rail track, as well as the speed of movement. They largely determine the level of dynamic loads in curves and in straight sections of the rail gauge.

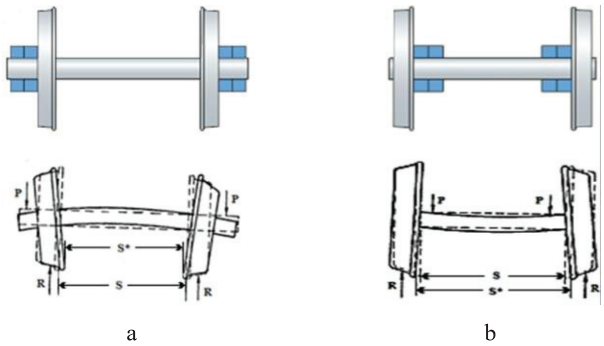


Fig. 1 Schemes of an application of loads and deformation of the axes of traditional wheelsets: a – external location of axle boxes; b – internal location of the axle boxes

Wheelsets are one of the most critical units of rail vehicles. In traditional wheelsets wheels are rigidly mounted on an axle and transfer the weight of the rail vehicle's upper structure to rails and perceive the corresponding efforts when interacting with the rail track. That is, they implement the functions of the reference, guide and brake mechanism, as well as the mover [1, 17, 24, 27]. Modern conditions of operation of wheelsets of rail vehicles determine the

increased requirements for their structural and dynamic characteristics [24].

The schematic diagram of a wheel pair consisting of an axle with two wheels mounted on it has remained unchanged for almost two centuries.

In the interaction of a rail vehicle and a track under operating conditions, the wheelsets are exposed to significant static and dynamic loads [12, 15, 16]. As a result, wheels slip occurs on the rails with elastic and plastic deformations in the contact surfaces [9, 18-20]. It also intensively proceeds the processes of wear of wheels and rails. Therefore, even with it massive constructions with large safety factors, in operation elastic deformations of the bending of the axis of the wheelset occur [8, 9]. They are due to the fact that the transfer points of the vertical loads *P* (Fig. 1) from rail vehicle's upper structure are offset from the sections of axle in which the wheels are mounted. The reactions *R* from the side of the rail track herewith act at the points of contact of the wheels with the rails. Fig. 1 shows the main schemes of application of loads and deformations of the axles of traditional wheelsets for structures with external and internal axle boxes [2, 25, 31]. Here, P_0 is the given axial load.

Considering the axis of the wheelset as a straight beam, it can be established that under the external forces acting in one of the main planes of this beam, its axis is bent in the same plane. In this case, the beams sections are not only progressively displaced, but also turn round [11]. Neglecting shear deformations, we can assume that the angle of rotation of the beam cross-section equals to the angle between the tangent drawn to the curved axis beam in this section and the non-deformed beam axis, i. e. the angle of rotation of the axis of the beam in this section.

From the physical fundamental of the bending phenomenon, it follows that the curved axis of the continuous beam must be continuous and smooth (without kinks) curve. In this case, the deformation of a particular section of the beam is determined by the curvature of its elastic line, that is, the curvature of the axis of the beam.

Taking into account the hard landing of the wheels in a wheel pair on the axle, turning its corresponding sections during bending should lead to corresponding turns of the wheels fixed on it. The magnitudes of these turns determine the additional (elastic or inelastic) displacements of the points of contact of the wheels with the rails in the transverse to axis of the rail track when the wheel pair is subjected to static and dynamic loads during the movement of vehicle.

2. Research Results

When rail vehicles are moving in a track, the safety of this movement and acceptable levels of force and wear processes of interaction between the running gear and the rails should be ensured. The showing of these processes is influenced by a significant number of factors. The main ones are the construction and condition of the crew and the rail track, as well as the speed of movement. They largely determine the level of dynamic loads in curves and in straight sections of rail gauge.

It is known that even insignificant transverse slippage at the points of contact of wheels with rails can significantly affect the conditions of their contact and the parameters of force interaction [10]. Therefore, it is necessary to estimate the magnitudes of these additional displacements and the possibility of their influence on the processes occurring in the contact of the wheels with the rails.

As calculations [11, 22] show, the axial moment of inertia of the wheel section relative to the perpendicular axis to the plane passing through the axis of the wheel pair is approximately three orders of magnitude greater than the corresponding axial moment of inertia of the wheelset axis. Therefore, the bending deformations of the wheel itself in this plane under the action of the system of loads under consideration can be neglected. At the same time, we believe that the possible displacement of the point of contact of the wheel with the rail in the across of the rail track at bending the axis of the wheel pair will depend primarily on the angle of rotation of the cross-section of the axis of the wheelset in which the wheel is mounted.

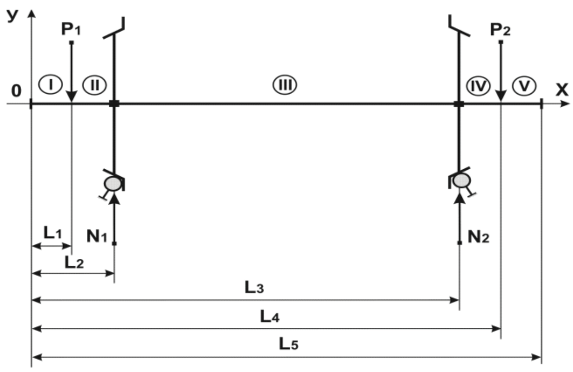


Fig. 2 A design scheme

With a simplified solution of the problem, we take the following assumptions: the axis of the wheelset is considered as a straight beam with a constant cross-section with a diameter *d*; the influence of the mounted wheels on the shape of the curve of bending of the axis of the wheelset is not taken into account, the distributed application of loads to the axis of the wheelset is replaced by the single force. The design scheme of the wheelset with the vertical loads acting on it is shown in Fig. 2. We consider a rectangular *x-y* coordinate system with the origin in the point *O* on the left side of the wheelset axis. With an uniform distribution of the acting vertical loads on the necks of the axis

($P_1 = P_0/2$, $P_2 = P_0/2$), normal reactions from the side of the rails are $N_1 = P_0/2$, $N_2 = P_0/2$.

For determination of the displacements of the axis sections, it is necessary to obtain equations relating the values of the angles of rotation and deflection of the beam sections with the x coordinate along the axis length. These equations can be obtained by integrating the known basic differential equation of the curved axis of a beam [11]:

$$\frac{d^2y}{dx^2} = \frac{M(x)}{E \cdot J_z}. \tag{1}$$

Taking into account the accepted assumptions for the beam of a constant cross-section $E{\cdot}J_z = const.$, after integration, we obtain the equation for determining the angles of rotation of sections of a beam:

$$\frac{dy}{dx} = \phi(x) = \int \frac{M(x)}{E \cdot J_z} \cdot dx + C = \frac{1}{E \cdot J_z} \int M(x) \cdot dx + C. \tag{2}$$

After double integration, we obtain the equation of the elastic line (the equation of the deflections of sections the axle) in the following form:

$$y(x) = \frac{1}{E \cdot J_z} \int \phi(x) \cdot dx + C \cdot x + D. \tag{3}$$

For this, it is necessary to write it in a general form of equations of bending moments $M^i(x)$ as a function of the coordinate x of the beam cross-section for the others sections of the beam under consideration (Fig. 2):

$$\begin{aligned}
&M^I(x) = 0;\\
&M^{II}(x) = -P_1 \cdot (x - L_1);\\
&M^{III}(x) = -P_1 \cdot (x - L_1) + N_1 \cdot (x - L_2);\\
&M^{IV}(x) = -P_1 \cdot (x - L_1) + N_1 \cdot (x - L_2) + N_2 \cdot (x - L_3);\\
&M^{V}(x) = -P_1 \cdot (x - L_1) + N_1 \cdot (x - L_2) + N_2 \cdot (x - L_3) - P_2 \cdot (x - L_4).
\end{aligned} \tag{4}$$

Then expressions (4) are substituted into Eqs. (2)-(3) and integrated. Since the expressions of bending moments for segments $I – V$ are different, the equations of the elastic line are also different in these segments. Therefore, the integration of equations (4) must be performed separately for each segment. The integration constants C and D for each segments of the beam can be determined from the boundary conditions, for example: $y^{II}(L_2) = y^{III}(L_2) = 0$, $y^{III}(L_3) = y^{IV}(L_3) = 0$, $Ø^{II}(L_2) = Ø^{III}(L_2)$, $Ø^{III}(L_3) = Ø^{IV}(L_3)$ etc.

Determining the displacements for beams having several segments can be quite laborious, since for n segments the number of arbitrary constants (C and D) increases to $2{\cdot}n$. To reduce the computational work, we use the method of initial parameters [3-5], which allows for any number of segments of the beam to provide a solution for finding only two constants – deflection and rotation angles of a section at the origin:

$$C = \phi(x = 0) = \phi_0; \quad D = y(x = 0) = y_0, \tag{5}$$

where, $Ø_0$, y_0 – are angles of rotation and deflection of the beam section at the origin.

Using the Clebsch method, we integrate equations (2) and (3) on all selected segments of the axis of the wheelset without opening the brackets. The universal equations of the method of initial parameters in relation to our problem are:

$$M(x) = \sum_i M_i + \sum_i F_i \cdot \frac{\left(x - L_{F_i}\right)^1}{1!}; \tag{6}$$

$$\phi(x) = \phi_0 + \frac{1}{E \cdot J_z} \cdot \left[\sum_i M_i \cdot \frac{\left(x - L_{M_i}\right)^1}{1!} + \sum_i F_i \cdot \frac{\left(x - L_{F_i}\right)^2}{2!} \right]; \tag{7}$$

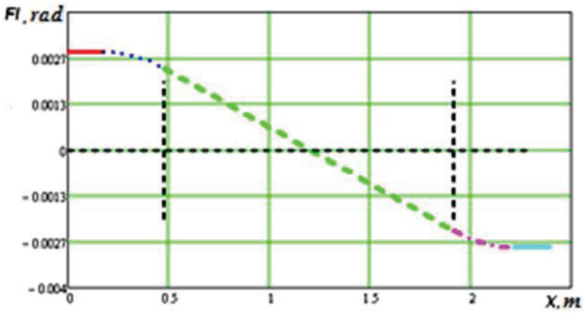
$$y(x) = y_0 + \phi_0 \cdot x + \frac{1}{E \cdot J_z} \cdot \left[\sum_i M_i \cdot \frac{\left(x - L_{M_i}\right)^2}{2!} + \sum_i F_i \cdot \frac{\left(x - L_{F_i}\right)^3}{3!} \right], \tag{8}$$

where L_{Fi}, L_{Mi} are coordinates of sections in which the corresponding forces are applied, bending the axis of the wheelset.

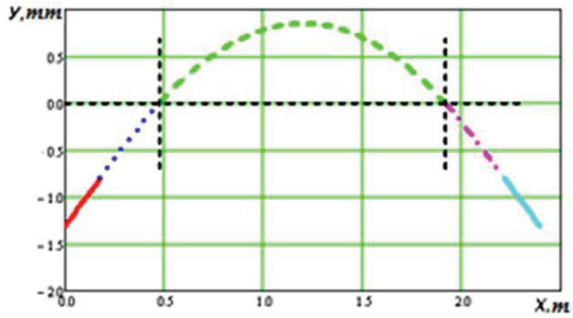
Having determined the integration constants y_0 and $Ø_0$ from the boundary conditions, using dependencies (7),

(8), we can create graphs characterizing the bending of the axis of the wheelset and calculate the angular and linear deformations of the axis in the sections of interest.

Fig. 3 shows the example of graphs characterizing the angles of rotation of the cross-sections $Ø(x)$ and deflections of the axis of the wheelset $y(x)$ with the axis diameter $d = 0.17$ m under the influence of the vertical loads applied to the journals of the axis $P_0/2$.



a



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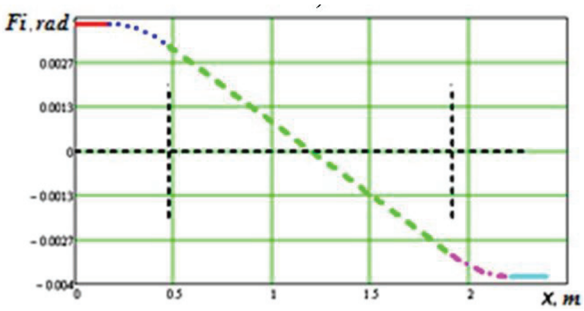

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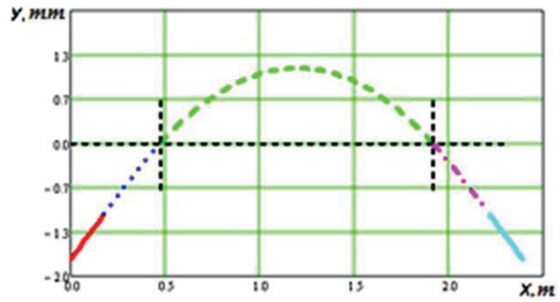

d

Fig. 3 Graphs of dependencies of $Ø(x)$ and $y(x)$ for bending of the wheelset: a – dependence of $Ø(x)$ for $P_0/2 = 90$ kN; b – dependence of $y(x)$ for $P_0/2 = 90$ kN; c – dependence of $Ø(x)$ for $P_0/2 = 120$ kN; d – dependence of $y(x)$ for $P_0/2 = 120$ kN

Analysis of the results of the calculations shows the following. Under the existing loading scheme of the wheelset with the static vertical loads in the range from 90 to 120 kN, the angles of rotation of the axle sections in which the wheels are rigidly fixed, can be from 0.0024 to 0.0032 rad for proposed initial conditions (positive angles of rotation of the sections, we think the angles when turning sections of counterclockwise). Corresponding to these angles of rotation, possible additional displacements of the points of the contact of each wheel with the rail in the direction perpendicular to the longitudinal axis of the rail track can be from 1.12 to 1.49 mm.

The main geometrical parameters of wheelsets are strictly regulated in terms of movement safety. Therefore, for example, the distance between the inner edges of the wheel flanges in the wheelsets intended for movement on the 1,520 mm rail track with speeds up to 120 km·h^{-1} should be 1,440 ± 3 mm [1]. However, the results of calculations described above show, that only due to the shortcomings of the existing loading circuit of a traditional wheelset with the static vertical loads, the distance between the wheels of the wheelset during crew movement in operation can decrease about 3 mm and taking into account the influence of dynamic processes and more. Under the influence of intensive dynamic processes, this value can be much higher.

It can be assumed that the noted possibility of additional transverse wheel slippage along the rails, due to the traditional design of the wheelset, during the movement of rail vehicles the negative effects on the processes of wear of the wheels and rails, significantly intensifying them. Therefore, for example, the presence of cyclic bending of the axis of the wheelset with the traditional loading pattern determines the uneven wear of the liners of the motor-axial bearings along their length. To avoid this, the inner surface of these liners is in the form of a hyperbola [27].

This structural disadvantage of the traditional driving wheelset, in addition to the intensification of wear processes in the contact of wheels with rails, should also have a negative impact on the implementation of traction and braking efforts by increasing the level of transverse slippage of the wheels along the rails, especially with a sufficiently high intensity of spatial oscillations of the railroad rail vehicle upper structure.

Summarizing the above, it can be noted that the traditional design of a wheelset of rail vehicles with a rigid wheel attachment to the axle has a significant drawback associated with the transmission of vertical loads on the wheels from the upper structure eccentrically (that is, not in those sections where the wheels are mounted on the axle). This causes deformations of the bending of the axis of the wheelset and the additional transverse movement of the points of the contact of the wheels and rails relatively to the rails during the movement of a rail vehicle.

One of the ways to eliminate this drawback is to change the load scheme of the wheels vertical loadings.

Obviously, this is only possible, if the traditional design of a wheelset is changed and the traditional axis is abandoned [1, 2, 10, 29, 31]. Fig. 4 shows some load schemes for such wheelsets (pairs of wheels).

It should be noted that the use of wheelstes (pairs wheel) of such design schemes allows to eliminate another significant drawback of traditional wheelset designs. It is associated with the high torsion stiffness of the axes of such structures, which does not allow relative rotation of the wheels relative to each other. The rigid coupling of the wheels of the wheelset in the torsion direction causes increased slippage along the rails when moving in curved sections of the track, and also limits the speed of steady movement of rail vehicles in straight sections of tracks.

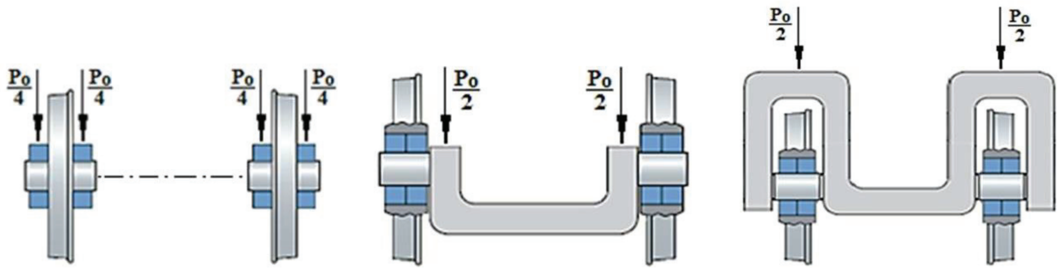

Fig. 4 Schemes of wheelsets with a rotational transfer of vertical loads from the upper structure to the wheels

However, studies show that wheelsets with IRW in accordance with the schemes of Fig. 4 are not centred in the rail gauge. In this regard, there is a long contact of the flange of one of the wheels and the rail and an increased level of their wear and resistance to movement [4, 5, 10, 30, 31]. Therefore, designs of running gears with independently rotating wheels are mainly used in urban rail vehicles with low floors, where the wear of the wheel flanges is low due to low speed and low axle load [2, 31]. In the case of the use of such structures on the magistral rail transport, it is necessary to take additional measures to ensure the self-centering of such wheelsets in the rail gauge [13, 14, 28]. For example, Talgo running gears, are being successfully used for several decades thanks to the original concept of the direction of wheelsets on a rail track [29].

A certain reduction in slipping of wheel flanges on rails can be achieved by improving the design schemes of the wheels themselves. Some from them provide the possibility of independent rotation of their support and guide surfaces [21, 26].

Structures that provide limited possibility for independent rotation of the wheels in the wheel pair relative to each other through the use of innovative axle structures and wheel attachment assemblies on it [2, 6, 18] are also being investigated.

One of the most currently developed areas of research in improving the dynamics of rail vehicles with IRW, reducing wheel and rail wear and resistance of movement is the use of mechatronic systems to control the position of wheelsets with IRW in a rail track in the horizontal direction. The results of numerous theoretical and experimental studies [6, 7, 23] confirm the effectiveness of this approach.

3. Conclusions

One of the significant drawbacks of traditional wheelsets of rail vehicles is that in operation, elastic deformations of the bending of her axis arise. They are due to the displacement of the points of application of vertical loads from the upper structure from the sections of the axis of the wheelset in which the wheels are mounted.

One of the ways to eliminate this drawback is to change the load scheme of the wheels with the vertical loads. Obviously it is possible only when changing the traditional design of the wheelset (abandoning its traditional axis and using IRW). In addition, the use of wheel pairs (pair wheels) with IRW eliminates another significant disadvantage of traditional wheel sets. It is associated with the high torsion stiffness of the axes of such structures. It does not allow the wheels to rotate relative to each other and causes their increased slippage along the rails when moving in curved sections of the track, and also limits the speed of steady movement of rail vehicles in straight.

However, when using wheel pairs with IRW, they are not centred in the track gauge. At the same time, there is a long contacting of the flange of one of the wheels with the rail and an increased level of their wear.

The most effective improvement of the dynamics of rail vehicles with IRW and reduction of wear of wheels and rails is possible through the use of mechatronic systems to control the position of wheelsets in the track gauge.

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Standardization of Selected Interfaces of Railway Traffic Control Equipment and Systems – the General Information

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Abstract:

The paper presents general information on a project aimed at developing a digital interface standard for selected rail traffic control command and signalling systems. 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 goal of the project is to develop, through research, specifications and requirements for interfaces used in traffic control systems, rail control systems and maintenance & diagnostic centre computer devices, which will become a standard enabling linking of system components from different manufacturers and of different types. The results of the project will be dedicated to use on the railway network managed by PKP PLK (and potentially also by other infrastructure managers) along with documentation containing descriptions of standards, guidelines for the application and design of these interfaces.
The project will enable implementation of a standardized specification of interfaces on the entire railway network in Poland in all computer control and command systems of rail traffic and accompanying systems.
The proposed solution for standard interfaces is significantly improved compared to competitive models of device and system linkages, where each manufacturer offers its own hardware and software interface solutions, actually ensuring full cooperation only between its own systems.
KEY WORDS: *control command systems, digital interfaces, safety data transmission, standardization of interfaces*

1. Introduction

The lack of comprehensive standardization; both in terms of specifications, as well as requirements for the use of interfaces in the rail traffic control systems is one of the most serious problems that both the designers, the contractors involved in the implementation of these systems, but also the operators of the infrastructure itself, have to face on a daily basis. In parallel, finding the solution to the problem becomes more pressing as the railway market becomes more open and the number of manufacturers for the railway traffic control equipment and systems, is observed to grow expeditiously. In response to this pressing problem, this article presents findings of the project that has been undertaken in order, to fill the existing knowledge gap in this area and to develop a framework that could be used as an effective tool in organizing the use of the interfaces and connections for the railway traffic control devices in a fully practical manner.

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, has been to develop specifications and requirements for the interfaces used in computer traffic control devices, based on purposely conducted research and tests, through which the validity of the adopted research key assumptions could be tested. The project findings would be then summarized in form of a guideline document which would encompass standards, requirements, as well as recommendations in respect to the design, as well as the implementation, and which would facilitate connecting various railway traffic control devices and systems, along with other possible accompanying systems of different types, regardless of their manufacturer. Moreover, the additional advantage of the project would be that it would allow to standardize interface specifications for the entire railway network in Poland. Finally, although the current project has been dedicated specifically to the needs of the railway network which is managed by the PKP PLK, the developed framework could also be successfully employed by other operators of the railway infrastructure.

To further emphasize the success of this project it should be noted, that thus far, it has not been possible to develop and implement an interface standard that would successfully link computer traffic control systems of varying

manufacturers, hence the project standardization guidelines will introduce a new level of quality in the management of the railway projects in Poland. To further explain the project context, it should be noted that currently in Poland there are already several domestic and foreign manufacturers which are supplying railway traffic control systems or are having equipment in operational tests, and their number is constantly growing. This, paired with, the large scale of ongoing and scheduled railway modernization works, as well as planned construction of completely new railway lines is only expected to increase the use of modern railway traffic control devices and associated with them interface related problems. Finally, although the project focus has been mainly on the solutions which have been already introduced to the market and which, so far, have not been coordinated. The project, also takes into account the wider context of ongoing development in the field of computer, as well as rail traffic control technology, along with the associated with it potential current and future challenges, such as; the implementation of the ERTMS / ETCS system, centralization of the control systems at the regional level, development of fiber optic technology, cybersecurity and others.

2. The Project Context

Designing railway traffic control devices and systems for a specific object on the railway network (station, route, remote control area, etc.) can be defined as a process of establishing and recording the hardware and software configuration of these devices and systems, alongside with all the connections between them. The connections between devices and systems provide both physical, as well a logical connection, which enables them to exchange information and to ensure their cooperation. Making connections requires equipping these devices and systems with interfaces, i.e. input / output systems, together with the appropriate software that enables them to perform as intended [2].

All rail traffic control devices and systems require some kind of connection with others, and with only a few exceptions, they usually cannot work as completely isolated or independent of other devices and systems, including the accompanying devices and systems such as; power supply system, tele-technical devices, video monitoring systems, as well as track layout and others.

The practice of design and the implementation of the rail traffic control devices and systems confirms that one of the most difficult tasks facing designers and contractors is to design, test and implement proper connections between devices of different systems for which no standard connections has been specified. This task requires consideration of many factors that do not occur in the design of standard solutions and which generates many problems, such as [5]:

— time-consuming - designing and implementing custom connections generates considerable amount of time that needs to be spent on obtaining information, coordination, and during implementation phase accompanied by extensive testing, research, and countless re-adjustments;

— capital-intensity – designing custom connections increases project and investment costs, generate unnecessary workloads, as well as creates considerable demands in terms of both equipment and human resources;

— no standardization – although introducing custom design connections for the incompatible interfaces, is possible, it usually has atypical character, and as such poses various challenges such as: it often cannot be automated, it requires specialized technical and functional solutions, and frequently it generate errors;

— limited access to information - device manufacturers knowingly limit access to information such as: transmission protocols, electronic circuit details, electrical parameters, input / output system operation logic, configuration files, data structure, which further complicates coordination efforts;

— lack of clear requirements at the tender stage – critical information is missing in the tender specifications and other pre-design documents, which leaves a lot of room for interpretation and generates problems;

— operational and exploitation problems – naturally the use of various, non-uniform solutions on the railway line, subsequently may generate a wide array of problems, e.g. in case a railway line needs to undergo modernization, or if any modifications or disassembly might be required at any level of the interconnected systems.

Of course, the noted above difficulties and limitations do not constitute a complete list of all possible challenges that might be posed by the lack of standardization for the interfaces and connections of the CCS (railway traffic control and signalling) devices and systems. However, they illustrate the breadth of the problem and the urgency for the research in this area, as well as developing interface standards, as soon as possible. Further, due to incorporation of mainly computer systems in the newly installed rail traffic control systems, the main research efforts should be placed on the standardization of the interfaces for these particular systems.

It should be also noted, that while, the connections between computer systems for the physical layer can be standardized relatively easy due to the low level of complexity of this layer and due to a relatively limited availability of possible solutions (e.g. copper twisted pair, fiber-optic cables, switches, routers, converters, etc.). The task remains considerably more challenging is regards to the standardization of interfaces and connections for the logical layer (i.e. software, data structures, telegram format, transmission parameters) hence that is where the main research and development, as well as implementation efforts of this project have been placed on.

The issue of interfaces have been raised in many publications, and during various technical conferences, for example in [1-6], as well as during the 85th Infrastructure Committee Meeting that have been held in May 2017 [7], during which the PKP PLK S.A representatives have firmly stated that the problem of interfaces is imperative from the standpoint of both railway safety as well as it's functioning.

Of course, the problem of interfaces is not limited only to the context of Polish railways but rather it expands onto all railway infrastructure operators in Europe, and as such it has also been under investigation by the EU. An

example of such joint international efforts is the initiative of EULYNX that has been established in 2014, and which have been aimed at developing interface standardization for the CCS devices for several European railway operators. The project is currently at the phase of trials and experiments. However PKP PLK S.A. has not participated in this project since its inception, not joining the project team until 2017. As well as, considering the high number of project participants and the significant differences in their respective railway traffic and signaling systems, it seems that the results of that study will not be fully useful in terms of specific PKP PLK S.A. needs.

3. Project Methodology and the Key Project Assumptions

The first step of the project, was to select connections of the railway traffic control systems and their respective interfaces, that should have the highest priority in order to be included in the standardization process. For example, on the railway line E-65 Warsaw-Gdansk, over sixty different interface connections, with a varying level of complexity, have been identified by the appointed contractor [6].

As such, establishing a list of interfaces that should be included by the standardization was a process that have been divided into several stages, as well as, that have been consulted and verified multiple times throughout the project. Effectively the framework to select and to complete the interface list consisted of the following steps:

(1) creating a list of all the elements present in the Control-Command and Signalling (CCS) based on documents;

(2) extending the list of elements based on the available engineering knowledge;

(3) identification of all theoretical possible interactions between the selected CCS elements (matrix of elements);

(4) limiting the list of interfaces to only those that are actually present in the CCS;

(5) finally, confirming with the PKP PLK S.A. the final list of interfaces that should be included in the standardization (Fig. 1).

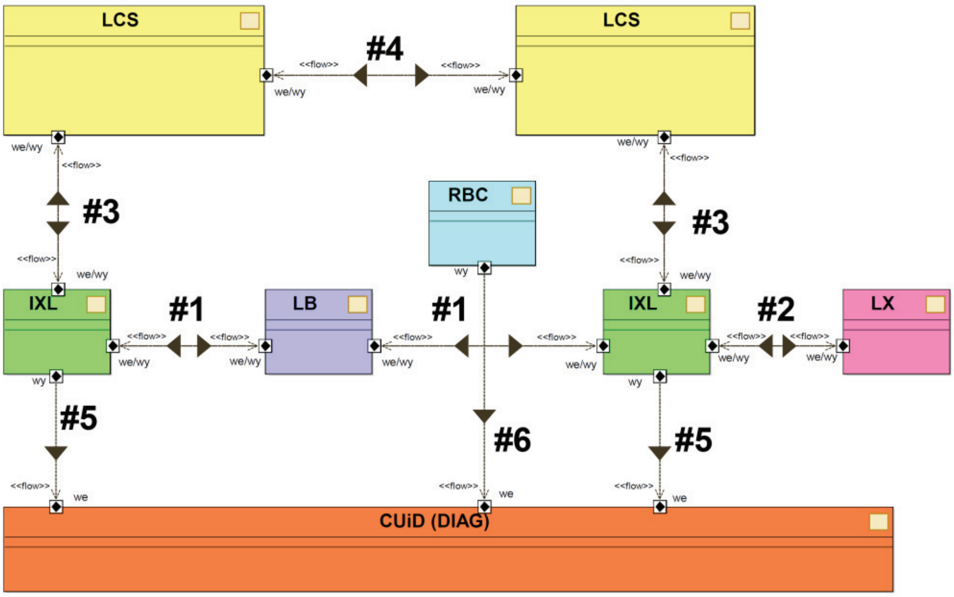

Fig. 1 Block diagram illustrating connections between the CCS system interfaces that have been included in the standardization (made in *SysML* Block Definition Diagram) [Copyrights by Rail-Mil Computers Sp. z o.o. sp. k.]

The CCS can be divided into elements which requirements have been specified in the TSI (hereinafter referred to as interoperability constituents) and elements which requirements are TSI open points and thus are defined in the national technical specifications and standardization documents.

In order to define the list of elements of the CCS, the two regulations were used as guideline:

— Regulation on the interoperability of the rail system [9], which lists the interoperability constituents based on the TSI;

— Regulation on placing in service [10], which contains a list of devices for which a certificate of release to service is required.

Next, the list prepared in this manner was further expanded by adding a list of elements and systems that have been present in the PKP PLK SA network, however which, due to their character (e.g. support and information systems), either didn't require any formal documentation in order to be released on the market, or they must have been added to the network from the level of the operator's safety management system (SMS), in accordance with the sms-pw-17 procedures [8].

Then, to determine the list of possible interfaces that may appear in the CCS, a matrix based on the previously prepared list of elements have been created. Based on the matrix prepared in this fashion, a list of several hundred interfaces was established, which then through analysis based on their actual occurrence in the CCS was downsized to several dozen - of which were actually practically used. The shorter list have been then consulted with PKP PLK S.A.

which further narrowed down the list; to only interfaces with the highest priority of being included in the standardization.

In accordance with the assumptions adopted by the project, the Consortium then turned to the leading, Polish manufacturers specializing in the construction and modernization of railway traffic control projects, and held a series of workshops and technical consultations which were aimed to provide further insights into the scale of the problem and to help further adjust the project scope, if necessary. Taking into account the results of the consultations and a detailed analysis of existing documentation, it was concluded that the interface standardization should practically be build from the ground up.

In terms of the scope, it was assumed that the project could be implemented on the entire railway network, for all the railway traffic controlling computer systems including the accompanying systems as well. In particular, the project would be aimed:

— to connect basic layer of the CCS devices of various types and manufacturers, as well as created utilizing different technology (in particular connecting the interlocking systems working at two adjacent stations);

— to link the basic CCS devices and the superior layer devices of various type and manufacturers, and as well as created utilizing different technology (in particular, connecting the interlocking systems with the remote control systems and regional control centers) and the prepare for the implementation of ERTMS / ETCS;

— to link the remote control devices operating in different areas (LCS, RCS);

— to unify monitor imaging and service method at the operator position of the railway traffic control system, regardless of the type of basic layer devices;

— to link the basic layer CCS devices with the diagnostic and maintenance subsystem devices, e.g. diagnostic and maintenance centers (CUiD).

A proposed initial list of interfaces has been again presented to PKP PLK S.A. and after some additional consultations and analysis, a final list of connections, and thus the following interface typology has been revealed:

(1) LB - IXL (block signaling - interlocking on the station);
(2) LX - IXL (level crossing signals - interlocking on the station);
(3) LCS - IXL (local control center - interlocking on the station);
(4) LCS - LCS (remote control center - remote control center);
(5) IXL - CUiD (interlocking on the station - maintenance and diagnostics center);
(6) RBC - CUiD (radio block center - maintenance and diagnostic center).

The interfaces and the connections they create has been shown in block diagram (Fig. 1).

Above typology of interfaces, of course doesn’t exhaust the long list of other possible interfaces that could be included in this standardization, however the enclosed list have been found to sufficiently address the most immediate needs of PKP PLK S.A and already at this stage, it should allow to significantly improve the investment proces, while reducing costs and shortening the overall time required to complete the implementation of future railway projects.

4. Project Scope of Work

The project scope of work has been divided into 9 distinct stages and among two consortium members, which has been shown in further detail in the Table. Accordingly, project scope of work have been divided into:

— stages 1, 2, 3, 6, 7, 9 which have been carried out by the Railway Institute (IK);

— and, stages 4, 5, 8 which have been carried out by Rail-Mil Computers Sp. z o. o. sp.k (RMC).

In addition, schedule of work has been spread over 42 months, based on which project is expected to be completed in November of 2021.

In stage 1, the technological problem that needed to be addressed was primarily focused on accurately defining the project scope of work and selecting interface groups that should be prioritized in the standardization process. In addition to creating the list of interfaces, a definition of interface usage classes have been developed, as well as the interface and system specifications (if available) were analyzed as well. The results of this stage are presented in the previous section. At this point it should be noted, that while work on stages 1 and 2 have been already completed, the work on stages 3 and 4 have been commenced, while the status of work on remaining stages have been idle.

As such, once stages 1-5 have been successfully completed the aim for the stages 6 and 7 will be to conduct laboratory tests of the interfaces that have been developed as part project stages 4 and 5, and according to specifications that have been previously set out in stages 2 and 3. The second aim of this stage will be to prepare the required technical documentation, as well as test reports for further testing.

The main objective of the laboratory tests will be aimed at confirming whether the requirements outlined in the specifications for each of the interfaces have been met. The specification for each of the interfaces that have been prepared in the previous project stages include; all applicable requirements for a given interface - including requirements specific to the PKP PLK S.A. network. Before conducting the laboratory test, it will be necessary to outline a detailed laboratory test program. Laboratory tests will be carried out using laboratory models prepared in previous stages.

The main aim of stage 8, will be focused on preparation of field studies of selected interfaces (previously developed and tested utilizing computer simulations). Activities at this stage will have predominantly organizational and documentary character, before the actual field tests can commence at the stage 9.

The aim for the final stage 9 of the project will be conducting tests of selected interfaces, in real conditions, which will allow the interface operating parameters to be checked under actual application conditions.

Table

Project stages and schedule for work [materials from Rail-Mil Computers Sp. z o.o. sp. k.]

Stage#	Responsible party	Project stages	
1	IK	Interface list definition	
2	IK	Interface specification #1 (IXL – IXL), #2 (IXL – LB)	
3	IK		Interface specification #3 (IXL - LCS), #4 (LCS – LCS), #5 (IXL – CUiD), #6 (RBC – CUiD)
4	RMC	Development of interface models #1 and #2	
5	RMC		Development of interface models #3, #4, #5 and #6
6	IK	Conducting laboratory tests of interfaces #1 and #2	
7	IK		Conducting laboratory tests of interfaces #3, #4, #5 and #6
8	RMC	Preparation of field tests of selected interfaces	
9	IK	Conducting field studies of selected interfaces	

The technological issue implemented in stage 9 will be tests in real conditions of selected interfaces. Conducting tests will allow the interface operating parameters to be checked under actual application conditions. Some interface performance parameters, as defined in their technical specifications, can theoretically be checked at the stage of laboratory tests, but their final verification can only take place in the conditions of actual use.

5. Expected Impact of the Project

The novelty of the project and its expected impact will be multifold in nature. The most advantageous impact of the project is that it will allow to connect systems; of different types, utilizing various technology, belonging to different layers of the CCS system, and while also performing varying functions within the railway network.

As such, the direct impact of the proposed project solution is that, it will significantly simplify the connection between stations without the need to install any components of a semi-automatic line block. It is also assumed to standardize the diagnostic interface of CCS systems.

In addition, the further value of the project is twofold:

(1) On one hand, because it accounts the participation of both manufacturers and suppliers of the CCS systems during the standardization process, and allowing for their input to be built into the process;

(2) Secondly, because the project solution is based on a simple yet ingenious concept of „universal interfaces" – that is, that the emphasis is placed not on providing „any" connection for two strictly defined systems, but on the contrary, on providing a strictly defined connection for „any" two given systems.

In context of a longer time horizon, the project is also expected to have a significant impact on the development of the entire, Polish CCS sector. Thus, it is forecasted that the introduction of standardized interfaces will make the market more accessible for the medium and smaller scale, domestic manufacturers and suppliers, which under current conditions doesn't have equal access to data, as well as, which are also in substantial disadvantage, as the tender process requirements mandate introduction of new solutions that would be compatible with already implemented solutions.

From a scientific point of view, the critical aspect of the research has been the development of universal assumptions for the standardization of the data exchange between CCS systems, but also a development of a coherent method for developing the universal interfaces themself. This scientific approach, as well as the established typologies which have been linked with the tested models and algorithms used in the simulation of system operations, may be the basis for further research work in the field of: optimization of IT structures, system architecture, data transmission parameters, data security methods, reliability and availability of systems and their logical and physical connections.

The further research into this field is considered especially vital, as it is, at the interface between various hardware and software structures, where the most critical information exchange processes seem to be most. Simultaneously, these „links" are usually the most vulnerable structural elements of the system which are the most susceptible to disturbances. For these reasons, further work should be focused on advancing functional and technical improvements of specific solutions in accordance with the standards developed under this project.

6. Conclusions

The solution proposed under this project is a completely new approach to the issue of connecting the CCS

devices and subsystems which will allow to connect them into one coherent system. In this regard this is a novel approach not only in the context of Polish railways, but also on a European scale. Thus far, despite a number of initiatives that have been undertaken to address this issue, the problem of non-standard interfaces, have remained unsolved. In context of Polish railways, to date, no standard interfaces have been developed that would allow an unobstructed exchange of information between systems of different manufacturers without the need to modify these systems and as such that wouldn't require the use of additional intermediary elements. There are also no other standards available that would be specifying open data exchange protocols, physical and logical parameters of transmission links, processing algorithms and data security.

Because of this situation, currently utilized solutions are always custom designed and as such the implemented technical solutions tend to have a low repeatability rate, generate serious operational problems, not to mention that they also have a very high implementation costs. Due to the obvious reluctance of manufacturers to provide information on their data exchange protocols, it is a common industry practice to build the relay interfaces which are expensive, space- and energy-consuming, not to mention that they are technologically outdated and are often used even where connection for only two computer systems is required. In this context, proposed interface standardization would eliminate those redundancies which are absurd from both financial, as well as a rational point of view.

The proposed project solutions, also have an obvious advantage over those fully electronic connections which while they might ensure the cooperation of two computer systems, they are likely not to be compatible with other types of systems. This means that each time one of the two related systems needs to be replaced, it causes a compatibility conflict. This tendency has been particularly evident during ongoing modernizations on the PKP PLK S.A. network. Further, even if a custom interface can be designed and used to connect two various systems, there is no certainty that replacing one of the systems in the future, will not cause a „snowball effect" and will likely force major modifications in the other system to, which under different circumstances could remain operational without any problems.

The project assumes the use of the latest technology in secure digital data transmission, utilizing the Ethernet standard, which is at the moment perceived to be the most developmental and universal. The proposed solutions will also have an advantage over the specialized and often atypical solutions that have been previously used by some suppliers, and which have been generating numerous problems. In addition, the rational approach of the applicant indicates the need to use elements and methods as universal as possible, so that none of the potential suppliers will feel more favored or hindered in respect to the selection of specific detailed technical solutions.

The result of the project will be a breakthrough solution in the field of CCS systems, not only in the context of Poland, but also on a European scale. The project is assumed to be supra-local, supra-regional and although it is dedicated to the specific needs of the PKP PLK operator, the potential project implications can be much wider.

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Car Harsh and Emergency Braking Intensity Perception by Novice Drivers

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Abstract

Road traffic safety enhancement is a complex and challenging problem for any society. Novice driver training is among the practical tasks to be organized with a goal of fatalities and heavy injuries reduction in road traffic. One of the most crucial skills every driver should have is the ability to brake the car at the right time at the required intensity. In order to acquire this ability, every driver must learn and obtain skills that include both theoretical and practical overview of braking process and braking intensities. In Latvian Road Traffic Regulations unneeded sudden or harsh braking is prohibited, but the term is not precisely determined in the document. The aim of the study is to evaluate drivers' perception of different braking intensities and capabilities of emergency braking. Novice drivers who were taking their state driving exam were involved in emergency braking tests while drivers with five to ten years of driving experience participated in driving intensities perception trials. The tests were organized by state driving examination inspector as a part of his master thesis. The perception of the sudden braking limit has been evaluated. Problems with emergency braking training have been appraised.

KEY WORDS: *car driving training, emergency braking, rapid braking*

1. Introduction

Reducing road traffic fatalities and injuries in agreement with ambitious goals set is a complex and challenging problem for any society. Acknowledging that the overwhelming majority of road traffic deaths and injuries are preventable [1] besides the many proven measures, countries still face challenges to finding specific local challenges to narrow the gap between the goals set and the real performance. Young drivers proper education is among practical tasks to be managed.

As in most European countries [2] in Latvia for novice drivers there is learning through professional instruction. Accepting that attention to higher hierarchical levels of driving behavior [3] is essential in drivers' education, when developing the training programs, the driving schools must not exclude from training the basics that may not be gradually acquired in everyday traffic. Knowing that making people more skilled drivers does not necessarily make them safer drivers, here we do not emphasize the skills that may allow or provoke to drive faster in inferior weather or road conditions but the skills that for good drivers may be needed quite rare, like emergency braking. Although emergency braking seems a quite a simple maneuver, especially for the majority of the cars having ABS, part of novice drivers seem confused with mild braking suggested in slippery road conditions or smoother brake profile [4] which enhances car steer ability and drivers' self-feeling but lead to higher braking distance, forgetting that stopping distance increase by one car length may cause impact speed above 35 km·h^{-1}. Knowing that Latvian traffic authorities and young drivers' examination body put additional attention to emergency braking some years ago, but in recent years emergency braking was eliminated from the driving tests, a hypothesis was raised that driving schools also do not include emergency braking in their training programs and that young drivers may do not perceive the difference between everyday rapid braking and emergency braking.

Another on-going braking study have started because in Latvian Road Traffic Regulations a vehicle driver is prohibited from sudden braking unless it is not necessary for road traffic safety while the sudden braking term is not precisely determined in the document. Some findings from that study were merged with the emergency braking tests.

2. Materials and Methods

The emergency braking tests were carried out during driving examination as a part of the master thesis by the student who is employed by the state driving examination body. Before the braking measurements were taken, each applicant was informed that an emergency braking phase will be included in the examination. Each applicant was informed about the emergency braking test. At a specific location, chosen by the examiner, when road safety permitted, applicants were asked to perform emergency braking from a speed approximately 50 km·h^{-1}. He or she had to imitate a situation where a person has run out on the road in front of the vehicle. The applicants were informed that this braking test will not affect the final examination result.

The tests were performed in Talsi City during the summer season from June to August. All measurements were taken on public roads with dry asphalt pavement. The map of the road sections used, is shown in Fig. 1.

Fig. 1 Location of measurement sites

The three test road sections are located within a 1 km distance of each other, so that if during the driving examination the emergency braking could not be done when passing one intended measurement location, in most cases it was possible to do it on other tracks. The road sections were chosen to be as similar as possible so that the road surface has similar friction and regardless of the chosen measurement location, the road surface does not essentially affect the emergency braking process. These road sections were also chosen due to a good visibility of the entire road sections, which ensured the necessary road safety while conducting the experiments, see Figs. 2-4.

Fig. 2 Test site on Kr. Valdemāra street, length 540 m

Fig. 3 Test site on Lielgabalu street, section length 560 m

Fig. 4 Test site on 1. Maija street, section length 580 m

The examination car used in braking tests Audi A3 Sportback, 2017, kerb weight 1460 kg was equipped with VBOX Sport GPS data recorder with external antenna, logging driving speed data with 20 Hz. Driving examination data were stored on an SD card, allowing easy transfer to a computer for extraction of the emergency braking events and speed data analysis and processing. Since the tests were done during driving examination tests, no sensors have been put on brake pedal for the registration of initiation of braking event. This allows to analyze the driver's actions only after the start of braking. In total emergency braking events were recorded for 110 novice drivers who have passed their driving school training and were applying for their first B category driving license.

After preliminary examination of the emergency braking test results, it was decided to include in this study data from another on-going research about driving intensities perception obtained by the same master student but with young drivers who have had their driving license for at least five years. The goal of the other study is to clarify the perception of rapid braking used in Latvian traffic rules. The tests were done using the same VBOX Sport data logger but with Audi A6 1998, kerb weight 1650, private car.

Each driver was instructed to perform a braking attempt from a speed of approximately 50 $km{\cdot}h^{-1}$ in order to stop as close as possible to the cones imitating a stop line, as shown in Fig. 2. The drivers were asked to brake as late as possible, as long as the driver considers the braking attempt is between acceptable and too harsh in traffic. Each driver performed 10 braking attempts. There were three passengers with driver license in the car who were asked to evaluate the braking process if it is close to being too harsh or already too rapid for braking before the traffic lights.

3. Data Processing

Although VBOX has a software for data analysis, it was used only for data export to csv file for processing in Excel using developed for this case Microsoft Visual Basic code locating the braking events and analyzing the braking process. VBOX Sport is not developed for braking tests. GPS tool without inertial module does not allow to distinguish between axes of movement, therefore when the car stops, there is still some vertical movement in car suspension, therefore the measured speed may be up to 3 $km{\cdot}h^{-1}$ above zero. Similar process is at the start of braking. To compensate for these processes the deceleration from 4 $km{\cdot}h^{-1}$ was assumed to be the same as the average deceleration between 30 $km{\cdot}h^{-1}$ and 4 $km{\cdot}h^{-1}$ and the start of braking process is analyzed when deceleration reaches 0.5 $m{\cdot}s^{-2}$.

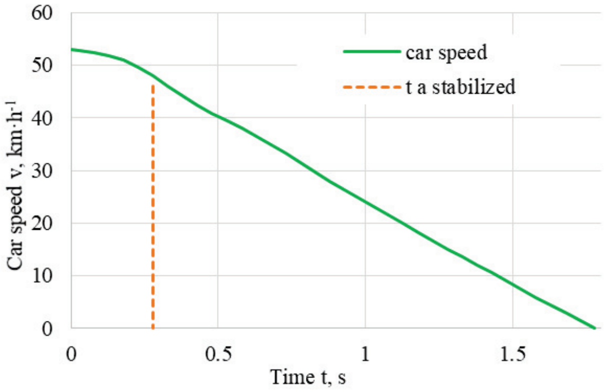

Fig. 5 Car speed in emergency braking test

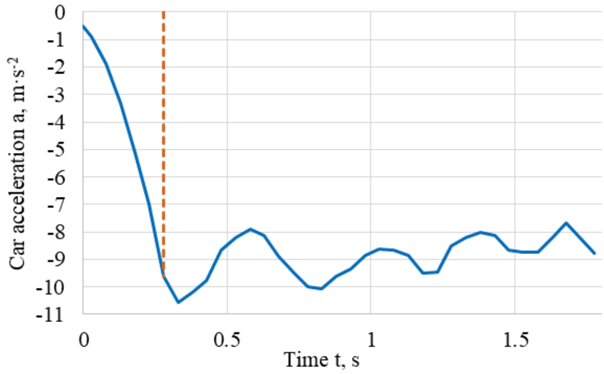

Fig. 6 Calculated car acceleration in emergency braking

The corrected speed and acceleration graphs are shown on Fig. 5 and Fig. 6 along with the time line, where deceleration reaches stabilized fully developed deceleration level. Although the acceleration graph indicates that 10 Hz measurement for braking analysis may be too low, if the action of ABS system is not analyzed, the speed graph ensures that the GPS logger can be used for braking harshness evaluation. For testing of the braking devices Directive [5] recommends to calculate the mean fully developed deceleration. But the novice driver braking patterns suggested that this does not give satisfactory results.

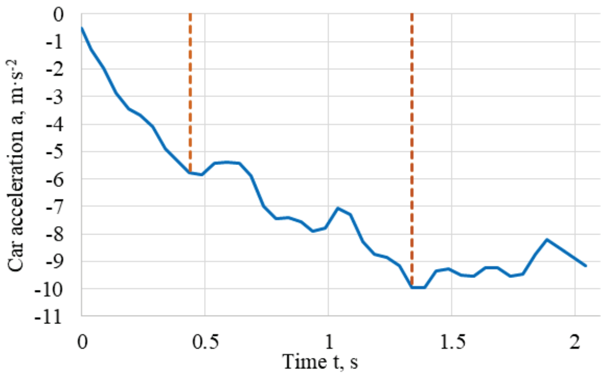

Fig. 7 Braking with unclear and long rising acceleration phase

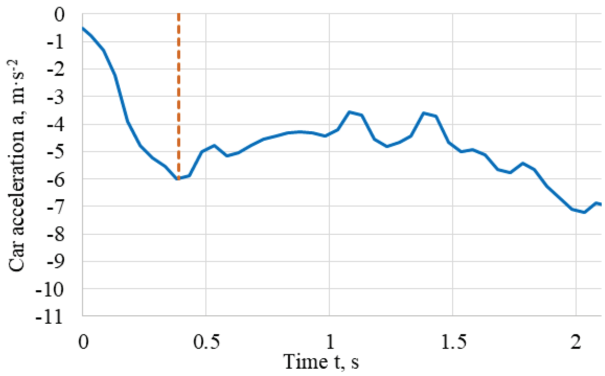

Fig. 8 Braking with low and changing fully developed acceleration phase

As in Fig. 7 it is unclear where the rise of deceleration ends and fully developed deceleration starts. In Fig. 8 the driver after reaching desired deceleration for about one second slightly decreases deceleration but just before stoppage pushes the pedal harder again. The braking patterns were so different that for braking evaluation it was chosen to disregard deceleration rise time and fully developed deceleration but to characterize the achieved deceleration by the maximal achieved deceleration at the length of any one second during the braking (Fig. 9).

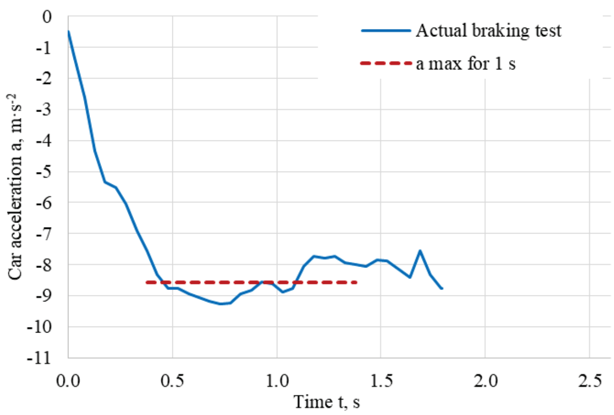

Fig. 9 Emergency braking by novice driver, showing maximum average acceleration level achieved for 1 second

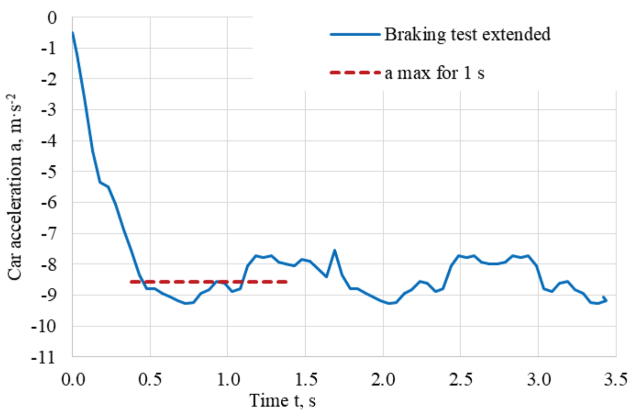

Fig. 10 Extension of measured acceleration values with maximum acceleration change pattern achieved for 1 second

To compare the braking distances it is essential to have the same braking start speed. Since the braking process can be best described by the changes in deceleration and deceleration is the parameter mostly affected by the driver's action while braking the vehicle, the speed adjustments were done by recalculating data using deceleration data. In case if the braking start speed was above the calculated speed, the speed during deceleration was calculated from deceleration change. In case if the calculated speed is above the measured braking speed, the speed change is still calculated from deceleration but at the end of braking for a required time, the deceleration from the maximum one second period is added (see Fig. 10). This allows to evaluate how the driver's actions during the start of emergency braking affects braking process from various speeds, especially if compared to achievable emergency braking intensity level. For this paper, analyzing the braking process of all drivers, the braking intensity level to be compared against was chosen to be fully developed deceleration -9 $m \cdot s^{-2}$ with a deceleration rising time of 0.2 s.

Emergency braking goal is to either stop before the sudden obstacle or to hit it with minimum speed. Braking distance – speed graph is the most suitable to visually analyze the braking efficiency. In Fig. 11 a sample of emergency braking analysis is given. The emergency braking test by a novice driver from 50 $km \cdot h^{-1}$ had slightly above 20 m braking distance. If the driver would have pressed the pedal firmly in 0.2 s up to the braking intensity he or she achieved for at least 1 s (further in the text – a1s), the braking distance would have been below 18 m while at this distance during the test braking the speed was above 20 $km \cdot h^{-1}$. If the driver would have braked in 0.2 s up -9 $m \cdot s^{-2}$ (further a -9), the braking distance would have been close to 12 m while at this distance the speed was almost 35 $km \cdot h^{-1}$.

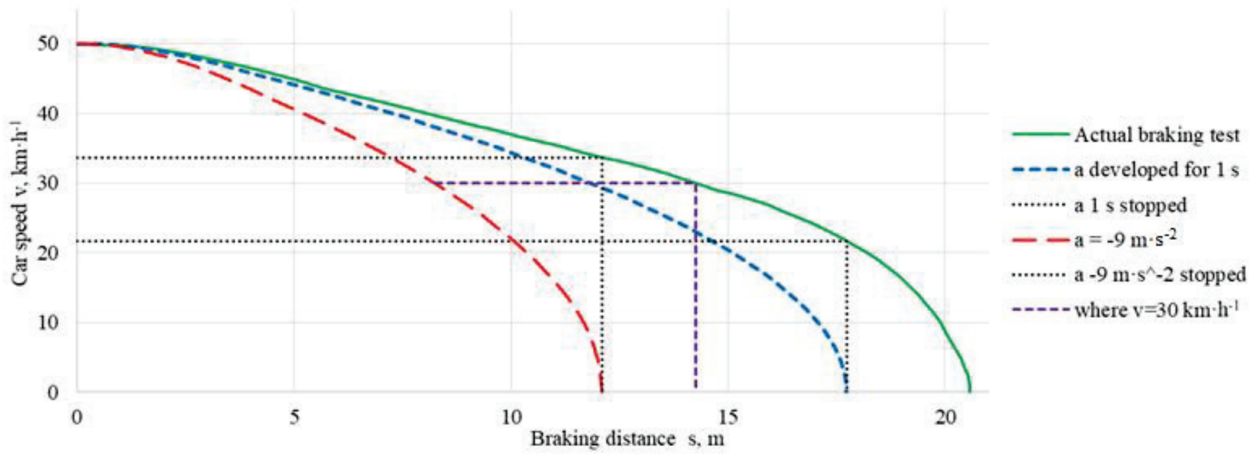

Fig. 11 Braking speed analysis comparing with calculated emergency braking

It is found [6] that 30 $km \cdot h^{-1}$ is a speed where the risk of pedestrian fatality starts to rise fast, therefore the distance where 30 $km \cdot h^{-1}$ was reached at test braking has been compared against a1s and a-9. It can be seen that for a1s the speed at this distance is below 25 $km \cdot h^{-1}$ and the speed 30 $km \cdot h^{-1}$ was reached some 2 m earlier, but for a-9 the vehicle had already stopped and 30 $km \cdot h^{-1}$ was reached before more than 5 m, creating additional safer zone.

4. Results and Discussion

The emergency braking distance from the examinations of novice drivers is given in Fig. 12. It can be observed that only a small part of examinees have been able to perform a real emergency braking close to -9 $m \cdot s^{-2}$.

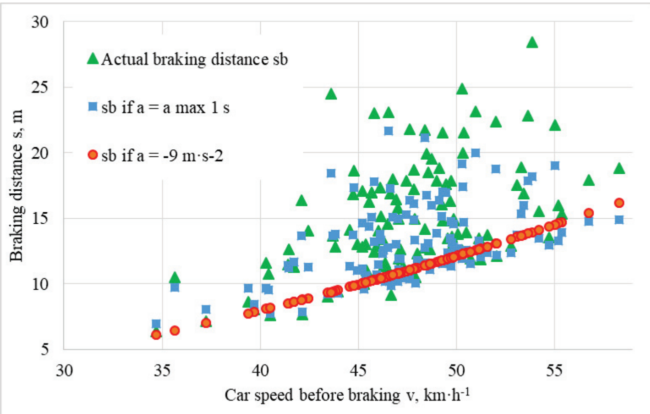

Fig. 12 Novice drivers emergency braking results – braking distance

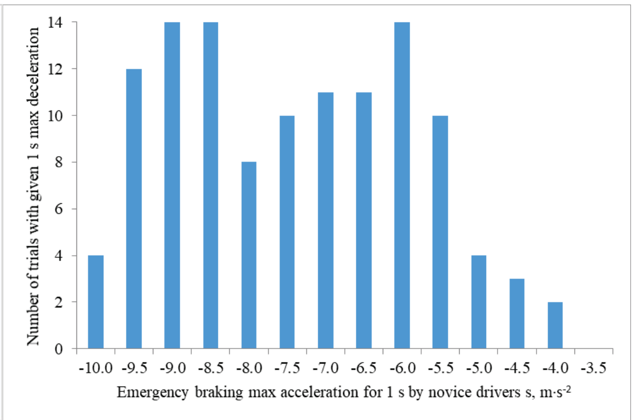

Fig. 13 Novice drivers emergency braking results showing seemingly a sum of two distributions

The distribution of a1s decelerations for all novice drivers reminds a sum of two distributions – one with a peak around -9 m·s^{-2} and other around -6 m·s^{-2} (Fig. 13). The obtained deceleration values are close to preliminary values in other on-going research where the same master student has made several tests regarding braking intensity evaluation, therefore it was decided to show the preliminary results in this paper. Getting steady fully developed deceleration values when the driver is instructed to brake nearly harsh was quite a challenge even for experienced drivers (Fig. 14), therefore the a1s deceleration was used for intensity evaluation. For this experiment the a1s value maybe even more suitable, because the harsh or no-harsh braking could be determined by the maximum force exerted on the driver for a certain time.

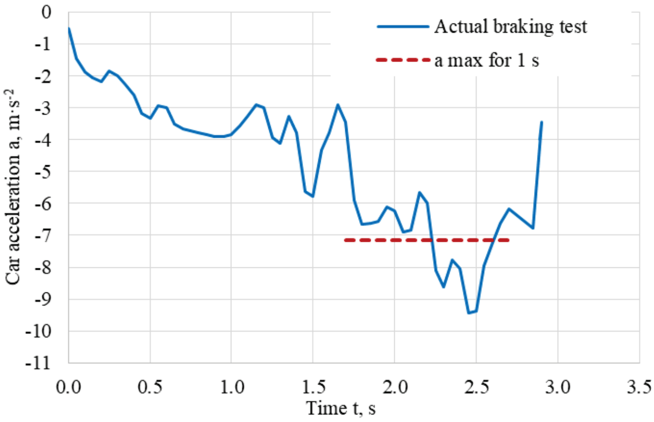

Fig. 14 Try of nearly harsh braking, showing maximum average acceleration level achieved for 1 second

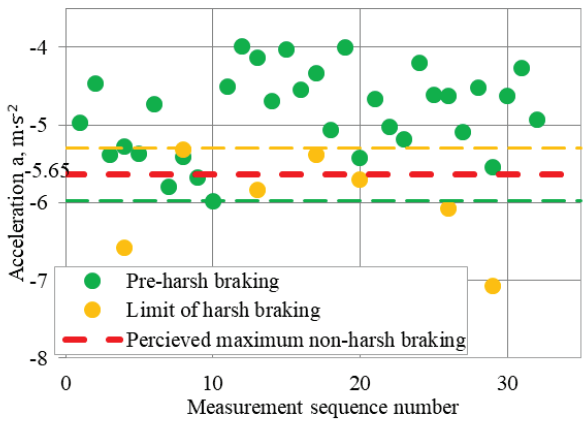

Fig. 15 Harsh braking intensity trial case study by drivers with 5 to 10 year driving experience

Braking intensity trial results are shown on Fig. 15. Only 32 from 40 braking attempts are shown where drivers and passengers did not have a contradictive evaluation of the braking intensity. Although this is still on-going research and well based conclusions could not be drawn from this case study only, in general the result of the harsh braking limit being between 5 m·s^{-2} and 6 m·s^{-2} is obtained also in other cases.

This leads to a conclusion that novice drivers who are not specially trained for emergency braking may percieve emergency braking at the level percieved by more experienced drivers as harsh braking but which is well below the achievable braking intensity and may cause more severe traffic accident results or may cause an accident where real emergency braking would have allowed avoiding the accident. Finding the reasons for failing to execute emergency braking during the driving examination may require additional research while the evaluation of consequences of emergency braking with reduced deceleration or with a very gradual increase of the braking intensity has been calculated and shown in Fig. 16 to 19.

Car speed distribution when braking from 50 km·h^{-1} (Fig. 16) where it could be stopped if braking with a1s shows that only below 20% young drivers were able to reach fast and hold a fully developed deceleration while for the others the changes in braking intensity caused a probability to hit an obstacle in traffic with essentially higher speed.

Car speed distribution if braking from 90 km·h^{-1} (Fig. 17) where it could be stopped if braking with -9 m·s^{-2} intensity gives a clear view that there is a mean braking intensity value different from the maximum possible and that braking from 90 km·h^{-1} this could lead to hitting an obstacle with speed fatal for pedestrians and even for car occupants.

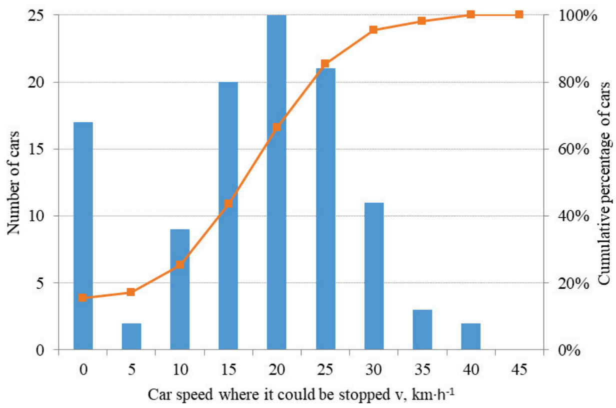

Fig. 16 Car speed distribution, braking from 50 km·h^{-1}, where it could be stopped if braking with maximum deceleration measured for 1 s (a1s)

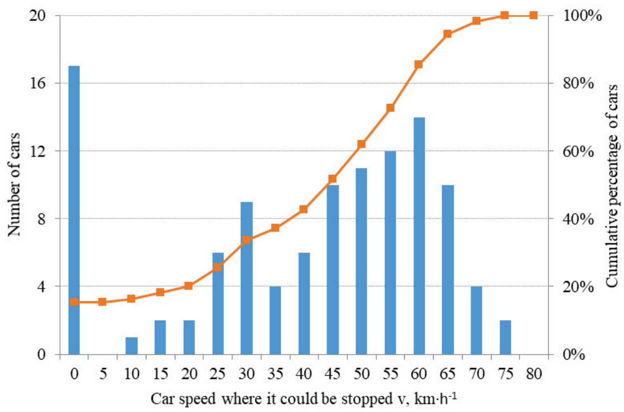

Fig. 17 Car speed distribution, braking from 90 km·h^{-1} where it could be stopped if braking with deceleration -9 m·s^{-2} (a-9)

From the Vision Zero perspective, traffic accidents that do not result in a fatality or serious injury are not considered to be an essential element in road traffic safety [7]. Therefore in Fig. 18 only braking distance to 30 km·h^{-1} where the risk probability for a pedestrian to be seriously injured starts essential rising is shown. If for 20% of the novice drivers who were taking their driving examination with braking close to -9 m·s^{-2} the high risk zone for a pedestrian to be seriously injured is close to 20, then for last 20% the risk zone is enlarged by some 10 meters or by one third while the braking distance for almost 20% of drivers has doubled.

The distribution of braking distance if calculated for speeds from 50 to 100 km·h^{-1} is shown in Fig. 19. For 25% of drivers the braking distance was close to a conceivable distance in real emergency braking. For the next 25% of drivers the distance has been extended up to 10 m at an initial braking speed close to 90 km·h^{-1}, for the next 25% another 10 m were needed to stop the car. The braking distance of the last 25% of drivers if the braking from 90 km·h^{-1} is done with a similar deceleration rise as it was done in driving examination emergency braking test and assuming that the peak deceleration is kept close to the average one achieved for 1 s in the examination, then up to 40 m for full stoppage could be required.

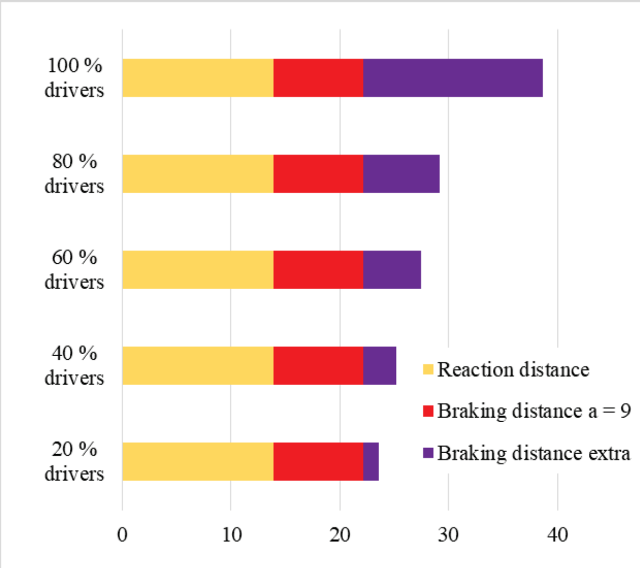

Fig. 18 Car stopping distance from 50 km·h^{-1} to 30 km·h^{-1} distribution, if compared to a-9

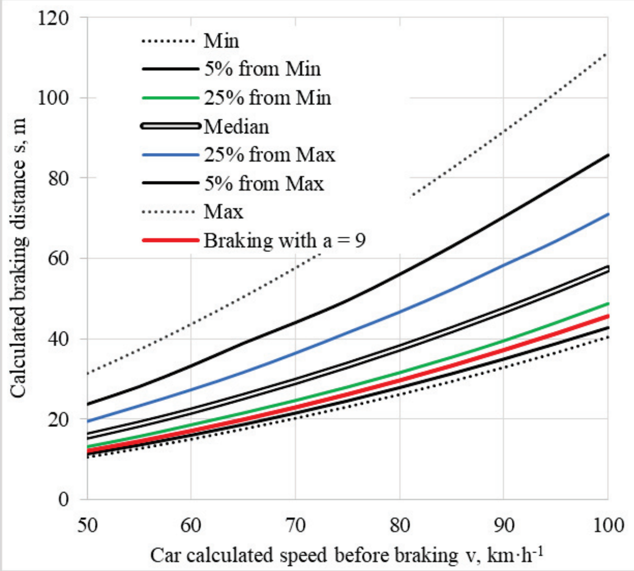

Fig. 19 Braking distance distribution, calculated for different initial speeds

The examination results suggest that the driving schools and the driving examination body may have to revise the attention drawn to novice drivers' emergency braking skills and perception.

5. Conclusions

More than half of young drivers who were taking a driving examination from the selected sample confused emergency braking with rapid braking in normal traffic.

Above 80 percent of the selected young drivers were not able to fast achieve and hold a steady fully developed deceleration during emergency braking causing additional safety risks in case of sudden obstacles in the road traffic.

There is no reason to assume that this concerns only the driving schools in and around Talsi city because attention that was given to emergency braking teaching in Latvian driving schools some years ago has diminished.

Changing the emergency braking perception and skills for novice drivers may improve traffic safety in Latvia.

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Experimental Study of Temperature Stabilization Process in Tribological Contact of Brake Friction Pairs Under the Impact of Forced Cooling

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Abstract

The article covers the experimental study, which aims to establish the dependence of friction coefficient and temperature in the contact «brake disc – pad» on the cooled air supply factor to the friction contact during the braking process. Experimental studies of braking were performed using a laboratory brake stand designed to test variations of brake devices and control their initial parameters. The development of method to increase the brake system efficiency is based on the task of improving the productivity of the disc brake by efficient use of compressed air, drained from the brake cylinder, and cooling the brake lining and the working surface of the disc, moving friction wear products from the contact. The task of increasing the interaction efficiency of the disc brake friction elements by controlling the temperature in contact during braking of the locomotive is achieved by cooled air supply to contact zone.
KEY WORDS: *friction interaction, braking, experimental study, cooling*

1. Introduction

Based on the analysis of theoretical and experimental studies of frictional contact, it was found that the control of the mechanical component is not enough to achieve stable high coupling qualities of tribological units [1, 2]. The question of the effect of temperature on the stabilization of the coefficient of friction is not fully researched. It was found that when the temperature in the metal contact reaches 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-pad» and «wheel-block-rack» by controlling the locally-mechanical and temperature components depending on the frictional contact conditions.

Experimental studies to determine the effect of stabilization of temperature processes on the output parameters of the brake were carried out on a laboratory stand [3-5]. The stand is designed to test various schemes of brakes and control their output parameters.

The stand allows to vary the moment of inertia with the help of rotating disks, rotational speed, duration of the drive and record the output parameters of the brake and drive, such as braking torque, traction, opening time of the brake and acceleration of the drive, response and braking times of the brake, speed of rotation of the drive, temperature of rubbing surfaces.

2. Experimental Study of Temperature Stabilization Process in Tribological Contact of Brake Friction Pairs Under the Impact of Forced Cooling

The stand as shown in Figs. 1 and 2 allows to accumulate kinetic energy by means of rotating disks, to fix frequency of rotation, number of inclusions, duration of work of the drive and to register such initial parameters of a brake and the drive: brake moment, efforts in draft, angle of rotation of brake racks.

The maximum error of thermocouple measurements is equal to 4°C for temperature values in the range from 0 to 400°C. In this case, strain gauges of the type PC – 30–400 were used with parameters: R: 400 ± 9 Ohms; S: 2.18 ± 0.01; P: 0.08 ± 0.07; σ: 0.5%; I: 15…30 mA. The dynamometer rings were calibrated each time before and after the series of examinations.

Acceleration time of the brake drive and speed are registered by means of the tach generator of a direct current.

The brake actuation time was measured from the moment the power was turned off from the brake actuator until the first contact of the pads with the brake pulley.

The braking time is measured from the end of the registration of the operation time to the moment of complete stop of the brake pulley, which is controlled by the voltage at the output of the tach generator. The number of inclusions is measured by a means installed in the computer.

Calibration characteristics were used to determine the actual values of the forces on the strain gauges. Thermocouples were calibrated in an oil bath using a thermometer and a digital measuring device DT-838T from Suns (its conversion error is not more than 1% of the measured value). The magnitude of the pressing force of the heat-

removing element to the brake pulley was determined by the deviation of the arrow of the micrometer indicator (GOST 577 - 68, the division of 10^{-5} m, the limit of the main error allowed, $\pm 20 \cdot 10^{-6}$ m) of the exemplary dynamometer (measurement range: 0.1…1 kN, threshold response not more than 0.02% of the maximum allowable measured value) followed by enumeration on the calibration characteristics.

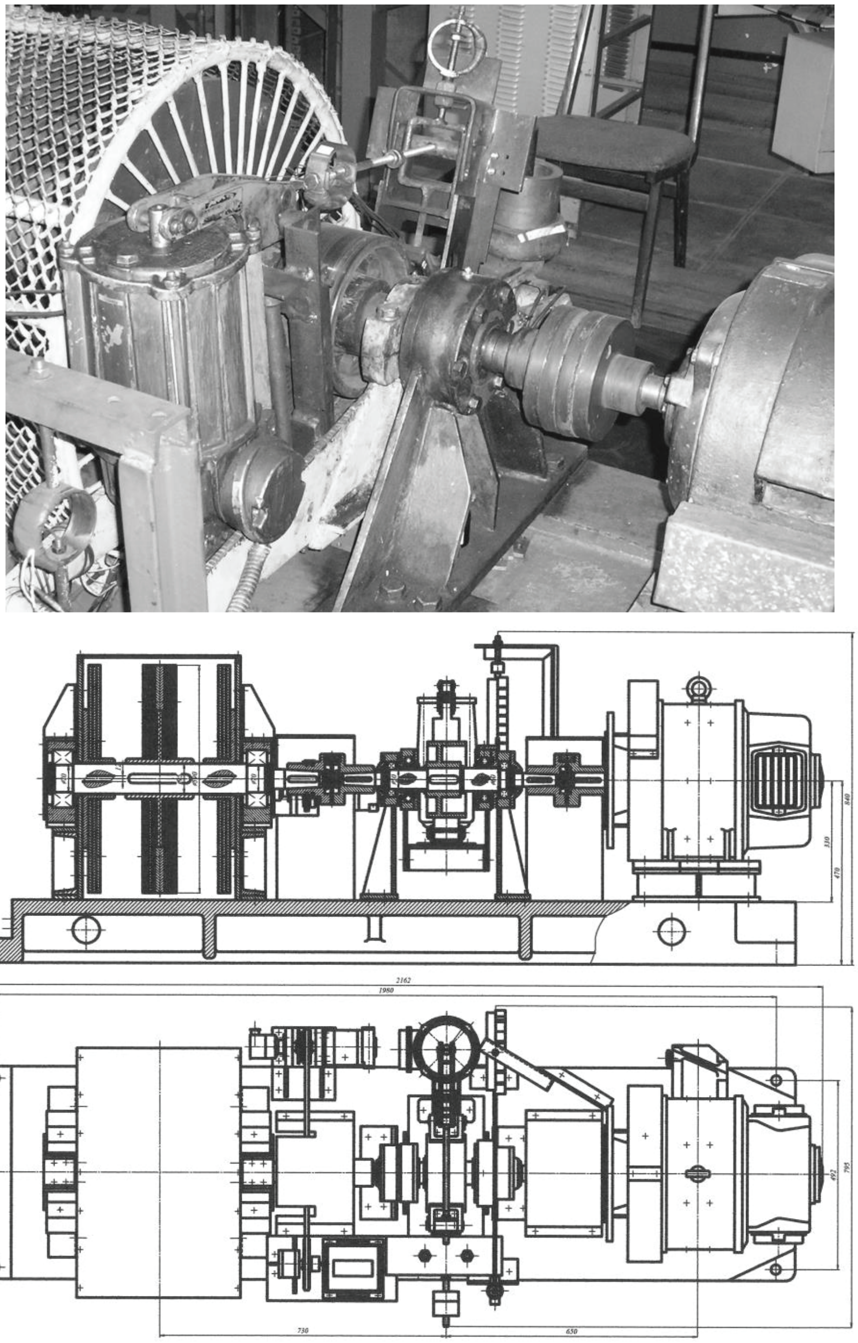


Fig. 1 The laboratory stand for studying brakes and controlling their output parameters

A PC/AT computer with an SDI-ADC14-32F ADC board compliant with the ISO 2000 certification standard and a measuring module that allows to record temperature, dynamic and static loads were used to know and process the initial data obtained during the experiment. Appropriate software was used to control the ADC.

To achieve the same conditions during each individual experiment, the working friction surfaces were carefully treated with alcohol both before and after the exam. In all experiments, the same pair of brake pads and heat-removing element were used. The purity of the treatment of these surfaces corresponded to the seventh class according to GOST 2789-73.

During the exams, the following external factors varied in these ranges:

- the force of pressing the brake pad to the pulley, consistently took values: 1500 and 2000 N;
- the initial value of the angular velocity of rotation of the brake pulley was: 1595 rpm (corresponding to the linear speed, respectively: 60 km/h. The magnitude of the linear deceleration during braking is about 1 m/s^2);

- the cooled air temperature varied: from -20°C to 20°C (which according to the theoretical estimate will correspond to the case when the brake cooling system will remove up to 25% of thermal energy generated during braking, respectively, for the above conditions conducting examinations and using in mathematical modeling of the process of complex heat transfer the calculation scheme adapted to the conditions of the experimental stand.

The cooling system was switched on before the start of the process of braking and recording of the studied values (if used in experiments) and operated with a fixed capacity. The nominal contact area of the brake pulley with the heat-removing element was 0.0055 m^2. External conditions during the experimental studies corresponded to the following: ambient temperature: 21°C, atmospheric pressure: 755 mm Hg, humidity: 65%.

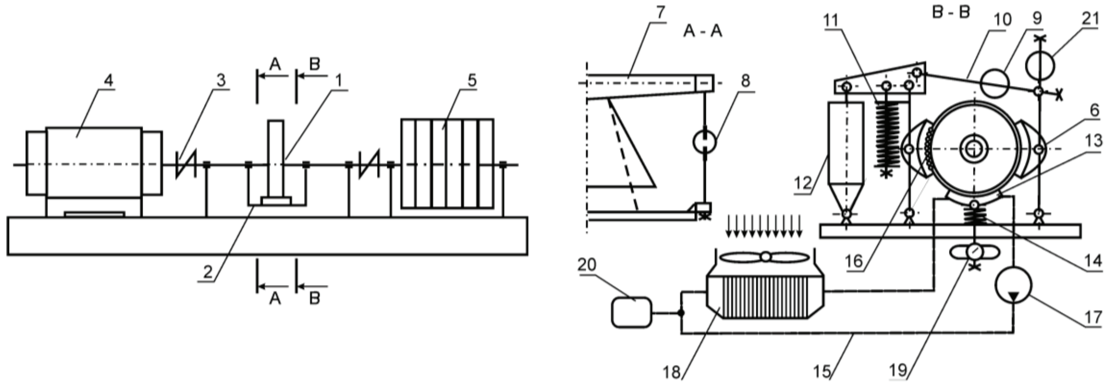


Fig. 2 Schematic diagram

The design of the stand is supplemented by a compressor and a cooled air supply unit (Fig. 3) [6-8]. By means of the compressor air supply in a pipe in which there is a temperature division into cold and hot air which are taken away from various apertures is carried out. The cooled air is supplied to the area of friction contact.

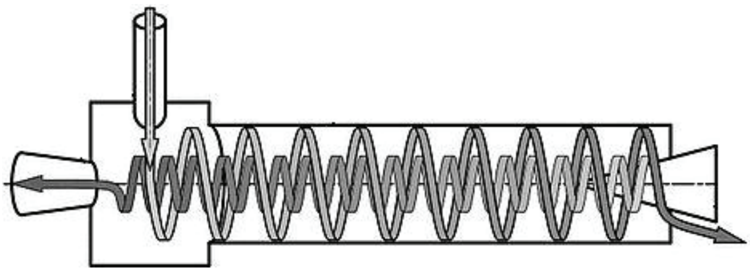


Fig. 3 Cooled air supply unit schematic diagram

Pre-compressed air is supplied to the nozzle, where it expands, cools and acquires high speed and kinetic energy. Since air enters the pipe tangentially, it forms a free vortex in the cross section of the pipe, the angular velocity of which is large at the axis and small at the periphery of the pipe. The excess kinetic energy of the inner layers is transferred (by friction) to the outer ones, increasing their temperature. This process occurs so quickly that the inner layers, having given off the energy to the peripheral and cooled even more, do not have time to receive an equivalent return of heat from them, i.e., thermal equilibrium does not occur in the field of air separation.

Being close to the central opening of the diaphragm, cold air exits through it to the right free end of the pipe, called cold. The heated peripheral layers move to the left towards the throttle valve and through it exit the hot end of the pipe. The quantities of hot and cold air received, and therefore the temperature of both, are controlled by the degree of opening of the valve.

The task of the research is to experimentally show the dependence of the coefficient of friction and temperature in the contact «brake disc - pad» on the factor of cooling air supply to the friction contact during the braking process.

All experimental values obtained in parallel experiments were checked for the absence of errors according to the planning of the experiment methodology [9, 10]. To process the results of experiments, the normality of the distribution of random errors is checked, which is characterized by the following conditions:

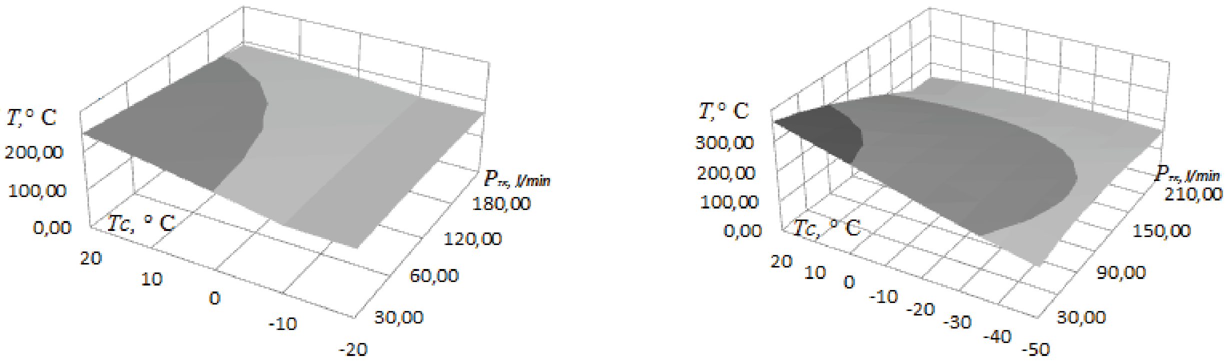
1) measurement errors can take a continuous series of values;
2) with a large number of observations of the error of one value, but different signs, are equally common;
3) the frequency of errors decreases with increasing values.

However, the large number of measurements that occur in practice corresponds to the normal distribution law. At the same time, it is established that measurements on the definition of the size of temperature, a braking moment, coupling force, follow normal law of distribution of errors. The results of the experiments are presented in Fig. 4.

With the increasing temperature in the area of interaction of the friction pair there is a change in the coefficient of friction, which affects the quality of braking. The high temperature in the friction contact leads to a change in the

strength characteristics of the surface layer.

The obtained dependences of the friction surface temperature in the process of single braking on time at different air temperatures and cooling productivity show the efficiency of temperature stabilization in the friction contact up to 25%.



a b

Fig. 4 Dependence of contact temperature on productivity and temperature of forced local cooling; the clamping force of one brake pad is: a – 1500 N, b – 2000 N

3. Conclusions

Experimental study of temperature stabilization process in tribological contact of brake friction pairs under the impact of forced cooling was held with a set of laboratory equipment that was improved (a bench stand for the studying influence of local cooling of a model disk-pad tribological contact), suitable experiment methods were developed. Based on the results of the experiments, substantiated parameters for controlling the brake friction contact were developed, as well as methods and devices for their implementation.

Acknowledgement

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The Technological and Economic Operating Conditions of the Innofreight Container Transport System

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Abstract

This paper is focused on further application of the Innofreight container transportation system in the Czech Republic, Austria and Slovakia. The author describes both the technical and operating characteristics of the most widely used transportation systems in railway transport of bulk material. It also provides a comparative analysis of the Innofreight container transportation system usage in selected European countries and in the Czech Republic, Austria and Slovakia. The aim of this paper is to set criteria determining the technological and economic interfaces of such system, as well as to suggest the implementation of such system into a specific transportation chain.
KEY WORDS: *container, innofreight, operating, bulk material*

1. Introduction

The basic features of the Innofreight system are volume-optimized containers, faster and more efficient railway transport on intermodal transport wagons, and safe and simple emptying of Innofreight containers (hereinafter referred to as "IFs") by turning them using front-loading forklift trucks or by means of a special stationary unloader [1].

IFs are currently used in transporting a whole range of primarily bulk materials, such as:

- Biomass (wood chips, sawdust…);
- Agricultural products (sugar beet, potatoes, cereals…);
- Chemical products (fertilizers, gritting salt…);
- Minerals (coal, coke, sand, peat, iron ore…);
- Waste management (municipal waste);
- Dangerous waste (sludge).

In addition to the means of transport and components being added to this transport system, other transport systems have been developed and named after the goods being transported [2, 3]:

- RockTainer – bulk materials (dump container);
- AgroTainer – bulk materials, primarily agricultural products (similar to ISO containers);
- stanchion pallets – steel tubes, logs;
- SlurryTainer – liquids;
- WireTainer – wire rolls;
- ChemieTainer – chemical products;
- CoilTainer – coiled sheets.

Furthermore, the individual means of transport within a transport system can be modified in different ways to accommodate the needs of a specific customer. All means of transport developed by this company have standard ISO corner castings, which allows for their transportation on commonly used intermodal wagons with fixation pins. As such, railway undertakings don't have to purchase new wagons for such carriage and can flexibly use the existing ones instead. Moreover, the risk involved in purchasing new wagons is lower as these can be used for the transportation of sea ISO containers, swapbodies and Innofreight containers [4].

2. Innofreight Systems in Europe

Since its first use in 2004, when a container was first unloaded using a forklift truck in the Austrian company Sappi, the Innofreight transport system has spread to 14 European countries where it is now available, including the Czech Republic and Slovakia. Innofreight currently operates 58 front-loading forklift reloaders, 6 stationary unloaders and 12,000 containers with about 1 million unloadings every year [3, 5].

Innofreight is involved in the implementation of its transport systems but to a great extent, the actual management of containers and wagons is up to the hirers (carriers/operators) or railway undertakings. Included in the analysis comparing the use of the transport system were Austria (where the system was developed), Slovakia and the Czech Republic [6].

2.1. Austria

Having developed this system, Innofreight has its headquarters in Bruck an der Mur, Austria. It was also in Austria where an IF was first unloaded using a front-loading forklift truck and in 2007, the first stationary unloader was

built in the Zellstoff Pöls pulp mill. The largest IF users include the Voestalpine ironworks (Donawitz) using the self-discharging ORE RockTainers for the transportation of iron ore and IFs with stationary unloaders for the transportation and unloading of coke and coal (coke is transported from the Zabrze or Zdzieszowice coking plants (PL) and coal is transported from Polish locations or from Koper (SLO)) (Table 1). Among important carriers is also Papierholz Austria procuring wood mass for multiple paper mills in Austria (Sappi in Gratkorn, Mondi in Frantschach and the Zellstoff Pöls pulp mill). Goods to these plants are transported by means of XXL IFs; and the Pöls pulp mill includes a stationary unloader as well. Chips are loaded in different locations not only in Austria, but also abroad (sawmill in Liptovský Hrádek and Tomášovce, Slovakia, sawmill in Ždírec nad Doubravou, Czech Republic and sawmills for instance in Brand, Ybbs, Retz and Fügen, Austria (at the end of 2018, the AustroCel Hallein pulp mill was added to the list)). Another example of the use of IFs is the transportation of energy gypsum for the building material producer Knauf (Weißenbach bei Liezen). This material is produced in the process of flue-gas desulphurisation in thermal power plants [3, 7].

Table 1

Transportation chains involving the transport of Innofreight containers in Austria [3, 8, 9]

<table>
<tr><th>Loading location</th><th>Loading location</th><th>Bulk material transported</th><th>IF type</th><th>Method of unloading</th></tr>
<tr><td>Zdzieszowice/Zabrze coking plant (PL)</td><td rowspan="3">Voestalpine Donawitz steelworks</td><td>coke</td><td>IF XL</td><td rowspan="3">stationary unloader</td></tr>
<tr><td>Radim (PL)</td><td rowspan="2">hard coal</td><td rowspan="2">IF XXM-L</td></tr>
<tr><td>Koper (SLO)</td></tr>
<tr><td>Celje (SLO)</td><td rowspan="3">Knauf Weißenbach bei Liezen (Selzthal)</td><td rowspan="3">energy gypsum</td><td rowspan="3">IF XXM</td><td rowspan="3">forklift truck</td></tr>
<tr><td>Pernhofer (A)</td></tr>
<tr><td>Zemianske Kostolany (SK)</td></tr>
<tr><td>Rettenmeier Tatra Timber Liptovský Hrádok sawmill (SK)</td><td rowspan="2">Sappi paper mill (Gratwein-Gratkorn)</td><td rowspan="7">wood chips</td><td rowspan="7">IF XXL</td><td rowspan="4">forklift truck</td></tr>
<tr><td>PRP Tomášovce sawmill (SK)</td></tr>
<tr><td>Stora Enso sawmill (Ždírec nad Doubravou) (CZ)</td><td rowspan="2">Mondi Frantschach pulp and paper mill</td></tr>
<tr><td>Stora Enso Brand sawmill (Waldhausen)</td></tr>
<tr><td>Stora Enso Ybbs sawmill</td><td rowspan="2">Zellstoff Pöls pulp mill</td><td rowspan="2">stationary unloader</td></tr>
<tr><td>Holzindustrie Maresch Retz sawmill</td></tr>
<tr><td>Binderholz Fügen sawmill (Jenbach)</td><td>AustroCel Hallein pulp mill</td><td>forklift truck</td></tr>
</table>

Approximately 107.5 million tonnes of goods are transported by rail in Austria every year. Approximately 1.9 million tonnes of goods are transported using IFs, which represents about 2% [10]. Wood chips for Austrian paper mills account for the greatest part of IF transport; specifically for 44%. Coke with hard coal represent 42% and energy gypsum has a share of 14% [11].

2.2. Slovakia

The IF transport system is common in Slovakia as well. Unfortunately the share of this transport is relatively low compared to other European countries. There are currently only four transportation chains involving IFs. Wood chips have been transported in the IF transport system for the longest time. All transport operations are carried out using block trains. As for the volume of goods transported, the most extensive in Slovakia is the transport of wood chips to Austrian pulp mills (Sappi and Gratkorn) from the Slovak stations Liptovský Hrádok and Tomášovce (Table 2). Approximately 200 thousand tonnes of wood chips are transported to these customers every year. The IF system has recently been introduced for the transport of wood chips for the Mondi paper mill (Ružomberok) from Ukraine as well. However, wood chips are only partially transported in IFs from the Čierna nad Tisou frontier gauge changeover station. From the Zemianské Kostoľany thermal power plant, energy gypsum used for the production of gypsum boards is transported to the building material producer Knauf (Weißenbach bei Liezen). The annual volume of approximately 60 thousand tonnes is relatively low as Knauf imports this desulphurisation product from multiple locations in Europe. Since 2010, IFs have been used for the sugar beet campaign of the Sereď sugar beet mill every year. Sugar beet is transported from sugar beet growing locations in western Slovakia (e.g. Želiezovce, Kalná nad Hronom or Skalica). Approximately 41 thousand tonnes of sugar beet are transported every year, with the transport volume depending on the harvest in the given year. In 2016, there were several test transport operations involving the transportation of iron ore concentrate from Kremikovtsi, Bulgaria to the U.S. Steel Košice ironworks. At the beginning of 2019, test transport took place involving the transportation of iron ore from the Polish port Świnoujście.

According to Eurostat, approximately 47.8 million tonnes of goods were transported by rail in Slovakia in 2019. Only 316 thousand tonnes of goods are transported in the IF system every year, which amounts to less than 1 percent of the total volume of freight railway transportation. Even though this share appears marginal, this transport system can be classified as a combined transport one; and these systems represent about 11% of freight railway transportation in Slovakia [10]. The IF transport system accounts for over 6% of the combined transport. Illustrating the different commodities transported in IFs, Table 4 shows that the most prominent commodity transported in Slovakia is wood chips, representing 68%. Wood chips are followed by energy gypsum with 19% and national sugar beet transport with 13% [11].

Table 2

Transportation chains involving the transport of Innofreight containers in Slovakia [3, 8, 9]

Loading location	Loading location	Bulk material transported	IF type	Method of unloading
Loading locations network in Slovakia	Agrana Sereď sugar beet mill	sugar beet	IF XXL	forklift truck
Rettenmeier Tatra Timber sawmill (Liptovský Hrádok)	Sappi paper mill (Gratwein-Gratkorn) (A)	wood chips	IF XXL	forklift truck
PRP sawmill (Tomášovce)				
Zemianske Kostoľany power plant	Knauf Weißenbach bei Liezen (Selzthal) (A)	energy gypsum	IF XXM	forklift truck
Ukraine (Čierna nad Tisou)	Mondi Ružomberok paper mill	wood chips	IF XXL	forklift truck

2.3. Czech Republic

The Czech Republic was one of the first countries implementing the IF transport system in a transportation chain using block trains. Block trains from sawmills (Ždírec nad Doubravou and Planá u Mariánských Lázní) to the Mondi paper mill (Štětí) have been in operation since 2005. In 2018, a stationary unloader was installed in the Mondi paper mill (there are currently 3 such facilities in the Czech Republic).

Table 3

Transportation chains involving the transport of Innofreight containers in the Czech Republic [3, 8, 9]

Loading location	Loading location	Bulk material transported	IF type	Method of unloading
ČSA Třebušice mine	Chvaletice power plant	brown coal	IF XXL	stationary unloader
Nástup Tušimice mine	Opatovice power plant	brown coal	IF XXL	stationary unloader
Bílina mine	Opatovice power plant			
Sokolovská uhelná	Plzeňská teplárenská	brown coal	IF XXM	forklift truck
Bílina mine				
(Temelín, Domažlice, Vimperk, Nejdek...)		wood chips	IF XXL	
Stora Enso sawmill (Planá u Mariánskych Lázní)	Mondi Štětí paper mill	wood chips	IF XXL	stationary unloader
Stora Enso sawmill (Ždírec nad Doubravou) (CZ)				
Less & Timber sawmill (Čáslav)				
Stora Enso sawmill (Ždírec nad Doubravou) (CZ)	Lenzing Biocel Paskov			forklift truck
Stora Enso sawmill (Ždírec nad Doubravou) (CZ)	Sappi paper mill			forklift truck
Loading locations network (A, DE)	Kronospan Jihlava	wood waste	IF XXL	forklift truck
Vlkov	DIAMO Dívčice disposal facility	excavated soil	IF XXM	forklift truck
Ostramo Ostrava lagoons	Vřesová pressure gas plant	oil sludge	IF XS	forklift truck
Zdzieszowice/Zabrze coking plant (PL)	Voestalpine Donawitz steelworks (A)	coke	IF XL	stationary unloader
Radim (PL)		hard coal	IF XXM-L	

An overview of IF transportation chains in the Czech Republic is provided in Table 3. Most goods are transported nationally using block trains. As for international transport, this mainly involves the export of wood chips to the Sappi paper mill (Gratkorn), the import of wood waste to Kronospan (Jihlava) and the transit of coke and hard coal to Austrian steelworks (Donawitz). The greatest volume of goods transported in IFs can be attributed to thermal power plants. The Chvaletice power plant is supplied with 2.5 million tonnes of brown coal and the Opatovice power plant with approximately 1.7 million tonnes of coal every year. Both plants include a stationary unloader. Another brown coal consumer is the Plzeňská teplárenská heating plant (with a lower annual volume of transported material – approximately 350 thousand tonnes). A total of more than 4.5 million tonnes of brown coal is transported in IFs in the Czech Republic every year from the surface mines in western Bohemia, which makes this commodity the most prominent one in terms of the weight transported. Brown coal is followed by coke together with hard coal. These are only transported on one transit relation with an annual volume of approximately 700 thousand tonnes for Austrian steelworks. In terms of the total annual weight transported, the third most transported commodity is wood chips. Wood chips are transported in group trains or as individual shipments (from the Čáslav sawmill to the Mondi Štětí paper mill) or in block trains (from the Ždírec nad Doubravou or Planá u Mariánských Lázní sawmills to the Mondi Štětí, Lenzing Biocel Paskov or Sappi Gratkorn paper mills). Approximately 460 thousand tonnes of wood chips are transported every year. 25 thousand tonnes of wood waste from Germany and Austria are transported in groups of wagons to Kronospan (Jihlava) every year. The IF system is also used in the sanitation of the Ostrava lagoons left after the former chemical plant Ostramo. The neutralized sludge is transported in small XS IFs with the HardTop cover and a volume of approximately 91 thousand tonnes to the Vřesová pressure gas plant, where it is disposed. Occasionally, IFs are used for the transport of excavated soils in reconstructing railway lines (for instance in the Vlkov u Tišnova station with a volume of approximately 40 thousand tonnes) [4, 7].

According to Eurostat, approximately 96.5 million tonnes of goods are transported by rail in the Czech Republic every year. The IF share in the total volume of freight railway transportation amounts to more than 6%, i.e. to

approximately 5.9 million tonnes every year [10]. As for the different commodities transported in IFs, about 77% percent of the total volume is represented by the transportation of brown coal to two thermal power plants and one heating plant. The transit transport of coke with hard coal over the Czech Republic accounts for 12%, wood chips and wood waste represent 9% and excavated soil and oil sludge have a share of about 2% (see Table 4) [11].

2.4. Comparison of Analysis Results

The following two indicators were used to compare the use of the IF transport system in selected countries [3]:

1. Share of volume of goods transported in IFs in the total volume of freight railway transportation

The volume of freight railway transportation in the countries analysed is shown in Table 4. From the data it is clear that the volume of freight railway transportation in the Czech Republic and Austria is more than twice that of Slovakia, with about 100 million tonnes of goods every year compared to Slovakia's less than half of this volume. The analysis of the use of the IF transport system identified different shares of IF transport in the different countries (approximately 2% in Austria, 6% in the Czech Republic and less than 1% in Slovakia). The commodities transported differ in the different countries as well. In the Czech Republic, the most transported commodity is brown coal (77%), in Austria it is wood chips (44%) and coke and hard coal (42%) and in Slovakia it is wood chips (68%).

Table 4

Share of volume of goods transported in Ifs [3, 8, 9]

	Austria		Slovakia		Czech Republic	
Goods	[th. tonnes]	[%]	[th. tonnes]	[%]	[th. tonnes]	[%]
brown coal	-	-	-	-	4 550	77%
wood chips	850	44%	215	68%	525	9%
coke and hard coal	800	42%	-	-	700	12%
sugar beet	-	-	41	13%	-	-
energy gypsum	260	14%	60	19%	-	-
others	-	-	-	-	131	2%
Total	1 910	100%	316	100%	5 906	100%

2. Volume of goods transported in IFs per one kilometre of railway line in the given country.

The comparison of the countries analysed in terms of the volume of goods transported in IFs per one kilometre of railway line and per total length of the railway network is shown in Fig. 1. The comparison shows that the Czech Republic has the most extensive railway network with a total length exceeding 9,500 km. Taking into account the area of the country as well, it is to be noted that the Czech railway network is the densest as well (121.3 m/km^2). In Austria, the network length is 5,500 km and density 65.9 m/km^2. With its approximately 3,600 km, Slovakia's railway network is denser than the Austrian one, with 74 m/km^2 [3, 9].

The order of countries remains the same even for the volume of goods transported in IFs per one kilometre of railway line every year. The resulting amount is 617 tonnes for the Czech Republic, followed by Austria with 346 tonnes per year and Slovakia with 87 tonnes of goods transported per one kilometre of railway line every year [3, 9].

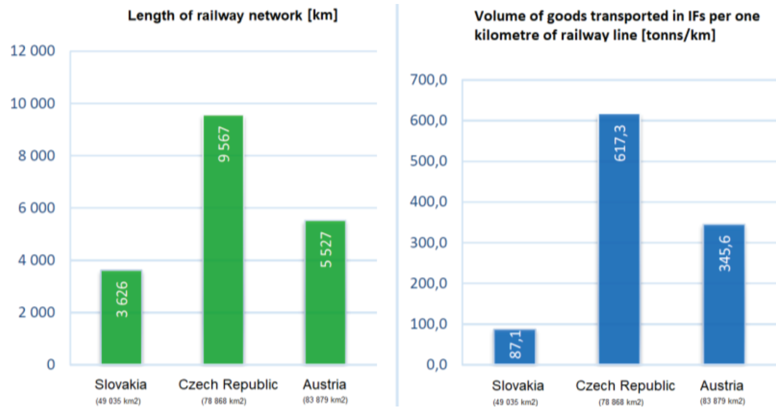

Fig. 1 Volume of goods transported in IFs per one kilometre of railway line in the given country [3, 8, 9]

3. Technical and Technological Aspects of the Innofreight System

This section evaluates individual technical and technological indicators of transport using a standard method (Falls railway wagons) versus Innofreight wagons for supplying coal to the Opatovice power plant (EOP). Considering the sensitive nature of the data of Czech Railways Cargo (ČD Cargo, a.s.), the only economic indicator assessed in greater detail is the price for the use of railway infrastructure through train rides. What is relevant here is mainly the total train mass and the discount for the use of combined transport.

One of the main advantages of container trains is the usable width of the containers used. Trains with Innofreight wagons have a greater pay-mass (see Table 5). The number of incoming wagons and the amount of coal transported to

EOP were compared for September 2016 and September 2019 (see Table 6) [12].

Table 5

Comparison of train unit parameters [12]

	Falls wagons	Innofreight wagons
Usual number of wagons per train [number]	32	15
Wagon length [m]	13.5	26.7
Train pay-mass with usual loading [tonns]	1,600	1,800
Usual train length excluding locomotive [m]	**432**	**400.5**

Table 6

Amount of coal transported to EOP per month of operation (30 days) [12]

	Falls wagons	Innofreight wagons
Number of incoming trains per month [number]	82	83
Number of incoming wagons per month [number]	2,621	1,221
Load weight transported in one wagon [tonns]	50	120
Total amount of coal transported per month [tonns]	**131,050**	**146,520**

The average turnaround time on the EOP siding in one month (September 2019) was calculated based on real data pertaining to incoming trains in EOP. As turnaround time is considered the time between the arrival at the siding and the wheeltapper's announcement about the completion of the technical inspection before the train departure. The information about the actual departure was not available. Anyway, the the time of departure is not relevant for the length of technological processes involved in the unloading [7, 12].

The calculation shows that the unloading of Falls wagons is significantly faster under standard conditions; the average train turnaround time in September 2016 was 5 hours 38 minutes. The situation during winter months was different. The average train turnaround time with Innofreight wagons on the EOP siding in September 2019 was 6 hours 43 minutes. According to train traffic diagram 2019, the shortest slot planned for the turnaround time on the EOP siding is 7 hours 31 minutes. After deducting the calculated average time from the planned turnaround time, there is still a certain reserve time so as to anticipate potential delays. In September 2019, the arrival times of loaded trains were more in line with the train traffic diagram. However, consideration must be given to the fact that there were different stations of origin (in 2016, they were in different countries as well). In September 2019, some incoming trains were irregular, i.e. not according to the annual train traffic diagram. In Table 7, the number of trains is broken down by different stations of origin.

Table 7

Number of incoming trains in EOP in September 2016 and 2019 [7, 12]

09/2016			09/2019		
Březno u Chomutova	Děčín hl.n. nákladové n.	Petrovice u Karviné	Březno u Chomutova	Počerady	Světec
54	15	13	44	28	11
Total: 82 trains			Total: 83 trains		

The comparison of economic indicators is somewhat clearer. The total costs of one pair of trains were compared based on the calculations of Czech Railways Cargo. Using train units with Innofreight containers, these costs are by approximately 13% lower compared to trains with standard wagons; and the new train units are capable of transporting by 200 tonnes of goods more [7, 13].

Table 8

Total price for the use of railway infrastructure through train rides [7, 12, 14]

Trains	Falls wagons [CZK]	Innofreight wagons [CZK]
1 loaded train	35,331.58	22,965.52
1 empty train	13,060.50	6,468.06
1 pair of trains	48,392.08	29,433.58
82 pairs of trains	**3,968,150.53**	**2,413,553.82**

Furthermore, the price for the use of railway infrastructure through train rides was calculated. For both methods of transport, the national and regional rail network statement 2019 was considered. Considered was the distance travelled on the Railway Administration infrastructure in the section: Březno u Chomutova – borders of infrastructure in Opatovice nad Labem. The total price is the sum of the prices of travel time of loaded trains and empty trains. The total price per month was calculated based on 82 trains arriving from Březno u Chomutova in EOP (see Table 8). Using the new train units, the monthly price for the use of railway infrastructure through train rides was by CZK 1,554,596.70 lower. This is mainly due to the lower mass of the wagons. The total mass of new train units including the load is lower than the BRUTTO mass of standard train units and furthermore, the new train units are capable of transporting greater loads. What is also relevant is the discount for the use of combined transport. Without regard to the rental of train units, the new method of transport is clearly more economically advantageous [14, 15].

4. Conclusions

What also has an impact on the results of the comparison of indicators is the structure of economies of the countries analysed. In Austria, the environmental policy of the government and public environmental awareness also play a significant role. Comparing the total energy mix of the selected countries (i.e. not only their production of electricity), it is to be noted that in Austria, the second most prominent share, after energy from oil products, is represented by energy from renewable sources with 30%. In the Czech Republic, solid fuel accounts for the largest share of energy production, with up to 40%. In Slovakia, nuclear energy and natural gas energy (with 24% each) are the most prominent components.

Based on the reloading time comparison, it cannot be clearly established which system is more advantageous. The unloading of dump containers is faster under standard conditions, but depends on external influences. The unloading time differs, with great differences during winter months. The unloading of Innofreight containers usually takes longer but as this system is modern and reliable, the unloading time remains relatively constant. Fewer personnel are required and the occupational safety is greater.

The new system reduced the travel time of empty trains by approximately 1 hour compared to standard train units. The average turnaround time on the EOP siding in September 2019 was more than 1 hour longer than in September 2016. Nevertheless, the main advantage of wagons with Innofreight containers is their low mass, i.e. greater pay-mass.

Low mass reflects in a lower price for the use of railway infrastructure through train rides and in greater possible loading. In financial terms, the new method of transport is certainly more advantageous. The total transport costs are by approximately 13% lower than in the past.

Even though the new transport system using Innofreight containers was introduced based on an arbitrary decision, it turned out that it there is a benefit to it and that it makes sense to use it for other destinations as well; for instance for the Chvaletice power plant, where it is currently used, too.

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Vehicle Trajectories on Road with Disturbed Road Surface

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Abstract

The road surface changes its quality with constant use. Gradually it develops small-scale failures (e.g., depressions, cracks, roughness, the disintegration of surface material caused by vehicle fuels and oils), but also large-scale failures (abrasion, longitudinal grooves, transverse waves, surface deformations, surface undulation). In our paper, we describe the criteria and mathematical models of several types of road deformations and vehicle trajectories on such roads.
KEY WORDS: *tire contact, road shape, trajectory model, singular points*

1. Introduction

Every carrier is interested in transporting undamaged goods safely to the destination station. The role of the carrier is not only to find solutions to problems related to logistics, optimization of suitable routes, or the timing of individual operations. The problems solved in transportation are also about specific elements of the transportation infrastructure, i.e., road communications. The interest in this area is mainly for cases when transporting chemically unstable substances and objects sensitive to shocks and impacts, e.g., gases, liquids, live animals, humans. Road safety, therefore, requires a limitation of the maximum speed and, on special sections of the road, a forced (intentional) deceleration of the vehicle. For this purpose, artificial obstacles are placed on the road surface. We call such deliberate obstacles to speed breakers. The unevenness we encounter on the road apart from intentionally placed speed breakers usually arises as a result of the dynamic effects of moving vehicles, the effects of weather changes and road repairs. A vehicle moving on the road is often forced to adapt its speed to the condition and shape of the road. It is therefore necessary to deal with the modeling of the roadway with unevenness and to examine the conditions for the occurrence of multi-point contact of the vehicle with the road [2]. And that is why road designers pay their attention to studying the longitudinal profile of the road. In this contribution, we present a mathematical description of the vehicle's trajectory while driving on roads of various profiles.

2. Multi-Point Contact Criterion

Consider the unevenness on the road to have the shape a terrain cutout according to Fig. 1, where the symbol l denotes the length and the symbol h the depth of the cutout. The symbol r represents the radius of the rolling wheel. Assume that $l < 2r$ and $h < r$. Other cases are either trivial or infeasible.

Assume r and h constant. Then for the variable l there is a three-point contact of the tire with the road surface if:

$$l = 2\sqrt{h \cdot (2r - h)} \,. \tag{1}$$

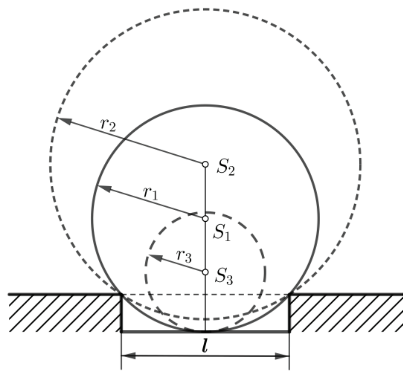

Fig. 1 Wheel contacts with the road surface

If $l < 2\sqrt{h \cdot (2r - h)}$, then the contact is two-point and if $l > 2\sqrt{h \cdot (2r - h)}$, then the contact is one-point. Further, assume that r and l are also constant. For the variable h, the case of a three-point contact occurs if:

$$h = r - \frac{\sqrt{4r^2 - l^2}}{2}. \quad (2)$$

If $h > r - \frac{\sqrt{4r^2 - l^2}}{2}$, then a two-point contact occurs, and if $h < r - \frac{\sqrt{4r^2 - l^2}}{2}$, then the contact of the tire with the road is one-point.

However, we most often encounter a road with a profile in the shape of the first, second or both halves of a generalized sinusoid. Let us denote l_0 according to Fig. 2 the length of the half-wave of the sinusoid, its amplitude h_0 and r will again represent the radius of the rolling wheel. The road equation is then described as

$$y = h_0 \cdot \sin\frac{\pi \cdot x_0}{l_0}. \quad (3)$$

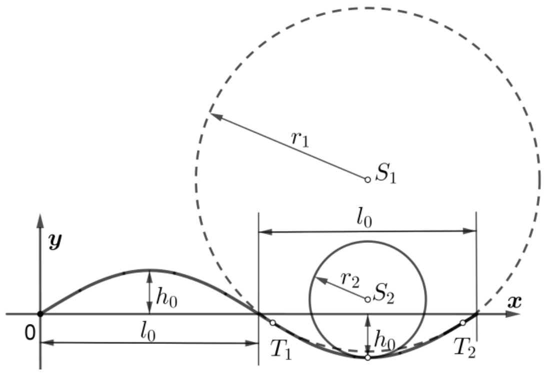

Fig. 2 Wheel contacts with the road surface

From the relationships for the first curvature, we derive the criterion of single-point contact of the tire [1]. For the given constants h_0 and r, the value of l_0 must be at least:

$$l_0 = \pi \cdot \sqrt{h_0 \cdot r}. \quad (4)$$

For the given constants l_0 and r, the value of h_0 can be at most:

$$h_0 = \frac{l_0^2}{\pi^2 \cdot r}. \quad (5)$$

3. Mathematical Model of the Trajectory

To simplify the situation, we identify the movement of the vehicle with the movement of the center of the moving wheel. Assume that the damage to the road surface has the shape of the cutout according to Fig. 1. The shape of the unevenness is described by a function that does not have a derivative at every point of its domain. From a mathematical point of view, the jump in the functional value at the start of the cutout represents a point of singularity. The wheel does not consistently copy its shape when passing over this terrain. Since the movement of the wheel axis in the vertical direction is the cause of the kinematic excitation of the sprung mass, it is necessary to approximate the actual shape of the trajectory of the wheel during the passage over the unevenness in the calculation. The wheel axis describes a trajectory consisting of line segments and circular arcs marked in Fig. 3 by symbols I., II., III. and IV. When passing over the terrain cutout, the wheel axis moves in circular arcs II. and III, which can be expressed mathematically in the coordinate system $(0, \vec{x}, \vec{y})$ in various ways, for example parametrically, explicitly, implicitly, or using polar coordinates.

Because the angle φ with respect to the depth h is small, but also for technical and practical use, we will work with polynomial approximations [4]. For a sufficiently accurate approximation of these circular arcs, it suffices to use sections of parabolas $y(x) = \frac{-x^2}{2p}$ or $y(x) = \frac{-(x-l)^2}{2p}$ respectively, where p is a parameter of these parabolas.

We distinguish three types of rectangular terrain cutouts. The first type (type 1) satisfies $l = 2r\sqrt{2rh - h^2}$. The mathematical description of the type 1 trajectory is as follows:

I. $$y(x) = 0,\ x \in (-\infty, 0); \quad (6)$$

II. $$y(x)=\frac{-x^2}{2r-h},\ x\in\left(0,\sqrt{2rh-h^2}\right); \tag{7}$$

III. $$y(h)=\frac{-(x-l)^2}{2r-h},\ x\in\left(\sqrt{2rh-h^2},l\right); \tag{8}$$

IV. $$y(x)=0,\ x\in(l,\infty). \tag{9}$$

Critical point, i.e., the point at which a multi-point contact of the vehicle with the road occurs is called a singular point. The critical point of this trajectory arises during the transition from section II. to section III. At this point, the vehicle makes a three-point contact with the road surface.

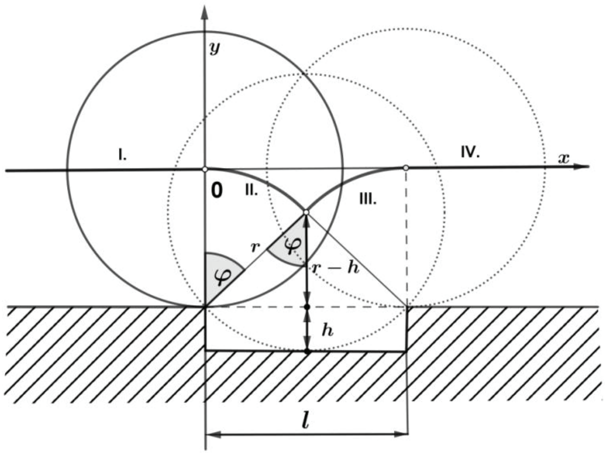

Fig. 3 Rectangular terrain cutout of type 1

The second type (type 2) of the cutout shown in Fig. 4 satisfies $l<2\sqrt{2rh-h^2}$. Let s denote the minimum y-coordinate of the trajectory of the wheel center. Then for type 1 we have $s = r - h$ as seen in Fig. 3, while for the cut-out of type 2, we have $s < r - h$ and $h < r\,(1 - \cos\varphi)$.

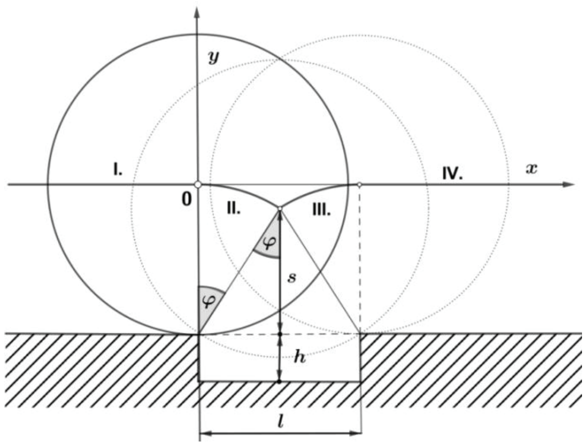

Fig. 4 Rectangular terrain cutout of type 2

Thus, the mathematical description of the type 2 trajectory model is as follows:

I. $$y(x)=0,\ x\in(-\infty,0); \tag{10}$$

II. $$y(x)=\frac{-x^2}{2r-h},\ x\in\left(0,\frac{l}{2}\right); \tag{11}$$

III. $$y(x)=\frac{-(x-l)^2}{2r-h},\ x\in\left(\frac{l}{2},l\right); \tag{12}$$

IV. $$y(x)=0,\ x\in(l,\infty). \tag{13}$$

The critical point of this trajectory arises again at the transition from section II. to section III. At this point, the vehicle makes two-point contact with the road surface.

Finally, the third type (type 3) cut-out is depicted in Fig. 5, where we again denote by the letter l the length of the cutout, h its depth and r the radius of the rolling wheel. The mathematical description of this model of trajectory is composed of five sections and can be expressed as follows:

I. $$y(x)=0,\ x\in(-\infty,0); \tag{14}$$

II. $$y(x)=-\frac{h}{-r^2}x^2,\ x\in(0,r); \tag{15}$$

III. $$y(x)=-h,\ x\in(r,l-r); \tag{16}$$

IV. $$y(x)=-\frac{h}{r^2}(x-l)^2;\ x\in(l-r,l); \tag{17}$$

V. $$y(x)=0,\ x\in(l,\infty). \tag{18}$$

In this case, two critical points will arise during the transition from section II. to section III. and during the transition from section III. to section IV., i.e., the wheel hits the road surface twice.

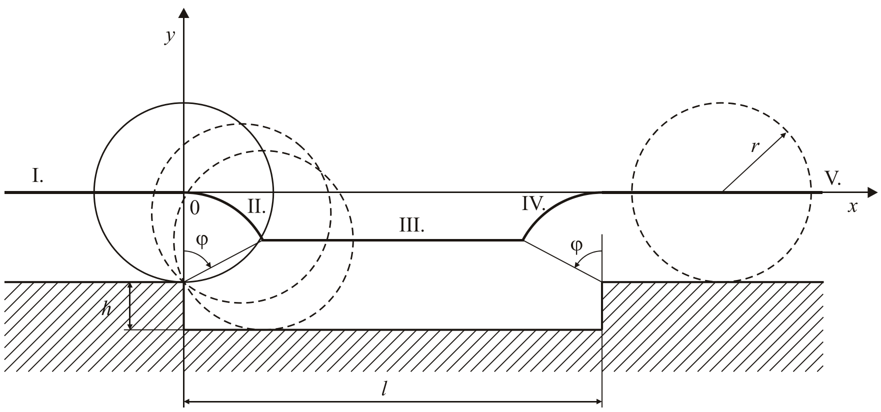

Fig. 5 Rectangular terrain cutout of type 3

A similar situation as with the type 3 cutout occurs also in the case of the road profile in the shape of a terrain threshold as shown in Fig. 6. We often encounter a situation where it is necessary to cover a hole after excavation work with, e.g., a steel plate. The terrain surface is then modeled using a rectangular terrain threshold. The wheel axle follows a trajectory consisting of five parts. Singular points occur in front of and behind the terrain threshold. The jump in the functional value at the beginning and at the end of the threshold is represented in the trajectory by a movement along the circular arcs II. and IV. when the wheel rotates by an angle φ. Therefore $u = r \cdot sin\varphi$ and $| r - h | = r \cdot cos\varphi$.

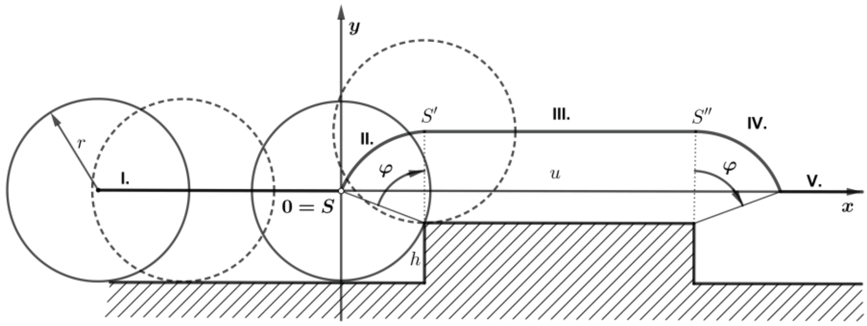

Fig. 6 Rectangular terrain threshold

The above circular arcs have various formulations in the Cartesian coordinate system, for example, the implicit form is as follows:

II. $$\left(x-u\right)^2+\left(y-h+r\right)^2-r^2=0\,,\ x\in\left(0,u\right);\tag{19}$$

IV. $$\left(x-l-u\right)^2+\left(y-h+r\right)^2-r^2=0\,,\ x\in\left(l+u,l+2u\right).\tag{20}$$

Since the arcs are short, from a practical point of view, we can approximate them with second-degree parabolas. This leads to the following explicit form:

II. $$y=h-\frac{h}{u^2}\left(x-u\right)^2,\ x\in\left(0,u\right);\tag{21}$$

IV. $$y=h-\frac{h}{u^2}\left(x-l-u\right)^2,\ x\in\left(l+u,l+2u\right).\tag{22}$$

Circular arcs can also be further expressed using the Taylor series expansion. For example, the expansion of the trajectory in section II. can be written as follows:

$$y=h+\left(-\frac{1}{r}\right)\frac{1}{2!}\left(x-l-u\right)^2+\left(-\frac{3}{r^3}\right)\frac{1}{4!}\left(x-l-u\right)^4+\left(-\frac{45}{r^5}\right)\frac{1}{6!}\left(x-l-u\right)^6+\dots\tag{23}$$

From this after adjustment we obtain the following formula:

$$y=h-\frac{\left(x-l-u\right)^2}{2r}-\frac{\left(x-l-u\right)^4}{8r^3}-\frac{\left(x-l-u\right)^6}{16r^5}-\dots\tag{24}$$

Note that from a technical point of view higher derivatives do not significantly affect the approximation of this part of the trajectory.

4. Mathematical Model of the Trajectory without Singular Points

If we want to model a trajectory without singular points, then the wheel must also roll on the road with a profile without singular points. Such a requirement is met by a road profile in the form of the first, second or both halves of the generalized sinusoid $y=h_0\cdot\sin\frac{\pi\cdot x_0}{l_0}$, where h_0 is the given amplitude and l_0 is the given half-wave length of this sinusoid. This means that it is a periodic phenomenon. However, if we have only one first half-wave of the sinusoid on the road, then to create its model, we first replace the half-wave with a circular arc with radius $R = l_0 + h_0$ (Fig. 7). We then position an approximation curve on it described by the following equation:

$$y\left(x\right)=h_0^2\cdot\left(h_0+\frac{x^2}{R}\right)^{-1}.\tag{25}$$

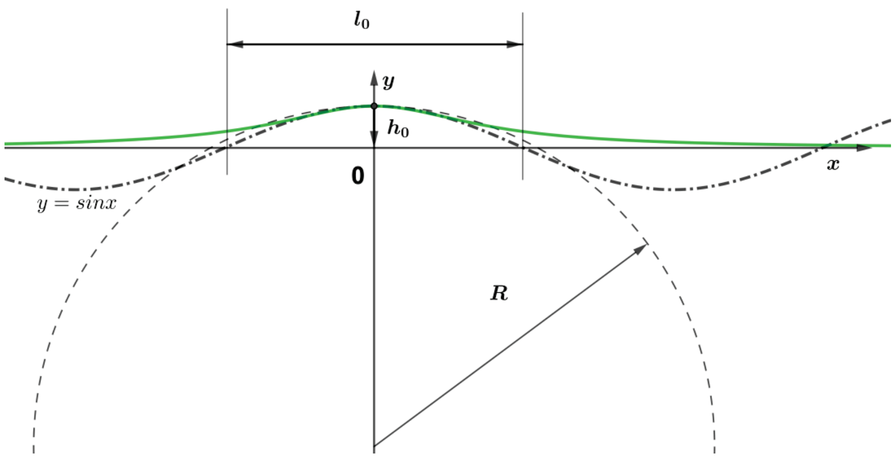

Fig. 7 The first half wave of the sinusoid

In an effort to remove the periodicity of the approximating function, we significantly increase the length of the half-wave l_0, and thus minimize the number of points with zero derivative.

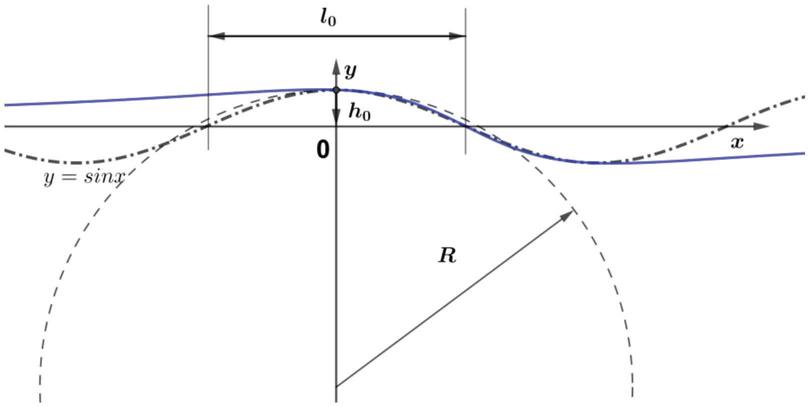

Fig. 8 Both half-waves of the sinusoid

We express the second half-wave analogously using symmetry along the x-axis of the Cartesian coordinate system. This yields the following equation:

$$y(x) = -h_0^2 \cdot \left(h_0 + \frac{x^2}{R}\right)^{-1}. \tag{26}$$

In the case of both halve-waves (Fig. 8), we can express part of the sinusoid explicitly as follows:

$$y(x) = -h_0(x - l_0) \cdot \left(2h_0 + \frac{x^2}{R}\right)^{-1}. \tag{27}$$

From these explicit expressions for the road profile, we can model the trajectory of a moving vehicle on such roads. If we consider the profile (25), then the trajectory equation is as follows:

$$y(x) = h_0^2 \cdot \left(h_0 + \frac{x^2}{R + r}\right)^{-1} + r. \tag{28}$$

For the profile (26), then the trajectory equation is as follows:

$$y(x) = -h_0^2 \cdot \left(h_0 + \frac{x^2}{R + r}\right)^{-1} + r. \tag{29}$$

Finally, for the profile (27), then the trajectory equation is as follows:

$$y(x) = -h_0(x - l_0) \cdot \left(2h_0 + \frac{x^2}{R + r}\right)^{-1} + r. \tag{30}$$

Using approximations for the parts of the sinusoid we have achieved the removal of the periodicity of the original functions. Another benefit of this is that this way the trajectory it described by a single continuous function on a set of real numbers.

To simplify all models, we neglected the deformations of the tire.

5. Conclusion

The most important criterion in transportation is safety. In the daily press we frequently find information about serious traffic accidents. The occurrence of such accidents is influenced by the following factors:

- human influence (driver behavior, driving style);
- influence of technical conditions (technical state of the motor vehicles);
- environment (weather impact, terrain shape).

The first two factors are the sole responsibility of each road user. The third factor can be controlled by building quality road communications. Quality roads are considered to be roads in the construction of which the prescribed technological procedures using quality materials have been followed. Road communications with a minimum number of

singular points are also considered to be good [3]. The modeling of road profiles with singular points and vehicle trajectories on such roads can thus serve as an aid in examining traffic situations.

Acknowledgement

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Communications-Based Train Control System –EMC Testing Disturbance Emission Generated by on-Board rmCBTC System

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Abstract

The paper presents the results of EMC interference tests on the rmCBTC system installed in vehicles of the Warsaw Metro Lines. The rmCBTC system was created as part of a project co-financed by The National Centre for Research and Development POIR.01.01.01-00-0276/17 "CBTC class automatic train control system, based on unique bi-directional wireless data transmission and interoperational ETCS components, which increases efficiency and safety level in the agglomeration rail transport".
The rmCBTC system has been installed on 2 types of vehicles - METROPOLIS 98B (Alstom) and INSPIRO (Siemens). The tests were conducted in real conditions on the Warsaw Metro test track. They were to verify the acceptable levels of EMC interference after installing the rmCBTC system on these vehicles. The tests were carried out by the Accredited Laboratory number AB 310. The tests were carried out in accordance with CENELEC standards EN 50121 series and an accredited testing procedure PB-LA-21 ver. 6 of 30 January 2017 [5]. Scope of test – radiated disturbance emission measurement and conducted disturbance emission measurements.
The paper presents the conditions for testing, their scope and the results obtained for the INSPIRO vehicle. Tests were carried out to certify the system for use in Poland by Urząd Transportu Kolejowego (Polish Railway Safety Authority Office).
KEY WORDS: *EMC test, rmCBTC, EMC emission, national certification, CENELEC standards,*

1. Introduction

Measurements of electromagnetic emissions of radiated and conducted disturbances were carried out on the STP-Kabaty Test Track. The tests were carried out on the SIEMENS INSPIRO electric multiple units with ATC class system type rmCBTC – Fig. 1. The measurements were carried out using a measuring receiver and three antennas: loop, biconical and log– periodic antenna for two modes of operation: stationary and slow moving test [5]. Tests were performed for polarization of the antenna: vertical and horizontal of the a biconical and log – periodic antenna. Measurement of conducted disturbance emissions has been made on the ports of the on-board low-voltage power supply network of 110V DC auxiliary circuits and control circuits in accordance with the methodology set forth in the EN 55016-2-1 standard [4] and the testing procedure PB-LA-21 [5] using the levels of EN 50121-3-2 standard [3].

Fig. 1 SIEMENS INSPIRO electric multiple unit with ATC class system type rmCBTCon the STP-Kabaty Test Track

2. Research Methodology

Tests of electromagnetic emission of radiated disturbances in accordance with EN 50121-3-1 standard [2] were performed in the 150 kHz ÷ 1 GHz frequency band in the following two sub-ranges [7-9]:

- magnetic component of the field strength (150 kHz ÷ 30 MHz);
- electric component of the field strength (30 MHz ÷ 1 GHz).

Depending on the type of components used in the right kind of antenna. During the measurement, the magnetic component of the field strength used a loop antenna, and for measuring the electrical component biconical antenna and the log-periodic antenna – Table 1.

Table 1

Measuring equipment

Device name	Model	Producer
Measuring receiver	ESCI3	Rohde & Schwarz
Log – periodic antenna	VUSLP 9111B	SCHWARZBECK MESS ELEKTRONIK
Loop Antenna	FMZB 1513	SCHWARZBECK MESS ELEKTRONIK
Biconical antenna	VBA 6106A	SCHAFFNER
10 m measuring cable	RG58CU/11N/11N/010000	HUBER SUHNER

Fig. 2 shows the limit values of intensity of magnetic and electric fields for urban vehicles powered by a voltage of 750V DC [4]. These limits were used during measurements performed on the SIEMENS INSPIRO electric multiple unit with an ATC class system type rmCBTC for the stationary and slow moving test.

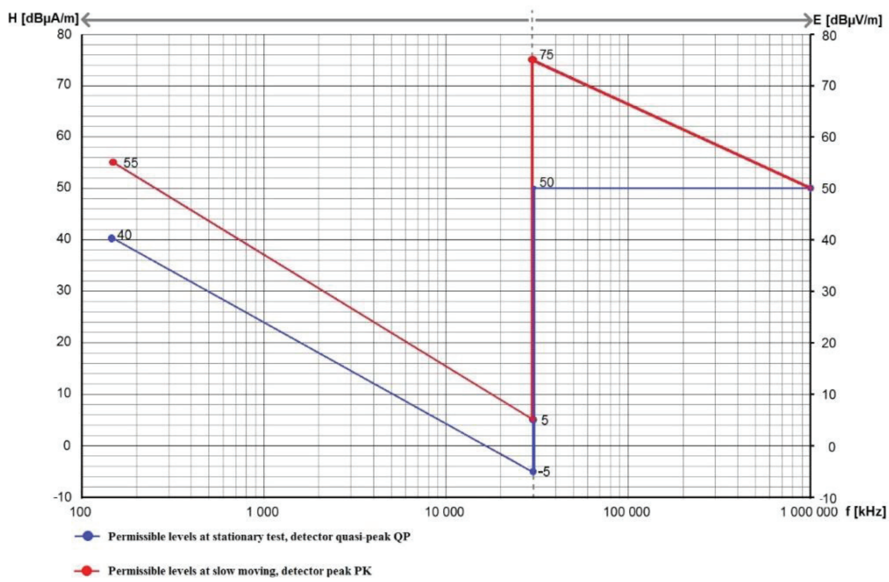

Fig. 2 Radiation emission limit values for urban vehicles powered by 750V DC

Before testing the emission of radiated disturbances generated by a rail vehicle, the background of the environmental electromagnetic field (STP Kabaty Test Track) was measured in the frequency ranges required by EN 50121-3-1 standard [2] and shown below – Table 2.

Table2

Guideline for test [4]

Subrange [Hz]	Bandwidth [kHz]	Sweep time [ms]
150 k ÷ 1,15 M	9 or 10	37
1 M ÷ 11 M	9 or 10	370
10 M ÷ 20 M	9 or 10	370
20 M ÷ 30 M	9 or 10	370
30 M ÷ 230 M	100 or 120	42
200 M ÷ 500 M	100 or 120	63
500 M ÷ 1 G	100 or 120	100

The background level of the electromagnetic field environment generated by other field sources should be at least 6 dB lower than the maximum levels – Fig. 2. If the background level of the electromagnetic environment exceeds the level of -6 dB for a given frequency band, when assessing the results, the sub-range should not be considered [8-9]. The SIEMENS INSPIRO electric multiple unit with an ATC class system type rmCBTC was tested in two modes: stationary test and slow moving of (20 ± 5) km/h. In the case of a stationary test, the measuring antennas were located opposite 1 vehicle section at the place of installation of an ATC class system type rmCBTC. The measurement was made using a detector: a quasi-peak accordance with the current normative requirements. During the test, the metro train accelerated using 1/3 of the tractive force and was traveling at a speed of 20 km/h. The measurement was made

with the use of the detector: peak, measuring the maximum radiation values during a given test [8-9]. The measurement antennas for the described operating modes were set at a distance of 10 m from the track axis, and the height of the antennas was selected in such a way as to obtain the maximum level of emitted electromagnetic field disturbances from the SIEMENS INSPIRO vehicle with an ATC class system type rmCBTC installed. Measurements in the 30 MHz - 1GHz frequency range were made for vertical and horizontal antenna polarization using a two-pin antenna and a logarithmic-periodic antenna – Table 1. The measuring stand is shown in the figures below - Fig. 3.

Fig. 3 Electric multiple unit SIEMENS INSPIRO with ATC class system type rmCBTC during emission tests for disturbance radiated on the STP Kabaty Test Track

According to the EN 55016-2-1 standard [4] containing the research methodology, the test procedure PB-LA-21 [5] and the requirements of the railway standard EN 50121-3-2 [3] measurements of electromagnetic emission of conducted disturbances were performed in the required frequency range from 150 kHz to 30 MHz - Fig. 4. The railway standard requires equipment and system disturbance tests to demonstrate that the object has an acceptable level of emission of conducted disturbances in the required frequency range [6]. The level of interference depends on the target operating conditions of the device under test. For these reasons, the interference level measurements should be carried out under clearly defined conditions EUT as far as possible corresponding to the normal conditions (the target), operation [6].

Shows a method of measuring the emission of electromagnetic disturbances conducted on the auxiliary and control circuits for 110V DC power supply port of SIEMENS INSPIRO electric multiple unit with an automatic ATC class rmCBTC train guidance system – Fig. 5. The measurements were carried out using a high-voltage probe to which a measuring receiver was connected via a coaxial cable – Table 3. The probe was connected respectively to the positive and then to the negative terminal of the battery with respect to the vehicle enclosure. The measurement was made by a quasi-peak detector, which allows the measurement of the maximum signal value after detection at a strictly determined measurement time – Figs. 14 ÷ 15.

Table 3

Measuring equipments

Device name	**Producer**	**Model**
Measuring receiver	Rohde & Schwarz	ESCI3
Measuringcable 10 m	HUBER SUHNER	RG58CU/11N/11N/005000
High voltage test probe	Schwarzbeck Mess Elektronik	TK 9420

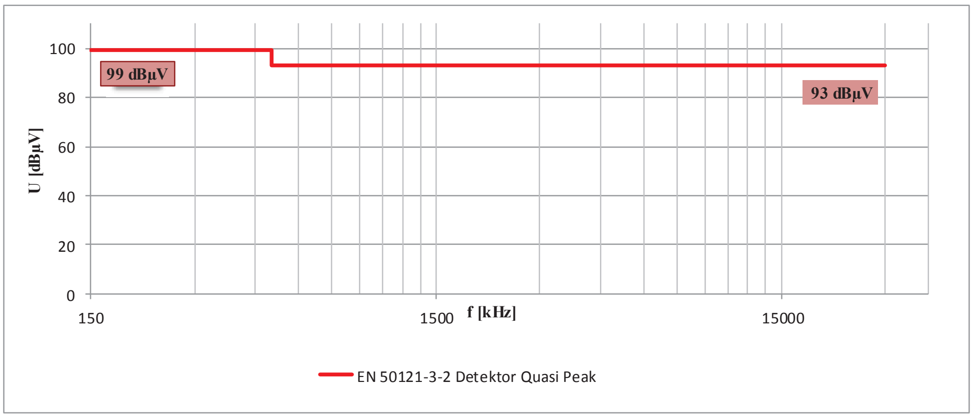

Fig. 4 Levels of electromagnetic conducted disturbances required by railway standards

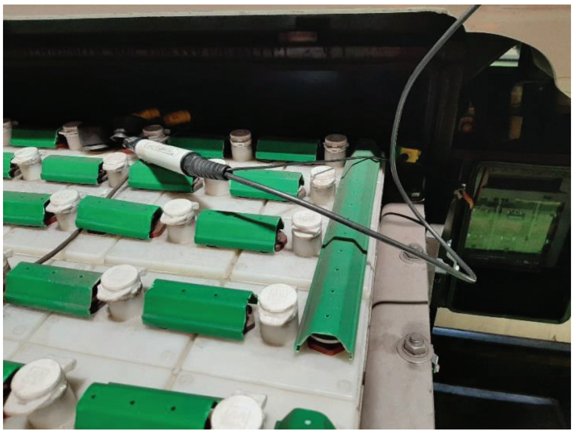

Fig. 5 Power port 110V DC when emission of conducted disturbances

3. Measurement Results

The following Figs. from 6 to 13 are shows examples of results of electromagnetic radiation generated by the SIEMENS INSPIRO electric multiple unit with installed ATC class system type rmCBTC in frequency bands in EN 50121-3-1 standard [2] for modes stationary and slow moving train. The presented results include the electromagnetic field measuring path used, i.e. amplified /attenuation of the antennas and the cable attenuation in function of frequency.

The measurements carried out show that the permissible disturbance values are exceeded, which sources are local radio transmitters and other telecommunications equipment and navigation systems operating at frequencies: 11.2 MHz, 15.3 MHz, 15.6 MHz, 17.489 MHz, 18.5 MHz, 18.8 MHz, 88 MHz ÷ 110 MHz, 183 MHz ÷ 193 MHz, 425 MHz, 523 MHz ÷ 540 MHz, 570 MHz ÷ 576 MHz, 680 MHz ÷ 695 MHz, 790 MHz ÷ 820 MHz, 920 MHz ÷ 960 MHz. Pursuant to the EN 50121-3-1 standard [2], the recorded exceeded limit value cannot represent a basis for a negative assessment, because of background electromagnetic interference exceeding the acceptable level - 6 dB.

During the tests on radiated disturbance emissions, it was also recorded that the limit value at 27.096 MHz exceeded for modes stationary and slow moving. The source of exceeded values is an antenna for vehicle–track communication according to the EN 50121-1 standard [1], the recorded exceeded limit value cannot represent a basis for a negative assessment.

On Figs. 14 and 15 are shows of actual measurements of electromagnetic emissions conducted generated by the SIEMENS INSPIRO electric multiple unit with installed ATC class system type rmCBTC on the 110 V DC power port. The presented results include the electromagnetic field measuring path used, i.e. probe attenuation and cable attenuation in function of frequency.

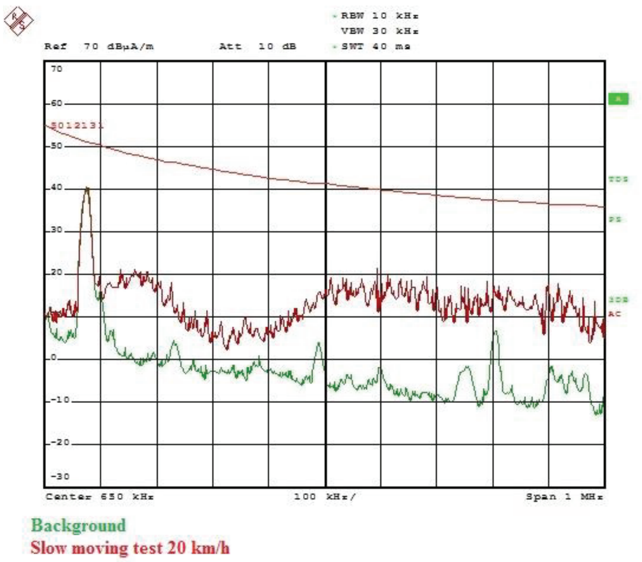

Fig. 6 Graph of the emission of magnetic disturbances while slow moving test, the band 150 kHz – 1.15 MHz

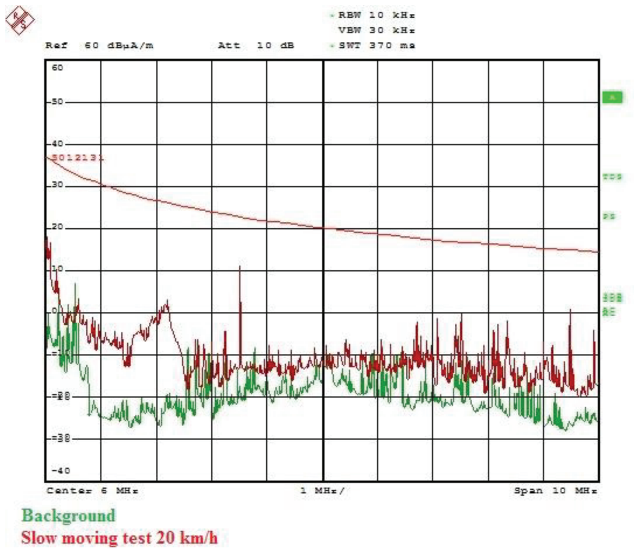

Fig. 7 Graph of the emission of magnetic disturbances while slow moving test, the band 1 MHz – 11 MHz

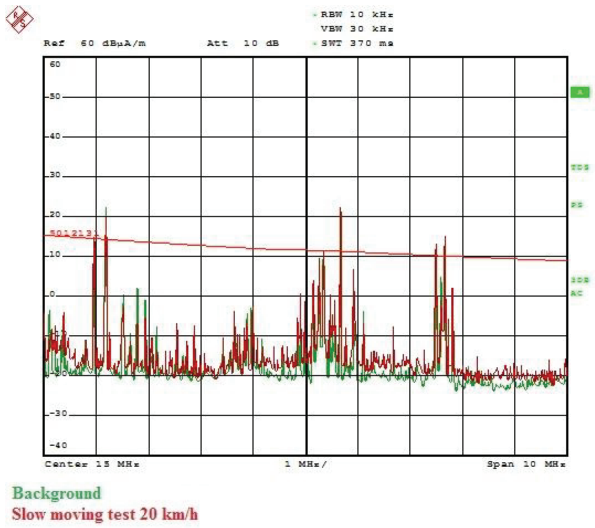

Fig. 8 Graph of the emission of magnetic disturbances while slow moving test, the band 10 MHz – 20 MHz

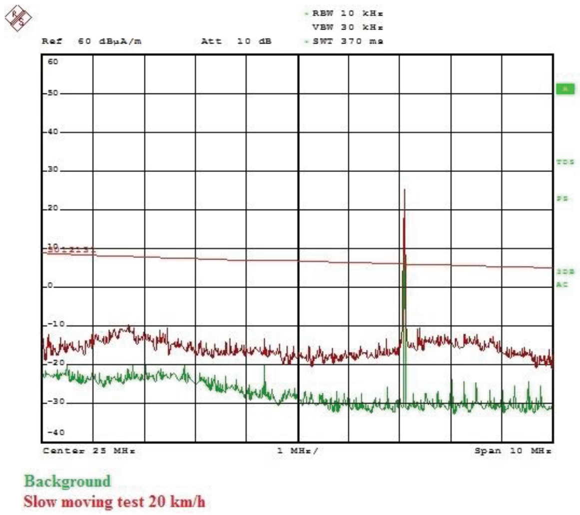

Fig. 9 Graph of the emission of magnetic disturbances while driving, the band 20 MHz – 30 MHz

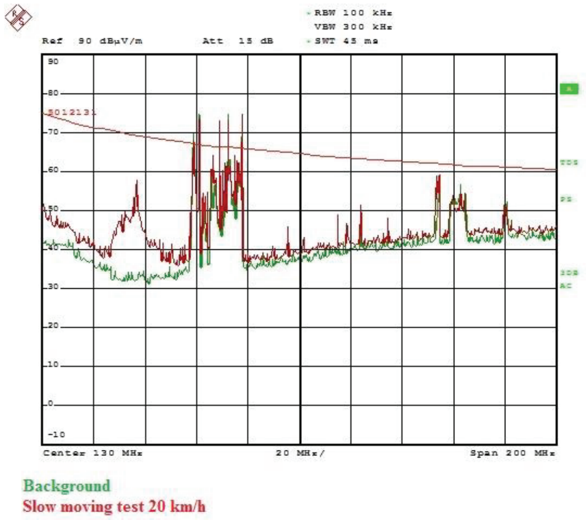

Fig. 10 Graph of emission of electrical disturbances for vertical polarization of the antenna while slow moving test, the band 30 MHz – 230 MHz

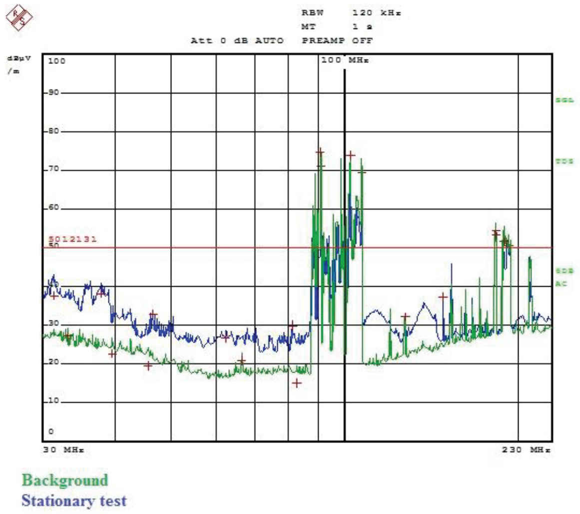

Fig. 11 Graph of emission of electrical disturbances at a stationary test for the vertical polarization of the antenna, the band 30 MHz – 230 MHz

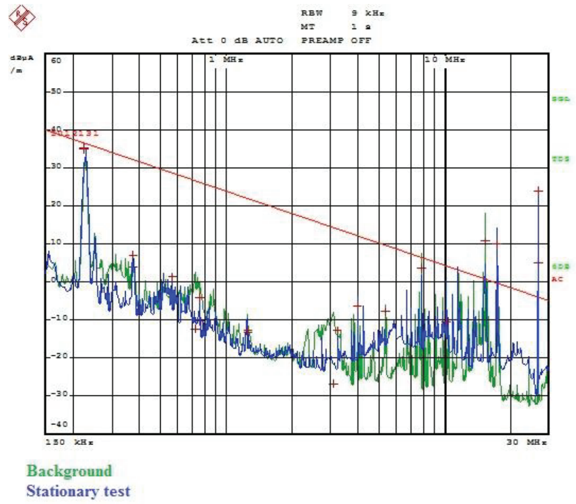

Fig. 12 Graph of the emission of magnetic disturbances at a stationary test, the band 150 kHz – 30 MHz

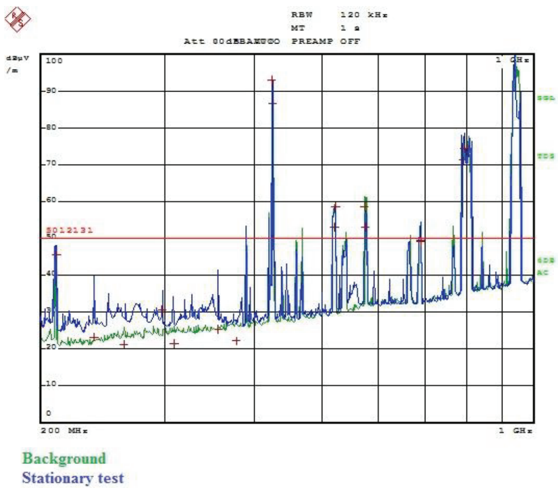

Fig. 13 Graph of emission of electrical disturbances at a stationary test for the vertical polarization of the antenna, the band 230 MHz – 1 GHz

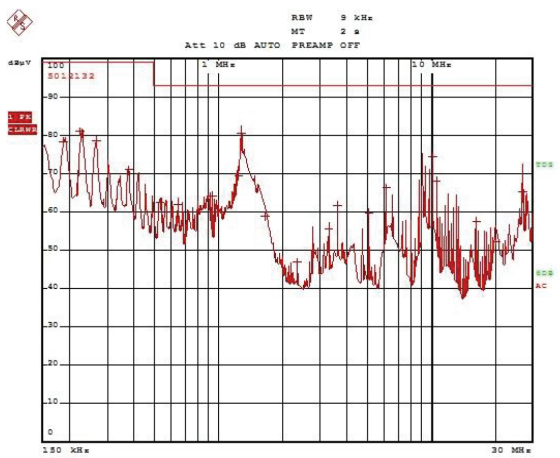

Fig. 14 Measurement of electromagnetic disturbances conducted on the power connector +110V DC

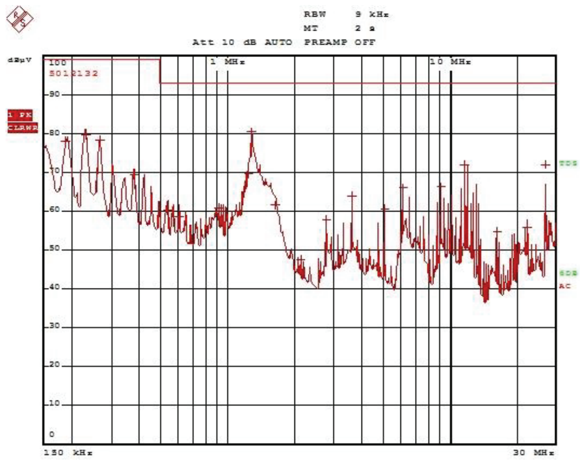

Fig. 15 Measurement of electromagnetic disturbances conducted on the power connector -110V DC

The measurements carried out did not show any exceeding of the permissible disturbance values at the on-board 110V DC supply port contained in the EN 50121-3-2 standard [3].

4. Conclusions

The article presents measurements of radiated and conducted disturbances generated by the SIEMENS INSPIRO electric multiple unit with installed ATC class system type rmCBTC in the frequency range from 150 kHz to 1 GHz. The conducted measurements show that the installed system has no negative impact on the above measurements and can be used as intended. No exceeding of permissible levels according to EN 50121-3-1 standard [2], which source is the SIEMENS INSPIRO electric multiple unit, has been found. Confirmation of compliance with the EN 50121-3-1 standard [2] is one of the tests required in the process of formal approval rmCBTC system into operation.

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Maritime Education and Training as a Tool to Ensure Safety at Sea in the Process of Introduction of Maritime Autonomous Surface Ships in Shipping

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Abstract

Rapid changes in technologies, such as the recently introduced Maritime Autonomous Surface Ships (*MASS*) which will coexist with conventional/traditional ships and will later predominate in shipping, determine new safety at sea concerns. Safety concerns can be discussed from the legal, commercial, technological, and human factor perspectives. Due to a high level of uncertainty, safety at sea can be ensured by using a proactive approach in the above mentioned fields. A crucial role in ensuring safety is played by the human factor, which can be influenced by proper Maritime Education and Training (MET). The paper focuses on ideas about making MET a reliable tool for ensuring safety at sea during the transition process of MASS introduction in shipping.
KEY WORDS: *maritime education and training (MET), maritime autonomous surface ships (MASS), safety at sea*

1. Introduction

The current trends and changes in shipping related to the introduction of new technologies are difficult to predict due to a high level of uncertainty. This uncertainty affects safety at sea and changes in the labour market, because it seems impossible to define all the challenges and risks of the period of transition from the currently prevailing conventional/traditional maritime transportation to the coexistence of such ships with MASS and to the predominance of the latter in shipping, due to unpredictable difficulties in: 1) the functioning of interconnected systems on board and ashore, 2) human-technology interactions, 3) revision and implementation of the regulatory framework at the international, regional and national levels, and 4) changes in the labour market and future demands for maritime and shore-based professionals, since new equipment, together with evolving shipboard and remote control procedures, will lead to crews and shore personnel performing new or different functions and, therefore, will necessitate follow-up training, which is not well defined yet. MET can provide assistance to the maritime community and the labour market in the areas of adaptation to technological changes over the above mentioned transition period and in the ensuring of safety at sea through proper identification of the new functions of the personnel dealing with the operation of MASS on-board and ashore, the establishing of standards of competence, and proper organisation of training and reskilling of needed specialists.

Safety at sea remains the main problem in the shipping industry. Major maritime accidents have resulted in heavy losses of human lives and severe environmental and economic damage. This issue becomes increasingly relevant with the introduction of MASS operation. The reactive approach as a response to maritime accidents in maritime policy leading to changes in regulations, procedures, or training has been used for over 3,800 years [16, 21]. Nowadays, the shift from the reactive approach in the Maritime Policy of International Maritime Organisation (IMO) to a proactive approach began since 2010. The 2010 amendments of the STCW Convention as not having "roots in maritime accidents" [6, 21] can be considered as an example of the proactive approach. This approach should be used for MET implications in order to ensure safety at sea in a world in which conventional/traditional ships coexist with MASS. MET can become a successful tool for ensuring safety at sea and making a positive influence on the maritime community and the labour market during the transition period only by using a proactive approach through the involvement of different actors of the shipping industry (policy makers, companies, educators, etc.) in the research and identification of issues for further actions, involving prediction of consequences in uncertain and hardly anticipated situations. The results of the investigation should be taken into account while taking respective measures in overcoming identified risks for safety, such as defining functions and standards of competence of an-board and shore personnel involved in MASS operation, changes in legal framework of MET, implementation of of changes on international, regional and national levels.

2. Maritime Autonomous Surface Ships, Levels of Autonomy

MASS is defined as a ship which, to a varying degree, can operate independently of human interaction. This definition anticipates that the ship will be operated autonomously, however, different descriptions of autonomy can be observed in literature, starting from the lowest level of automation - manual operation - without an autonomous function and ending with a fully autonomous level without human involvement, with differently defined levels of automation in-between: e.g., DNV provides 5 levels of autonomy for navigation functions [5]; Lloyds Register defines 6 levels - from manual steering to full autonomy [14]; Sheridan lists 10 levels of autonomy, dependent on the ship type, size, the

operational area, and conditions [20]; and IMO names 4 levels [8]. The description of the levels of autonomy according to different sources is provided in Table 1.

Table 1

Definitions of levels of autonomy provided in literature

<table>
<tr><th>Levels of autonomy according to Sheridan [20]</th><th>Degrees of autonomy according to the IMO [8]</th><th>Levels of autonomy for navigation function [5]</th><th>Cyber-enabled ships: autonomous levels [14]</th></tr>
<tr><td>10 - The computer does everything autonomously, ignores human</td><td>1 - Fully autonomous ship: the operating system of the ship is able to make decisions and determine actions itself</td><td>A - Autonomous function (the system will execute the function, normally without the possibility for a human to intervene on the functional level)</td><td>AL6 - Fully autonomous (& with no supervision)</td></tr>
<tr><td>9 - The computer informs human only if it (the computer) decides so</td><td rowspan="4">2 - Remotely controlled ship without seafarers on board: the ship is controlled and operated from another location. There are no seafarers on board</td><td rowspan="4">DS - Self controlled function (the system will execute the operation, but the human is able to override the action. Sometimes referred to as ‘human on the loop”</td><td rowspan="3">AL5 - Fully autonomous (& rarely supervised)</td></tr>
<tr><td>8 - The computer informs human only if asked</td></tr>
<tr><td>7 - The computer executes automatically, informing human when necessary</td></tr>
<tr><td>6 - The computer allows human a restricted time to veto before automatic execution</td><td>AL4 - Human on the loop – operator/supervisory</td></tr>
<tr><td>5 - The computer executes the suggested action if human approves</td><td rowspan="4">3 - Remotely controlled ship with seafarers on board: the ship is controlled and operated from another location, but seafarers are on board</td><td rowspan="3">DSE - System decision supported function with conditional system execution capabilities (human in the loop, required acknowledgement by human before execution)</td><td>AL3 - ‘Active’ human in the loop</td></tr>
<tr><td>4 - Computer suggests single alternative</td><td rowspan="2">AL2 - On and off-ship decision support</td></tr>
<tr><td>3 - Computer narrows alternatives down to few</td></tr>
<tr><td>2 - Computer offers a complete set of decision alternatives</td><td>SC - System decision supported function</td><td>AL1 - On-ship decision support</td></tr>
<tr><td>1 - Computer offers no assistance, human is in charge of all decisions and actions</td><td>4 - Ship with automated process and decision support: Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated</td><td>M - Manually operated function</td><td>AL0 - Manual- no autonomous function</td></tr>
</table>

Undoubtedly, when the ship is at the highest level of autonomy – *"The computer does everything autonomously, ignores human"* - the said ship will be crewless, and the main responsibility for the safety at sea falls on the competence and duties of the personnel working ashore. Therefore, it is important to clearly define their functions, standards of competence, and concerns for their education and training as implications for changes in MET. It has to be noted that the definition of the levels of autonomy describing human involvement in decision-taking processes and the presence of people on-board is important not only for MET, but also for future demands on maritime and shore-based professionals operating MASS.

3. Benefits and Risks of Maritime Autonomous Surface Ships Introduction to Shipping

The benefits of MASS have been presented in several papers. They can be divided into three groups [14; 13]:

- Related to safety as eliminating human error - they might reduce maritime accidents caused by fatigue and alcohol abuse, poor judgment, stress, inadequate staffing, poor living conditions, etc. [13];
- Financial benefits are highlighted, since MASS reduces operational manning costs, fuel consumption, increase operational times, maritime shipping capacity, etc. [19];
- Social impact is emphasized, because it is envisaged that MASS compensates for a shortage of seafarers,

improves the lifestyles of seafarers, etc. [19].

However, according to Komianos [13], it is difficult to calculate the overall financial benefits on a large scale, since some costs will be reduced, including the costs for the crew, fuel consumption, etc., however, additional costs for land-based services, such as the control center, equipment, maintenance crews in port expenses, etc., will appear, and the shore personnel wages will increase. Moreover, the implementation of new legal regulations and the introduction of changes to MET also imply costs.

As noted before, MASS have the potential to reduce human-based errors, however, simultaneously new types of risk will arise and will have to be addressed. They can be divided into several sectors, including, e.g., ship safety, cargo safety, maritime traffic safety, environmental safety, and occupational safety and security [20]. According to the results of AAWA project, due to the nature of the shipping industry, the transition from the current conventional concepts on marine transportation to a stage dominated by autonomous, unmanned ships is expected to take place slowly and has been claimed to require at least a couple of decades. During that period, there will be a mixture of vessels with different levels of autonomy operating at sea. In the worst case, this may lead to unexpected behaviour of some systems, hazards, and, consequently, risks [20]. The most important issue is that the impact of MASS on safety has not yet been studied sufficiently extensively and deeply. The gaps in such a kind of information are being to some extent filled by a performing number of industry initiatives and projects, with over 20 of them being recently implemented or in progression [3, 17], e.g., AAWA [20], NAVSAC, performed by USCG Navigation Safety Advisory Counsel; MASRWG – by UK Maritime Autonomous Systems Regulation Working Group); SARUMS – by EU Safety and Regulations for European Unmanned Maritime Systems, etc.

Researchers identified the following safety-related risks: the system, human-system interactions, software, network and communications, cyber security, risk assessment and response to emergencies due to the lack of trained crew members on-board and a decreased crew size, firefighting and damage control, liability, insurance, quality assurance, higher vulnerability to hijacking or piracy, etc. [13, 14, 20]. The challenges dealing with safety can be divided into legal [11], commercial [24], technical [19], and human-factor related ones [25].

Some benefits and challenges of MASS introduction to shipping from Human factor, commercial and social impact points of view are presented in the Table 2.

Table 2

Benefits and challenges of MASS introduction to shipping

Benefits	Challenges
Human factor	
Elimination of human error by reducing maritime accidents caused by fatigue and alcohol abuse, poor judgment, stress, inadequate staffing, poor living conditions, etc.	Uncertainty in human-technology interaction, no clear definition of functions on-board and ashore, no clear standards of competence of personnel: knowledge and skills
Commercial	
Reduction of operational manning costs, fuel consumption, increase of operational times and maritime shipping capacity	More investments needed in land-based services, technologies, implementation of legal acts, changes in MET
Social impact	
MASS compensates for a shortage of seafarers, improves the lifestyles of seafarers	Uncertainty in changes in labour market demand-supply of needed personnel: maritime and shore-based professionals.

Some of investigations to overcome the challenges identified in literature needed to be done in order to be implemented in MET:

1. According to Komianos [13], since MASS consist of several interconnected systems and will be run by remote land-based or offshore services. Safety in the era of rapid evolution of technology with hardly predicted consequences cannot be assured based on the knowledge gained from earlier systems. Functioning of all the different systems (a system of systems) on board and ashore, their design and installation, integration of innovative technologies into the design and operation of the ships, their relations, management, and regulation, has to be investigated thoroughly.

2. The human-technology interactions with the growing digitalization and automation due to rapid technological advancements creating unprecedented challenges and gaps need multidisciplinary research in: 1) integration of systems with the cognitive capabilities of the users; 2) coordination between humans and machines; 3) influence of fast introduction of technology on crew's traditional learning experience; 4) comparison of pace of technology introduction on board and the regulatory development [15].

3. Investigation of legal issues is needed having in mind, that: 1) the existing international regulatory framework (safety, security, and environmental protection conventions and regulations) does not cover MASS operation [10]; 2) as identified through research, over 50 IMO legal documents related to autonomous vessels need urgent revision (e.g., [14, 13]; 3) the number of regulatory barriers increases as the autonomy level is increased [19]; and 4) regulatory approaches at the national, regional (e.g., EU), and international (IMO) levels will take not less than 6 years

[19].

4. Research in human factor in needed, because: new skills will be essential for the effective operation of new technologies in an increasingly developing transport system, and the identification of these skills at an early stage is the key to success in the necessary adaptation process in a country or a transport mode [20]; the importance of requalification and retraining of workers will be the key to the successful transition of tasks to the age of automation and technology; thus, e.g., in the maritime sector, remotely controlled automated ships could lead to the elimination of certain jobs on ships, although this is not likely to happen before 2040 [25].

Comprehensive investigation and identification of possible risks for safety at sea contributes to the definition of standards of competence, which have to be split up and described as particular knowledge, skills, and attitudes of the personnel on-board and ashore according to their functions. This information has to be taken into account in the drafting of a legal framework and the adjusting of MET to the changes in the labour market while meeting new technological changes.

4. The Need for the Legal Framework Revision

According to IMO, the goal of sustainable MET is properly trained and educated seafarers with emphasis on refresher training and education upgrades [7]. The role of proper MET in achieving the main objectives of the maritime community – to make oceans cleaner and ships safer – is crucial. As emphasised by IMO Secretary-General K. Sekimizu, "the shipping industry depends on competent, well-trained seafarers to ensure safety of life at sea, maritime security, efficiency of navigation and protection and preservation of the marine environment" [9]. This process is continuous and dynamic; it depends on a number of factors, including the technological, social, cultural, political, and economic background of the country and depending on the international (IMO), regional (e. g., EU) and national legislations.

An updated training regime of STCW will be needed before any further steps are made to allow changes in labor market, foe example, crew reductions. Crew members need to be trained in any case to fulfill all the functional tasks and capabilities left for the crew in autonomous ships [20]. The importance of requalification and retraining of workers will be the key to successful transition of tasks to this age of automation and technology: thus, e.g., in the maritime sector, remotely controlled automated ships could result in elimination of certain jobs on ships, although this is not likely to happen before 2040 [25].

The requirements for training and certification of seafarers serving on board sea-going ships are provided in the STCW Convention, and they have been almost universal (over 160 states have ratified the STCW covering 99% of world tonnage), therefore it is logical to extend its coverage by creating a sister convention (such as e.g. STCW-F) that caters to the crewless nature of autonomous ships [1, 20]. According to Rolls-Royce [20], it is probably safe to apply (at least) the STCW and other national requirements analogically (as if person were on board the ship). If and when unmanned ship operations are considered as requiring particular training, relevant provisions would probably have to be amended to accommodate the new requirements for the operation of unmanned or largely automated ships. Similar types of requirements as in STCW may eventually have to be developed for persons operating ships remotely.

The changes in the legal framework regulating MASS operations have to be taken into consideration while adjusting MET. For the implementation of MET at the national level, of special importance are the requirements for the standards of the personnel competence related to the MASS operations on-board and ashore which have to be defined in the revised (or newly developed) STCW convention.

5. Considerations for the Training of Personnel Dealing with MASS Operations

MASS are more likely to alter jobs rather than to eliminate them [22] and this, combined with the creation of new types of jobs, will lead to the definition of training and reskilling needs and changes in MET. The demand for seafarers will be reduced, however, the need for the new concept-oriented crew who necessitate heavy training programs will be increased [8], and the workforce in shipping will need training and reskilling [25]. However, more investigations have to be done in this respect as well.

A proactive approach to accidents has to be taken into consideration in education and training, based on multidisciplinary/interdisciplinary research involving intersections of computer science, social science, engineering design, and psychology [15] and involving different parties, such as policy makers, business representatives, educators, etc. As noted in Lloyd's Register [14], special training will be needed in: relevant information technology knowledge, knowledge of conventions and regulations, customized specialized training, engineering technology training, logical and critical thinking training, and leadership training.

The literature review revealed some considerations related to the skills and competences of personnel involved in MASS operations, which need more research:

- Seagoing experience: will ashore personnel need experience in seagoing to better understand the consequences of their decisions [8]; do persons working in the Shore Control Centre (SCC) require to have a sufficient amount of experience related to similar ships, i.e. with regard to dimensions, deadweight, and power and their relations; should the requirements of competence, based on hands-on training in sea service and simulators, be higher for the supervisors in the SCCs [20].
- Dividing engineering functions into two parts: 1) automatic support (AS): operation of ship by automation

systems and personnel in combination, 2) automatic operation (AO): without the need for personnel intervention [5].

- Communication functions: 1) of unmanned ships with conventional ships; 2) communication in ports with different entities due to the shipping traffic in ports [8]. Communication between the ship and shore needs to be bidirectional, accurate, scalable, and supported by multiple systems creating redundancy and minimizing risk as well as having sufficient communication link capacity for the ship sensor monitoring and remote control and the ability to monitor equipment in service in real time detecting [20].
- Watchkeeping: the responsibilities for safe watchkeeping involve several persons, including the company, the master, the chef engineer officers, and the whole watchkeeping personnel, whose responsibility is to ensure "that a safe continuous watch or watches appropriate to the prevailing requirements on lookout, bridge, engine room, radio watches and conditions are maintained on all seagoing ships at all times" [20].
- Skills in safety critical and challenging situations: well-designed simulator training would be needed for practicing challenging safety critical situations, but this is problematic, since, at least in principle, the simulator cannot present unimaginable surprising situations. Generation of challenging situations demands creativity and understanding of maritime accidents from the developers of training [20].
- "Digitalization" skills and combination of them with maritime skills: the tasks of seafarers will change to more digital ones, especially in operation monitoring and system management, and also in less operational work. Skills can be divided into three domains: 1) data fluency and the ability to interpret and analyze large amounts of data; 2) digital operation of equipment such as ships, cranes and winches; and 3) software engineering of fundamental programs and systems Education and training will need to be adapted to equip seafarers with the new skills required [25].
- Port operations: in order to understand the skills required in major areas of port operations in the context of automation, these can be categorized as follows: terminal operation, including waterway ship scheduling service; foreland transport service, including railway and road transport service connected to the port; hinterland transport service, including including railway and road transport service connected to the port; and warehouses related to the port [25].
- Personnel operating ships from a remote location need the combination of maritime and technology skills in operations: planning of voyage, mooring, unmooring, operations at open sea, port approach and docking, etc. [20].

The needs for special training in information technology knowledge, the knowledge of conventions and regulations, customized specialized training, engineering technology training, logical and critical thinking training, leadership training, and seagoing experience have to be taken into account while adjusting MET to prepare the labour market for the introduction of MASS in shipping.

6. Continuous Upgrade of Qualification of Trainers/Instructors Needs Attention

In order to make MET a reliable tool the issue of competence of trainers/instructors have to be considered while implementing changes. After conducting “Train the Trainers” and “Train the Assessors” courses for more than 15 years for Lithuanian, Turkish, Ukrainian trainers, it was noticed, that trainers need continuous upgrade of their qualification in education sciences, especially in teaching/learning and assessment methodology. It was noticed, that teachers/instructors need better understanding of some ideas of education science:

- understanding and application of three domains or learnings (cognitive, psychomotor and affective);
- proper understanding of importance affective domain in education and training;
- ability to formulate learning objectives depending on the selected domain of learning and the levels of competence in the selected domain;
- ability to select teaching/learning means and methods, assessment and evaluation methods depending on the formulated learning objective according to the levels of competence in the selected domain of learning (e.g. the teaching and assessment methods to reach learning objective in cognitive and psychomotor domain have to be different);
- be creative to engage learners in learning activities by using different teaching/learning methods, promoting higher levels of learning domains (e.g., synthesis, evaluation in cognitive domain);
- use new investigations of neuroscience, psychology, education sciences to improve education and training, e.g. neuroscience for learning [2], brain based ergonomics [4, 18, 26], using algorithms in education and training process in development of study books can save financial and human resources, effectively organize group work and simulations. For example, the practical courses in the field of emergency medicine provided by Crisis Research Center in Lithuanian University of Health Sciences based on application of algorithms in education and training process have great success in preparation of specialists for emergency situation.
- transformational role of education and training, in which people are engaged in a new way of seeing, thinking, learning and working [23];
- involvement in educational research together with specialists in education sciences, such as for example, action research, on continuous basis.

The issue related to the continuous upgrade of competence of teachers/instructors in education sciences need special attention in order to make MET a successful toll in implementing changes and new challenges in shipping.

7. The Need for a Comprehensive Research Project Involving Different Actors

In order to be prepared to meet the challenges of technological changes in the shipping industry, a number of initiatives related to the regulatory framework, safe operations of MASS, and technology developments [17] have already been taken. However, not much has so far been done with respect to MET, which has to be adjusted to the needs of the labor market based on a constant dialogue and close monitoring of the developing technologies and the levels of automation [25]. Having in mind, that training and education require years from the initial idea to a fully developed and introduced program constantly supplying specialists with the required skills and knowledge, an interdisciplinary comprehensive research project, involving different actors from the shipping industry and aiming to facilitate the understanding of potential impacts and opportunities for maritime transportation, preparing appropriate responses for industry partners, and identifying appropriate MET-building needs for workers in the transport chain, is immediately needed. The following topics have to be included in the research:

1.Identification of the functions of crew onboard and personnel ashore according to the levels of autonomy of MASS and the foreseen risks and challenges.

2.Description of the knowledge, skills, attitudes, and standards of competence according to each identified function.

3.Strategy (Road map) for the implementation of international regulations at the regional and national levels, including the development of model courses for MASS operators.

4.Practical recommendations and measures of MET adjustment in order to implement changes.

8. Conclusions

By summing up, it can be mentioned that autonomous shipping is possible from a technological perspective; the benefits of autonomous shipping has been recognized for different actors in the maritime industry from safety, financial and social perspective, even issues regarding the regulatory environment, appear to be solvable [20]. However, at same time new types of challenges from legal, commercial, technological and human factor perspectives will appear. The challenges and risks of introduction MASS to shipping can be reduced by proper MET, which has to take into consideration the following ideas: a proactive approach has to be used in adjusting MET; the regulatory framework establishing the requirements for personnel dealing with MASS operations has to be established and implemented at the international, regional, and national levels; the continuous upgrade of competence of teachers/instructors in education sciences need special attention; an interdisciplinary comprehensive research project involving different actors from the shipping industry and aiming to facilitate the understanding of potential impacts and opportunities for maritime transportation, to prepare appropriate responses for industry partners, and to identify appropriate MET-building needs for workers in the transport chain is immediately needed.

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Quality of Service in Transport Systems: Wireless Communications Under Weather-Based Disruptions

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Abstract

The current paper gives the review of wireless communications used in transport systems and offers the approach to control the quality of service (QoS) under weather-based disruptions in transport systems. The introduction – shows the actuality of the current topic. Currently, the most relevant form of communication and data transferring in transport systems is wireless. Therefore, to ensure the proper level of service and security in transport systems, it is necessary to ensure uninterrupted communication in all weather conditions. The above is due to the relevance of this article. The goal of the research also is defined here - the aim of this work is to review the wireless technologies used in transport systems and offer solutions to improve the quality of service when using wireless technologies in all weather conditions. Any information processes in a particular system are associated with the transfer of information between objects or subjects of information interaction. Therefore, it is actually also for transport systems. Wireless networks used in transport systems are classified here according to the classification of the International Telecommunication Union (ITU). Among individual sub-technologies, there are varieties of solutions that differ from each other according to different criteria. As a result, the key ones are selected here. Given the negative impact of weather on wireless, it is obvious that in order to increase QoS, you should try to maximize the uninterrupted availability of all system functions, regardless of the availability of each of the communication channels at any given time. This can be achieved by using duplicating various communication channels, constant monitoring of the system and instant response to malfunctions by eliminating them. A short review of two practical examples is also given in the article. The approach - how to increase the quality of service in the transport system is offered.
KEY WORDS: *QoS, transport system, communications, wireless, weather-based disruptions, quality of service*

1. Introduction

Usually, when we talk about the quality of service in transport, we do it from the passengers' point of view, and then it is significant to know how to count passengers in the transport system [14]. It is significant, for example, for planning the effective schedule of public transport. In the other hand, in the modern sustainable public transport system, it is significant to talk also about the quality of service of wireless communications. The effective functioning of modern vehicles is impossible without widespread use of the entire spectrum of information technologies [9]. The information flows between the objects of the transport system form both feedback that carries information about the current state of motor vehicles, as well as direct communication, which ensures the transfer of control actions. The quality and timeliness of the information coming in the forward and reverse directions depends on the quality of management of individual objects of the transport system, as well as the possibility of its coordinated functioning in order to maximize the satisfaction of the company's requests for the carriage of goods and passengers. The technologies used at all stages of the receipt, storage, processing and transmission of information should fully ensure the timeliness and high quality of information support when making management decisions at all levels of the transport system. A transport system is a combination of vehicles and infrastructure. Vehicles are designed to perform useful work on the transport of passengers or goods, depending on what there is a division into passenger and freight. Vehicles are a moving element of the transport system; their position in location, in the general case, varies with time. Infrastructure forms the transport network through which traffic is carried out; its components are rigidly fixed in location. The main elements of the transport network are nodes between which transportation processes are carried out, and segments through which traffic flows directly. Each fragment of this network is characterized by a certain capacity, the closer the value of the traffic flow to it, the higher the efficiency of the transport system as a whole. Since traffic flows are characterized by significant variability in time, their timely coordination is an indispensable condition for the efficiency of the transportation process; Here one of the leading roles is played by their quality information support. In addition to the physical structure of the transport system, which is formed by the totality of the physical objects that make up the system, it is also necessary to take into account the functional structure determined by the main goals and tasks that are constantly being solved during its functioning. From this point of view, the transport system can be represented as a combination of two interconnected subsystems: the control one, designed for setting tasks and monitoring their implementation, and the production one, carrying out transport work. Structural detailing of each subsystem is performed in accordance with the functions performed by it. The control part of the system is divided into subsystems of the following level: collection and processing of information, analysis and development of draft decisions, personnel

work, accounting and financial accounting. The production part includes the technological (which performs the main transport functions), which provides (solves the tasks of supporting transport processes) and restores (supports the operability of technical elements) subsystems. Accordingly, it is necessary to constantly maintain communication between all elements of the system. Currently, the most relevant form of communication and data transfer is wireless. Therefore, to ensure the proper level of service and security in transport systems, it is necessary to ensure uninterrupted communication in all weather conditions. The above is due to the relevance of this article.

The aim of this work is to review the wireless technologies used in transport systems and offer solutions to improve the quality of service when using wireless technologies in all weather conditions.

2. Wireless Information and Communication Technologies in Transport Systems

From [9] it follows that any information processes in a particular system are associated with the transfer of information between objects or subjects of information interaction. In the case when the data transfer occurs not between the internal elements of a single computing system, but using a transmission medium connecting two or more independent devices, it is called telecommunication and is carried out on the basis of the use of appropriate telecommunication technologies. Telecommunication interaction presupposes a communication system, the basic element of which is a communication channel; The interaction structure is shown in Fig. 1. Signals are used to transmit information over the communication channel. In general, a signal is understood as a change in time of a physical quantity, and the type (character, law) of such a change reflects some information; the transmission of this information encoded in the signal is the purpose of using the signal. As a means of transmitting information over a communication line, electromagnetic waves are used, which can be transmitted by wire, or wirelessly, when an antenna is a mandatory element of the receiver and transmitter. The effectiveness of the antenna depends on the frequency of the wave that it emits or receives; its dimensions should be comparable to wavelengths. Low frequencies require unacceptably large antenna sizes; therefore, the range of practically used frequencies is limited to several hundred kilohertz.

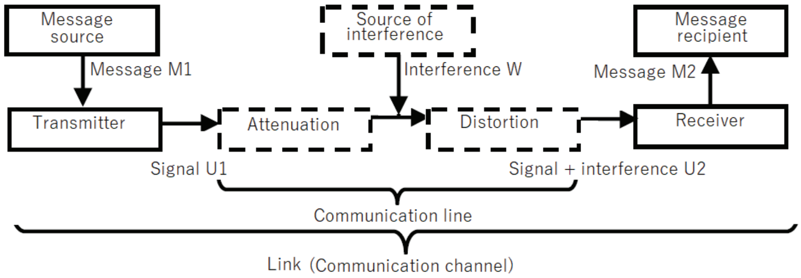

Fig. 1 The main elements of telecommunication interaction (adopted from [9])

It is understandable, that signals can be regular and irregular. A regular signal is considered as a carrier of useful information; the number of forms that he can take is strictly limited. In the transmitter and receiver there are means for extracting information from a signal of any provided (permitted) form, as well as for the inverse transformation - creating a signal that carries certain information. Irregular signals can be of any shape, they do not carry useful information and are sources of interference or disturbance. When transmitting useful information, irregular signals are superimposed on the information-carrying signals and distort them. The mathematical description of the signal is a function of a varying quantity versus time. If the values of this function are repeated after a certain period of time T, then the signal described by it is called periodic; for such a signal, condition (1) holds [9]:

$$f(t) = f(t+T). \tag{1}$$

The simplest form of a periodic signal is the harmonic signal described by the Eq. (2):

$$f(t) = A \cdot \sin(\omega t + \varphi_0), \tag{2}$$

for which it is enough to know only 3 parameters (A, ω and φ_0) in order to determine the signal value at any value of t. Therefore, when transmitting such a signal over a communication channel, there is no need to describe the set of $f(t)$ values throughout the signal duration $t1 \le t \le t2$. It is enough to transfer only the three above parameters, and $f(t)$ for any t will be easily restored on the receiving side. A non-periodic signal can take almost any shape; its use in the information transmission system is complicated by the need for a detailed description of the waveform (function $f(t)$ over a certain range of t). Therefore, non-periodic signals are usually represented as the sum of several harmonic signals, the transmission of which is as simple as possible [9]. Therefore, if it is possible to formalize signals, then it is possible to monitor them using adequate control mechanisms and react to failures as fast as possible, to guarantee higher level of quality of service in transport systems.

According to [11], wireless communication technologies, a subclass of information technologies, are used to

transmit information between two or more points at a distance, without requiring wired communication. Radio waves of various ranges, infrared, optical or laser radiation act as information carrier in such networks. So, the sub-technologies of wireless communication are communication networks, on the basis of which wireless communication is built. Wireless networks used in transport systems are subdivided according to range and are classified below according to the classification of the International Telecommunication Union (ITU) as: WAN (Wide Area Network). A global communications network covering large areas and including a large number of communication nodes; WLAN (Wireless Local Area Communication). Communication network technologies designed to provide wireless coverage and access within local spaces; PAN (Personal Area Network). Technologies of communication networks built "around" a person, that is, connecting devices used by a person as part of his activity; MAN (Metropolitan Area Network). Communication networks used to provide coverage within the city; BAN (Body Area Network). Technologies of wireless body computer networks, as a particular example of WBAN - Wireless Body Area Networks - technologies of connects independent nodes (e.g. sensors and actuators) that are situated in the clothes, on the body or under the skin. In the process of developing communication networks and related technologies, networks such as PAN absorbed BAN, thereby becoming a component of wireless personal communication. Due to this transformation, only PANs are considered in the further analysis. WANs, on the contrary, require decomposition into several elements - LPWAN and satellite communications. So, in the framework of the focused development of technology with the aim of segmenting technological tasks and further priorities, the following network classes were also identified: LPWAN (NB-IoT, XNB, NB-Fi). Technologies for energy-efficient long-range networks aimed at ensuring the operation of devices in IoT solutions; Satellite communications technologies. Technologies for the transfer of communication between space and earth by using the antenna of a spacecraft as a repeater.

Thus, the list of end-to-end wireless technologies includes 5 sub-technologies: WAN (Wide Area Network); LPWAN (Low Power Wide Area Network); WLAN (Wireless Local Area Network); PAN (Personal Area Network); Satellite communications technology.

Among individual sub-technologies, there are a variety of solutions that differ from each other according to different criteria. As a result, the key ones are as follows: WAN 5G. The fifth generation of mobile communications, the next development stage after LTE and 3G. It is a set of technological solutions, including M-MIMO, centimeter / millimeter RF, D2D, virtualization of routing functions; WAN LTE. The direction of evolution of third-generation cellular networks (3G). LTE includes the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and the Evolved Packet Core (EPC); WLAN Li-Fi. Wireless technology, similar in principle to Wi-Fi, but using the visible spectrum (light) as a channel for transmitting information; WLAN Wi-Fi. The generally accepted name for a family of technologies that use an unlicensed frequency spectrum to provide broadband wireless access in a local area; PAN RFID. Automatic identification and data acquisition technology that uses electromagnetic or inductive coupling via radio waves; STS Satellite Broadband. Satellite communications technology implemented on the basis of spacecraft in geostationary orbit, as a rule, using VSAT technology; STS Satellite Internet of Things. Satellite communications technology implemented on the basis of spacecraft in the geostationary orbit and spacecraft constellations in low orbits designed for mobile-satellite service systems; STS Satellite personal communication. Satellite networks for personal telephony and data transmission using geostationary or low-orbit satellites operating in the ranges of the mobile-satellite service, using hands-on type equipment for subscribers.

Sub-technologies are arranged in order - the highest priority on the top, the lower priority on the lower. So, the most significant technology is WAN, within which 5G stands out as a solution, the implementation of which forms 70% of the total economic effect of wireless technologies. A number of other "end-to-end" digital technologies to some extent depend on the development of the fifth generation of cellular mobile communications, which will provide high bandwidth, ultra-low latency on the network and other critical characteristics. Existing 4G networks do not make it possible to provide new subscribers with the need for innovative mobile services. At the same time, operators were faced with insufficient flexibility of communication networks, an increase in their complexity and an increase in the cost of their operation. 5G / IMT-2020 technologies, which make it possible to mitigate these shortcomings, are a natural stage in the development of mobile communication networks. The next priority sub-technology is LPWAN, since sub-technology is the basis for ensuring the operation of devices in IoT solutions, thereby acting as a driver for the development of industrial Internet technology. An additional advantage of the technology is the ability to work in both licensed and unlicensed communication ranges. The key solution in the licensed range is NB-IoT, in the unlicensed one - LoraWAN, Sigfox. There are also regional technologies of the unlicensed range - XNB, NB-Fi. WLAN, in turn, is a lower priority sub-technology, however, the Wi-Fi 6 standard is currently under active development. In this regard, it is necessary to pay attention to the development of software for Wi-Fi of the new standard. Li-Fi-based solutions are safe (light is limited by the walls of the room, while the radio frequency signal has a much wider coverage and can be intercepted), cheap to implement and able to work in special conditions (does not interfere with radio signals, there is the possibility of working under water). At the same time, technology development is required in terms of software and hardware development. PAN sub-technologies (RFID) can be considered quite mature, only further development of these technologies is required.

Obviously, it is important not only the continuous development of existing data exchange technologies, but also the development of new ones, as well as quality control of the service within the framework of existing solutions. A systematic approach to monitoring the quality of the data exchange service can help to increase the level of service quality, which will have a beneficial effect on the safety of the transport system and its functioning.

3. How to Increase QoS in Transport Systems

There are many discussions have been made in the frame of COST CA15127 Action "Resilient Communication Services Protecting End-user Applications from Disaster-based Failures" (RECODIS) [1] about wireless communications under weather-based disruptions. Given the negative impact of weather on wireless, it is obvious that in order to increase QoS, you should try to maximize the uninterrupted availability of all system functions, regardless of the availability of each of the communication channels at any given time. This can be achieved by using duplicating various communication channels, constant monitoring of the system and instant response to malfunctions by eliminating them.

Thanks to [1], supported by [7], in upcoming book chapter [8] it is given, that in accordance with the ITU-T Rec. E.800 [2], Quality of Service (QoS) is defined as totality of characteristics of a telecommunications service, that bear on its ability to satisfy stated and implied needs of the user of the service. The QoS can be characterized by any QoS variable, e.g. delay, jitter, packet loss, etc., which is perceivable by a user. On the other hand, the ITU-T Rec. P.10 /G.100 [3] defines Quality of Experience (QoE) as follows the degree of delight or annoyance of the user of an application or service. Minhas et.al. [4] described Quality of Delivery (QoD) as the quality characteristics of data transmission process on the transport and application layers. Quality of Protection (QoP) [5] gives us an ability to specifically measure and describe a security of the telecommunication systems or services. A characterization of the telecommunications network, system or service reliability can be done by Quality of Resilience (QoR) metrics. Generally, the QoR is a guarantee of a recovery after a failure occurrence. Therefore, it means, that the QoR also specifies a probability to have an available network, system or service. In this case, the QoR [6] includes variables from the QoS, QoD, QoE and QoP and can be expressed by such metrics as availability, Mean Time to Repair (MTR), Mean Time to Recover (MTR), Mean Time between Failures (MTF), etc.

3.1. An Example. Quality of Service in Public Transport

For example, in paper [10] the evaluation methodology applied for the purpose of detecting the impact of Public Transport priority system on the Public Transport Quality of Service is elaborated. Authors define a set of evaluation indicators which are used for the decomposition of Public Transport vehicle operation time into different segments. The operation time decomposition enables the identification of different background data impacts on the Public Transport system performances. In addition, different data collection methods are described and evaluated: manual time recording, GPS (Global Positioning System) vehicle tracking, PDA computer system and manual video data processing. Each method is set against several criteria and comparative analysis is carried out.

3.2. An Example. Quality of Service with Remote Monitoring and Control of the Vehicle Route

A good example is given in [9] - when remotely monitoring and controlling a vehicle's route of movement, it requires not only its automatic identification, but also regular location determination in any coordinate system. To solve this problem, the vehicle is equipped with a set of sensors, which automatically, with a certain interval, record the motion parameters and based on them determine the current location (most often presented as the coordinates of the object), which is transmitted to the center for monitoring and control of movement. Parameters for determining the current location may be relative or absolute; often the vehicle is equipped with sensors to determine the parameters of both types. Relative parameters allow you to calculate the change in coordinates for a certain period of time; adding this change to the initial coordinates, get the current coordinates of the vehicle. In the process of calculation, an error inevitably accumulates, which increases with increasing distance traveled. For this reason, periodic synchronization is required: accurate determination of the current coordinates by any other methods, as a result of which the accumulated error is reset; after this, the calculation resumes, but with respect to the new initial coordinates. The determination of relative parameters, as a rule, is carried out by means of the moving object itself, without resorting to third-party information systems. Absolute parameters allow you to calculate the current coordinates directly and with constantly high accuracy, but require the establishment of communication with positioning systems external to the vehicle. The relative parameters in determining the current location are most often served by the distance traveled and the rotation angles, moreover, their synchronous determination is necessary, with very small time intervals between measurements. To determine the distance traveled, distance sensors are used, which are transmission and wheel. Electromagnetic transmission sensors generate a voltage proportional to the speed of rotation of the transmission element. Moreover, the relationship between the rotation speed and the generated voltage is not always linear, and in addition, at low speeds, the voltage spread can be unacceptably large. Hall sensors also belong to transmission, and are characterized by high accuracy, but require protection from temperature and magnetic fields, and also require accurate installation and the absence of displacements during operation; these requirements, combined with the inaccessibility of transmission sensors for maintenance and regulation, limit their scope. Wheel sensors are the easiest to install and maintain; rotation sensors generate voltage linearly with the wheel speed, and pulse sensors generate a single pulse for each full revolution of the wheel (the distance traveled is determined by the number of recorded pulses). Rotation angles are determined using gyroscopes, which can have different principles of action; on motor vehicles, vibration-type gyroscopes are most common. Absolute positional parameters are usually the coordinates obtained from global positioning systems. Currently available GPS (Global Positioning System) and GLONASS. The basic principle in determining the current

location is to compare the time of reception of signals from several satellites operating in the corresponding system and generating constant and synchronized signals with each other. Based on the analysis of the time between receiving a signal from different satellites, the position of which is known, it is possible to determine at which point on the earth's surface the intersection of rays occurred - the trajectories of signals; this is equivalent to determining the coordinates of a given point. The determination of coordinates requires the presence of at least three satellites from the same system in the signal availability zone; with an increase in the number of satellites available, the accuracy of the obtained coordinates increases. Despite the convenience of using absolute positioning parameters, their determination can be fraught with temporary difficulties. Under adverse conditions (being in a tunnel or under dense foliage, low cloud cover, interference from particularly powerful magnetic storms), signals from satellites can come with significant distortion, up to its complete loss. Therefore, the most appropriate is the combination of relative and absolute parameters when determining the current position of the vehicle, which guarantees acceptable accuracy of its positioning in any conditions. This approach is implemented in integrated systems of current positioning, when the position is determined in two independent ways, based on motion and rotation sensors, as well as using a global positioning system, then the results are compared (usually based on a mathematical apparatus that implements a Kalman filter), and then finally corrected coordinates are calculated. If the use of sensors on the vehicle for any reason is not possible, a differentiated current positioning system can be applied, which takes into account signals from both satellites and reference stations, the system of which must be present in the traffic area. Each such reference station, which has known and unchanged (unlike satellites) coordinates, is used to refine and adjust the coordinates defined in the global positioning system.

3.3. The approach. Increasing Quality of Service in Transport Systems

Thus, it becomes clear that the increasing quality of service in the transport system is possible by maximizing the uninterrupted availability of all system functions, regardless of the availability of each of the communication channels at any given time. This can be achieved by using duplicating various communication channels, constant monitoring of the system and instant response to malfunctions by eliminating them. A systematic approach to solving this problem is obviously necessary. The transport system is defined as a dynamical system [13] with X and Y defined as input and output data/signals. Such kind of systems is changeable in time. Then the system can be described at different time moments and necessary parameters can be defined, also calculations continuously can be made for all periods. Such controls a dynamic process control. In the current case, it is the control of QoS in the transport system (Fig. 2). For dynamic systems, knowing the set of input parameters X_1 at time t_1, can develop such control C to time t_2 it would be an output parameters set Y_2, so we can make the technological/transport system regulation by the following condition.

$$S(t_1)\xrightarrow{C^1}S(t_2)\,. \tag{3}$$

Transport systems can by defined as large systems with many different situations during operation. Such kind of large systems analyze as systems under conditions of risk and uncertainty.

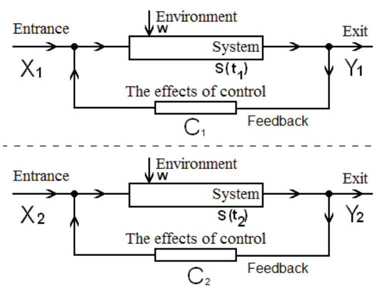

Fig. 2 Control of QoS in transport system

It is possible to characterize signals and impulses using a mathematical model: $s(t)$, $u(t)$, $f(t)$ ect. Then transport systems management organize with control signals. The function that describes the signals can be both - real and imaginary. If the signal described by some function of time, it is one-dimensional function. If the output signal characteristics with a number of time functions of the given sequence, then it is a multidimensional function (Fig. 3, A). The notion of transport systems suggests the idea that different elements are linked and interdependent, forming a system, "a combination of interacting elements organized to achieve one or more stated purposes" [12]. The structure of the functional scheme of the transport system is shown as (Fig. 3, B). According to control theory and system theory fundamentals, it is offered a scheme to global control of QoS and other criteria of the transport system (Fig. 3, C).

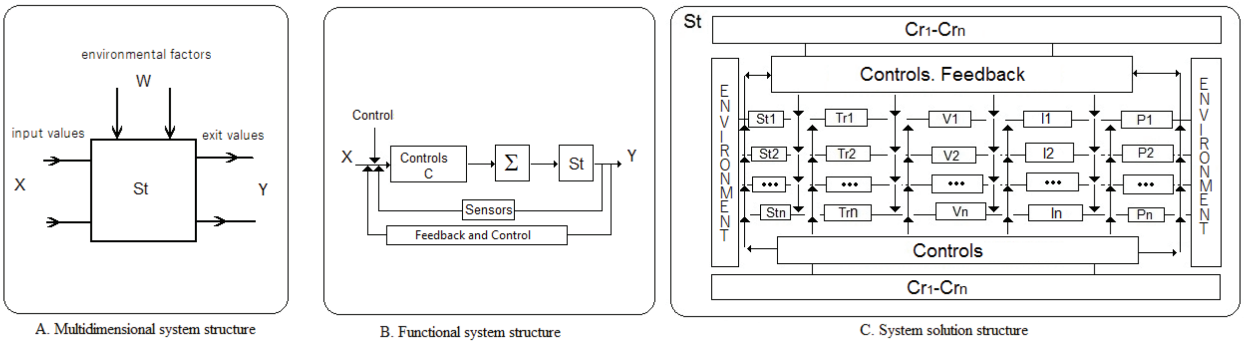

Fig. 3 System solution structure. Control of the QoS and other criteria of the transport system. {*St*} – transport system; {*St*1-*Stn*} ϵ *St* – subsystems in whole transport system including communication and data transferring subsystems; {*Tr*1-*Trn*} – kinds of public transport; {*V*1-*Vn*} – vehicles of public transport; {*I*1-*In*} – infrastructure objects in public transport system; {*P*1-*Pn*} – passengers; {*Cr*1-*Crn*} – transport system sustainable development criteria list: (environmental sustainability, safety, comfort level, QoS, economical aspects, influence of governance).

It will allow to plan more competently work of transport system using corresponding methods and algorithms of control.

4. Conclusions

This article is aimed at creating a holistic and systematic view of the information and communication processes taking place in the transport industry, offering the review of communication technologies and the approach to increase QoS of wireless communications under weather-based disruptions in transport systems. As a result, the organization and maintenance of information exchange with high quality become practically possible. At the same time, there are no universal solutions - the possession of information and communication technologies is only the basis for the development of specific engineering solutions that fully take into account the individual characteristics of a particular motor transport structure. At the same time, the basic principles that underlie certain information technologies, as well as the software and hardware that implement them are developing at an ever-accelerating pace. This requires continuous self-improvement, the ability to timely see the most promising information technologies, evaluate their benefits and be prepared in advance for their timely implementation in production. Further expansion and deepening of knowledge in these areas is achieved both by studying the software and hardware base of the future (quantum computers, nanotechnologies, intelligent and robotic systems, and so on), and by a more detailed analysis of transport systems and objects, in order to identify and optimization of information exchange processes taking place in them.

The goal of this research is reached by offering the system solution for keeping the transport system in a sustainable and safe position, improving the quality of service when using wireless technologies in all weather conditions.

Concluded, that controlling of transport system like large-scale dynamical system, gives the possibility for centralized control of QoS and all other criteria of the transport system for its sustainability.

The offered system solution is open for further researches on the whole and in each component in particular.

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Experimental Study of the Limit-Maximum Adhesion Coefficient

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Abstract

The article discusses the modernization of the Wheel-Rail full-scale bench stand for studying wheel-rail grip. The test bench is designed in a way that allows testing to take into account the effect of each separately acting factor, its value and their combination, which are observed under real operating conditions. To obtain quantitative characteristics of the adhesion influence from various surface contaminants, the authors developed a methodology for conducting experimental studies to determine the limit-maximum adhesion coefficient. The results obtained make it possible to predict the control of the change in the adhesion coefficient of the wheel and rail under various frictional contact conditions.
KEY WORDS: *railway transport, wheel-rail, adhesion coefficient, load, sand, abrasive material*

1. Introduction

Analysis of the creation of railway transport showed that the most expensive and problematic is the development and technical implementation of the crew of the locomotive, which largely determines the technical and economic efficiency of the traction vehicle [1-4]. At the same time, the assessment of this efficiency is contradictory, caused by the complex and ambiguous dependencies of the towing and hitching, braking and dynamic qualities of the locomotive in various operating conditions.

2. Research Results

To determine the experimental dependences of the wheel and rail adhesion coefficient on the factors such as the vertical load in the contact, the kinematics of the position of the wheel on the rail and the wheel and rail surface condition, the authors modernized the Wheel-rail full-scale stand, created at the department of railway, automobile transport and hoisting-and-transport machines of the Volodymyr Dahl East Ukrainian National University [5-7]. The authors have made and installed on the stand the device for changing the position of the wheel on the rail with varying vertical and horizontal loads in single-point and two-point contacting, while creating the possibility of changing the frictional state of the contacting surfaces of the full-scale wheel and rail, as well as the possibility of using various methods of cleaning surfaces and varying the temperature in tribological contact. The scheme and general view of the Wheel-rail full-scale stand are shown in Fig. 1 and Fig. 2.

The stand is designed in a way that allows testing to take into account the effect of each separately acting factor, its value and their combination, which are observed under real operating conditions.

The main parts of the stand are: full-scale wheel, rail section, frame, drive, loading system, braking system. The scheme “electric motor-flywheel-multiplier-torque converter-reducer” allows for relatively short drive power to achieve short-term powers sufficient to simulate skidding even at high wheel loads on the rail.

The stand includes a base *1* mounted on a foundation, a drive comprising an accelerating motor *2*, a flywheel *3*, a multiplier *4*, a torque converter *5*, an auxiliary brake 6 connected by a cardan *7* to a gear *8*. The latter is rigidly connected, via a clutch *9*, to the wheel axle *10* A wheel *10* with a semi-axis is installed in the axle box *11*, which is connected with the frame *12* of the stand. On the base *13* of the stand, the main support rollers *14* are installed, as well as two horizontal thrust rollers. The rail *15* is mounted on the support rollers *14* with the possibility of movement relative to the wheel *10*. In the upper part of the stand frame *12,* a loading system is installed, which includes a set of elastic elements *16* and a hydraulic cylinder *17* connected in series with it. The vertical load from the wheel *10* on the rail *15* is created by the hydraulic cylinder *17*, which transfers the force through the elastic elements *16* and axle box *11* to the wheel *10* [5].

The braking system consists of a main magnet-rail brake *18*, designed to create reactive braking force during simulating a traction mode, and an auxiliary drum brake *6* mounted on the drive shaft of the torque converter *5*, designed to control the drive.

It is known that the adhesion coefficient is influenced by a number of factors, the main of which in the operating conditions of locomotives, is the presence of various contaminants on the contacting surfaces of the wheels and rails,

the kinematics of the movement of the wheel along the rail, the presence of static and dynamic vertical and horizontal forces. To obtain quantitative characteristics of the adhesion from various surface contaminants, a methodology has been developed for experimental studies to determine the limit-maximum adhesion coefficient [8, 9].

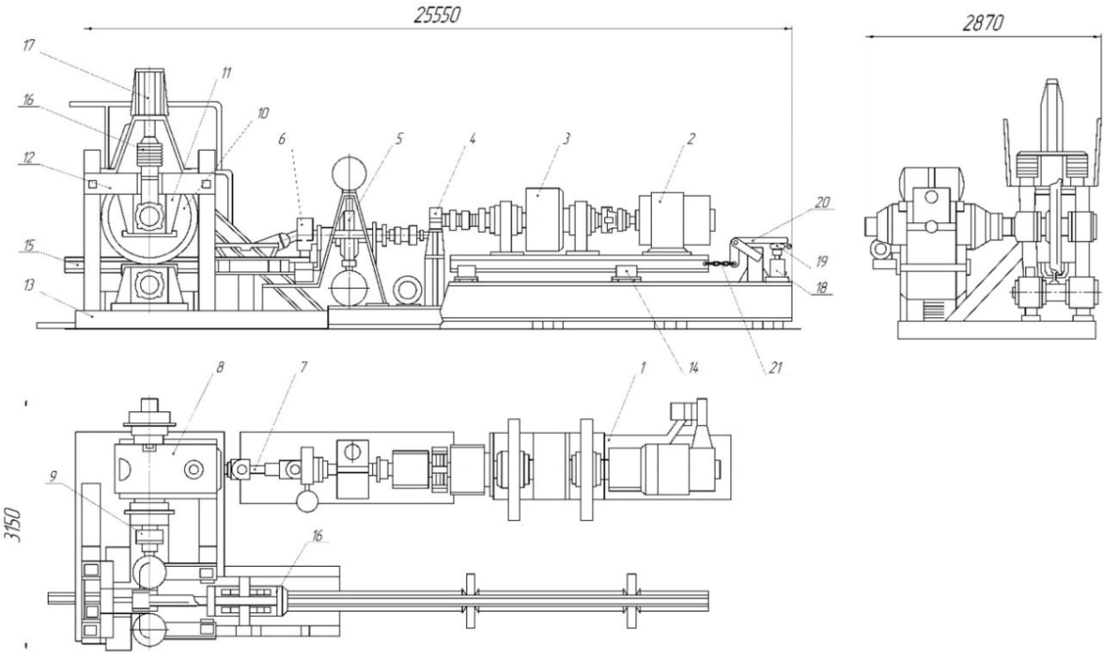

Fig. 1 The scheme of the Wheel-rail full-scale stand

Fig. 2 General view of the Wheel-Rail full-scale stand: *17* – hydraulic cylinder; *12* – frame; *11* – axle box; *15* – rail; *16* – set of elastic elements; *10* – wheel

The studies were carried out at the stand according to the method developed by the authors. The rail *15* on the support rollers *14* rolled up under a previously raised wheel *10*, which then fell on the head of the rail *15*. The wheel *10* was braked by jamming the axle shaft and loaded with a hydraulic cylinder *17*, creating a vertical load $P_{st} = 115$ kN .

The normal wheel effort on the rail was counted on the gauge scale *4* (maximum measured pressure of 25 MPa, accuracy class 2.0), which shows the oil pressure in the cylinder of the hydraulic jack. Recalculation of pressure gauge readings into load value P_{st} was completed according to the formula:

$$P_{st} = P_w + \frac{P_m \cdot \pi \cdot d^2}{4}, \tag{1}$$

where – $P_w = 1 \cdot 10^4\ N$ own weight of the wheel; P_m – pressure gauge readings, Pa; $d = 92 \cdot 10^3$ m – the inner diameter of the cylinder of the hydraulic jack.

After the vertical loading of the wheel *10* and its jamming, tangential loading was carried out using a specially designed tangential loading mechanism.

Tangential load F_T transferred from the jack *18*, installed on the base *1*, to the rail *15* through the dynamometer *19*, the bracket *20* and the chain *21*. The value of this load was determined by the deviation of the dial indicator (GOST

577-68, division value 0.01-10^{-3} m) with the following listing according to the calibration characteristic of the exemplary dynamometer 19 (DOSM-3-5 according to GOST 9500-84), which takes into account the gear ratio of the bracket *20*, which equals $i = 2{,}445$.

Since the wheel *10* is jammed and frictionally connected with the rail *15*, the force F_T tends to create a slip of the wheel *10* relative to the rail *15*. As a reaction to this force, an external, relative to the rail, adhesion force $F_{ad} = F_T$ occurs that prevents the wheel *10* from slipping relative to the surface of the rail *15*. When the tangential load F_T exceeds the adhesion limit, the wheel *10* is slipping in the contact. At the moment of slipping on the indicator scale installed on the dynamometer *19*, the force value F_T is fixed, which corresponds to the maximum adhesion force F_{ad}.

In this case, the limit-maximum coefficient of adhesion is determined according to the formula:

$$\psi = {F_{ad}}\big/{P_{st}} \,. \tag{2}$$

As the initial frictional states of the rail surface, the following states were used: the rail is clean and dry, covered with water, coated with diesel fuel and coated with waste oil [8, 9].

The experimental technique provided for three series of trips with the following sequence of actions:

1. The rail was brought into one of the listed friction kinematic and loading states, after that a series of measuring rolls of the friction machine were carried out;
2. Next, quartz sand was applied to the rail in an amount (≈ 0.1-0.2 kg/m^2), which corresponds to the standard sand supply of 1 kg/min with a standard sand system at a locomotive speed of 5 km/h and the characteristics of this modified frictional state were obtained [10];
3. After that, the rail was subjected to jet-abrasive impact (Fig. 3) using the most effective cleaning mode, and the frictional characteristics for various types of contaminants were determined again.

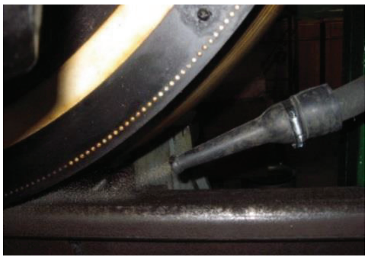

Fig. 3 Jet-abrasive impact on the rail surface

For studying the influence of the frictional state of the contact on the limit-maximum adhesion coefficient, the rail was divided into zones, on each of which a certain frictional state was studied. After each test, the surfaces of the wheels and the rail shifted relative to each other. To obtain reliable and objective data, each test was carried out repeatedly.

As a result of mathematical processing of the experimental data, the values of the limit-maximum coefficient of adhesion (Fig. 4) were obtained for each investigated frictional state of the rail, as well as when sand supply and the jet-abrasive impact on the rail surface (JAI).

For a rail covered with surface contaminants, it is representative that the contact conditions of the rail and wheel will deteriorate. Moreover, this deterioration depends on the type of pollution.

As can be seen from the diagram presented in Fig. 4, with JAI, the adhesion coefficient increases, which can be explained by improvement in the frictional state of the wheel-rail contact due to its cleaning, absorption, and removing of contaminants.

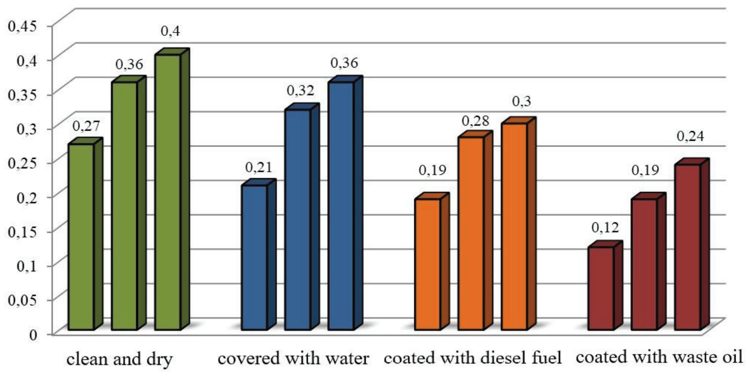

Fig. 4 The dependence of the limit-maximum adhesion coefficient on the frictional state of the rail: *1* – without sand; *2* – with sand supply; *3* – with JAI

Comparing the experimental results obtained for a rail covered with water, fuel and oil, we can see that the effect of cleaning a contaminated rail using a two-phase jet-abrasive stream is more effective than sand supply provided to a rail covered with contaminants.

According to the results of mathematical processing of the obtained experimental data, it was found that the difference in the adhesion coefficient between the sand supply and JAI on the fuel-covered rail is 6.6%. On a clean and dry rail, their difference is 10%, on a water-covered rail – 11.1%, on a oiled rail – 20.8%.

These results allow us to predict the change in the wheel to the rail adhesion coefficient under their various frictional contact conditions.

3. Conclusions

The Wheel-rail full-scale bench stand was modernized and methodology for conducting experimental studies to determine the limit-maximum adhesion coefficient from a different frictional state of the rail was developed.

In accordance with the purpose of the work, theoretical and experimental studies determined the limit-maximum adhesion coefficient, which indicates that on a clean and dry rail the difference between sand supply and jet-abrasive impact is 10%, on water-covered – 11.1%, on fuel-coated- 6.6%, on oiled rail – 20.8%.

Based on the results obtained, it can be concluded the effectiveness and practicability of using jet-abrasive impact on the contacting surfaces of the wheel and rail under different frictional conditions, as well as the opportunity to investigate a number of developed technical solutions in further studies.

Acknowledgement

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Mitigating of Negative Environmental Impact of Transport on the Level of Smaller Municipalities

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Abstract

In the European Union, up to 94 % of the transport energy needs are currently provided by fossil fuels. This is followed by the level of emissions on the EU territory and its negative impact on the lives of the population in areas with high traffic levels. It is important to realize that current EU cities provide housing to 72 % of the EU population, accounting for up to 85 % of GDP. The long-term forecast of the EU demography reveals that the population of cities increases to as much as 80 % of the total EU population. It is therefore desirable to eliminate the negative environmental factors of transport. The study focuses on the introduction of low-carbon mobility ensuring the elimination of the negative environmental impact applied to a particular city.
KEY WORDS: *Mobility, emissions, charging infrastructure, energy efficiency of a vehicle*

1. Introduction

One of the measures to ensure the transport in modern EU cities to meet the needs of the population in the field of mobility as well as the transport of services is the implementation of means of transport that will ensure the elimination of negative environmental impact during their life cycle. One of the measures is the use of low-carbon mobility in EU cities. The negative impact of the operation of transport activities on humans and the environment (and the elimination of these consequences) is determined as an external cost of transport. In urban traffic, it is mainly the air pollution, noise emissions, traffic collisions as well as capacity overcrowding. Therefore, another measure is the internalization of external costs, which means that they are objectified and attributed to those who cause them and are responsible for them. In this way, it is possible to motivate the polluter with a view to reduce the negative effects of their transport activities.

In the study, we focus on the introduction of the low-carbon mobility applied to a specific city, which is associated with city regulations and plans (Bulkeley, H. and Betsill, M. M., 2005, Campbell, T., 2012, McCann, E., 2011).

The theoretical impetus for an interest in urban mobility processes is related to several discussions on globalization, smart society and the reconfiguration of the state power (Brenner, N., 2004, Castells, M., 2000, Sassen, S., 2000, Swyngedouw, E., 2004, Jessop, Brenner, & Jones, 2008).

2. Emission Load of Transport within the Municipal Competences

2.1. Characteristics of the Municipality

The town of Senec was selected for the study (Figs. 1-2), which is a rapidly developing town, operating as a "satellite" of the capital city Bratislava. It currently has a population of almost 20,000 inhabitants. The city is located on flat terrain with a direct connection to the D1 motorway, which ensures quick transportation to the capital city and to the international airport. It also has a direct rail connection with the capital city.

According to statistical data, transport in the zone of the Bratislava region produces a higher level of pollution than e.g. heating. This is due to the high traffic load of the D1 motorway with an intensity of more than 80,000 vehicles per day. The D1 motorway also significantly affects traffic in the city, because in the case of congestion on the D1, the road through the city is a detour route for the D1.

Fig. 1 The territory of Senec

Fig. 2 Transport network of Senec and surroundings

2.2. Urban Public Transport

At present, the city public transport is provided by one bus line (during the day the individual connections have different routes - circuits - with a bus station and railway station nodes) using two vehicles with a transport capacity of 19 seats and 15 standing places, including space for prams or wheelchairs. Public transport is free, but uncompetitive in time. Therefore, in this region, a large proportion of transport is performed by individual transportation (e.g. delivery of children to schools) and public transport serves more or less to those who depend on it.

To determine the carbon footprint of conventional buses, it is necessary to identify input parameters such as:

- driving route, vehicle mileage, type of drive, consumption, number of trips, utilization, etc.

Calculations of daily mileages are based on available information on daily mileages (connections are 7 to 21 km long with travel times of 23 to 65 minutes). The total value of the annual mileage of public transport vehicles is 86,400 km. The costs for the annual operation of public transport in Senec are approximately at the level of 116,640 € at the mentioned annual mileage.

- fuel / energy consumption

The methodology for calculating the emission load is in accordance with the standard EN 16258 “Methodology for calculation and declaration of energy consumption and GHG emissions of transport services”, which was subsequently included in the Slovak standardization system.

- energy consumption and emissions production

When calculating the energy intensity of vehicle operation and related emissions, emissions that are linked to the processes associated with the production of fuels are also included, in addition to production, which means the production and distribution of fuel/energy).

To calculate the energy performance of the vehicle and the corresponding CO2e emissions, the “Well-to-wheel” approach is chosen, which includes energy consumption and emissions production (so-called total emissions) from the fuel / energy production process to consumption itself. This approach consists of two parts:

$$WtW = WtT + TtW\,, \qquad (1)$$

where *WtT* (Well-to-Tank) is the sum of the emission loads from the consumption of raw material/energy that was used in the production of fuel/energy, and *TtW* (Tank-to-Wheel) are emissions that are produced during the vehicle operation (local emissions).

In accordance with EN 16258, both *T-t-W* and *W-t-W* are given when calculating the vehicle's energy consumption. If the transport service consists of several parts, then it is necessary to perform a partial analysis in order to identify them. The result is the sum of the values of energy requirements corresponding with individually analyzed parts. The method of the energy consumption calculation is conditioned by the use of a conversion factor according to the following table (Table 1), indicating the considered density for diesel 0.832 kg / l and petrol 0.745 kg / l.

Table 1

Energy factors for diesel and petrol

Type of fuel	Energy factor			
	T-t-W (eT)		W-t-W (eW)	
	[MJ/kg]	[MJ/l]	[MJ/kg]	[MJ/l]
Diesel	43.1	35.9	51.3	42.7
Petrol	43,2	32,2	50,5	37,7

Subsequently, the equation for the calculation of energy consumption according to W-t-W is applied:

$$E_T = F \cdot e_T\,, \qquad (2)$$

where E_T is the energy consumption according to T-t-W [MJ], F is the fuel/energy consumption [l, kg, kWh], e_T is the energy factor T-t-W [MJ] following the equation:

$$E_W = F \cdot e_w , \tag{3}$$

where E_w is the energy consumption W-t-W [MJ] and e_w is the energy factor for W-t-W.

Greenhouse gas emissions for emission loads T-t-W and W-t-W are calculated using the emission factor for the fuel used (Table 2).

Table 2

Emission factors for diesel and petrol

Fuel type	Emission factor			
	T-t-W (eT)		W-t-W (eW)	
	[kg CO_2e/kg]	[kg CO_2e/l]	[kg CO_2e/kg]	[kg CO_2e/l]
Diesel	3.21	2.67	3.9	3.24
Petrol	3.25	2.42	3.86	2.88

When calculating the emission load, the following equation is used:

$$G_T = F \cdot g_T , \tag{4}$$

where G_T are the greenhouse gas emission CO_2, CO_2e for T-t-W [kg], g_T is the greenhouse gas emission factor CO_2e for T-t-W [kg], following the equations:

$$G_W = F \cdot g_W , \tag{5}$$

where G_W and CO_2, CO_2e for W-t-W [kg] and g_W is the greenhouse gas emission factor CO_2 for W-t-W [kg]. Before the calculation itself, recalculations of energy (Table 3) and emission factors were performed (Table 4).

Table 3

Recalculation of energy factors

Energy factors of fuels		
W-t-W	kWh/kg	kWh/l
diesel	14.25	11.86
T-t-W	kWh/kg	kWh/l
diesel	11.97	9.972

Table 4

Recalculation of emission factors

Emission factors of fuels		
W-t-W	kg CO_2/kg	kg CO_2/l
diesel	3.9	3.24
T-t-W	kg CO_2/kg	kg CO_2 /l
diesel	3.21	2.67

With declared fuel consumption of 12 liters per 100 km of minibus travel, the energy consumption value in cycle W-t-w is 142.33 kWh and 119.67 kWh in cycle T-t-w, with CO_{2e} emissions in cycle W-t-w being 38.88 kg and 32.04 kg considering the cycle T-t-w. The total annual value of CO_2e emissions when operating a minibus with an annual mileage of 86,400 km is 33.60 tons of CO2e, while the energy of a conventional vehicle consumes 119.67 kWh determined on the basis of the specific energy of the type of fuel used (Table 5).

If an equivalent electric vehicle is used for public transport, direct vehicle emissions can be completely eliminated. With an electricity consumption of 52.63 kWh / 100 km of driving, the indirect emissions are 19.47 kg CO_2e / 100 km driving, i.e. 16.82 tons of CO_2e / 86,400 km of driving (Table 5). The savings in indirect CO_2e emissions are 47.50% compared to a conventional public transport vehicle.

Table 5

Comparison of basic data of a conventional minibus and its electric version

Conventional version of city urban transport		
Annual mileage [km]	Energy consumption 100 km [kWh]	Direct emission CO_2e [kg/100 km]
86,400	119.67	32.04
Electric version of city urban transport		
Annual mileage [km]	Energy consumption 100 km [kWh]	Indirect emission CO_2e [kg/100 km]
86,400	52.63	19.47

2.3. Urban Vehicle Fleet

In the case of the analysis of the emission load from the operation of vehicles (data of 18 vehicles with their consumptions and annual drives were provided), calculations of direct emissions of these vehicles were performed analogously, reaching from 22.11 tons of CO_2e to 27.09 tons of CO_2e considering a year period.

If the replacement of these conventional vehicles with electric vehicles is realized, it will be possible to achieve total indirect emissions of 7.09 tons of CO_2e. This represents an emission saving of 15.02 - 20 tons of CO_2e compared to conventional vehicle versions. In the calculation, the replacement of conventional vehicles with electric cars was considered, the specification of which was very similar to the specification of original vehicles. The estimated costs of renewing the vehicle fleet by electric vehicles are 583,450 € without charging infrastructure (increasing the efficiency of vehicle use is worth considering, as 18 vehicles have a cumulative annual mileage of 131,000 km, which is an average of 7,300 km/vehicle/year).

3. Charging Infrastructure

At present, there are two charging stations in the town of Senec which were built by commercial entities - at the gas station and in the car park of the department store. The charging station at the gas station is operated by GreenWay. The charging station allows the simultaneous charging of two vehicles via the Type 2 connector. The charging station in the car park of the department store has an output of 2 × 22 kW and also the Type 2 connector.

The town of Senec joined the international project eGUTS (Electric, Electronic and Green Urban Transport Systems) [5] implemented through the Interreg Danube Transnational Program. As an output of the project, a charging station for electric vehicles with an output of 2 × 22 kW and the Type 2 connector was built. The method of charging is currently being addressed because currently, the charging is free of charge. The same project also addressed electric bicycles and the necessary infrastructure.

Another charging station of a commercial business entity is currently under construction (IONITY). Due to this, it can be assumed that it will be a fast-charging station (DC / CCS).

The construction of additional charging stations can be expected in connection with the expected subsidy schemes at the level of the Government of the Slovak Republic – by both private and public entities. The town of Senec has these plans included in the strategic documents of the town (Economic and Social Development Plan, Local e-mobility Action Plan for the town of Senec [5]).

The addition and usage of new charging infrastructure will require an increase in electricity consumption. Only in the case of city vehicles, the annual consumption of 19.16 MWh per year is assumed.

A further increase is related to the mobility of the population. For now, let's consider the mobility for work. Following the last Report on the Evaluation of Spatial Planning Documentation - the Spatial Plan of the Town of Senec from 2016 [5], Senec has 8,796 economically active inhabitants, 86.6% of them work outside the urban area, which represents 7,617 inhabitants. If an increase in the electrical mobility of these inhabitants is expected and at the same time a theoretical daily mileage of 60 km [1] and estimated electricity consumption of 9 kWh (i.e. with an estimated consumption of 15 kWh / 100 km) are considered, then to meet the energy needs of their electric vehicles 35 MWh of electricity per day (or 8.6 GWh per year) has to be delivered. The previous recalculation applies to the case where 50% of the economically active population would use an electric car as a means of transport for commuting. For these cases, it is necessary to build charging infrastructure mainly in the place of housing with the predominant demand for overnight charging [2].

Another potential segment for the transition to electromobility are urban public service systems (post office, courier services, supply, health and social services, etc.) [4] and, in the future, also the freight transport (there are industrial enterprises and logistics centres in the city and in its surroundings) [3]. While in the first case the unit requirements would be close to that of a passenger car, in the second case (e.g. a semi-trailer truck) they will be considerably higher. The scope of these requirements could be known from the transport model of the town, which is being developed within the Transport Master Plan.

According to this document, a power reserve of 60 to 70 MW is available for the whole city, which could partly cover the requirements for future charging stations. However, the city is prospectively preparing the infrastructure for a more rapid development of electromobility. Especially when preparing new development areas, the city thinks about the

future and there is built-in protection in the distribution networks, which will serve to cover the future energy requirements of electromobility.

4. Non-Motorized Transport

The restrictions of traditional modes of transport (road transport - frequent congestion, rail transport – a few connections) are an opportunity for the development of other modes of transport. Due to the size of the town and terrain conditions (in the district of Senec 97% of the area is flat, i.e. with a slope of 0-1°) the town has the prerequisites to increase the share of non-motorized traffic, i.e. pedestrian and bicycle (Fig. 3).

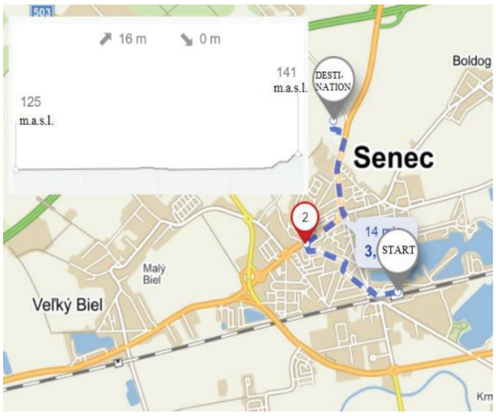

Fig. 3 Example of a cycling route and its profile

Fig. 4 Cycling route tracking

Fig. 4 shows a comprehensive tracking of bicycle routes in Senec and its surroundings as a part of the concept of territorial development of bicycle routes in the region.

4.1. Availability of Points of Interest

The following examples illustrate the availability of a selected point of interest within the town of Senec - specifically the railway station (Fig. 5) and the post office in the city centre (Fig. 6). These so-called isochrons were generated for the case of walking and subsequently for the case of driving a vehicle, but without taking into account the current traffic situation, i.e. without any restriction of actual traffic (see below).

It can be seen that despite the relatively moderate walking distance of 15 minutes, the coverage area forms a relevant part of the city.

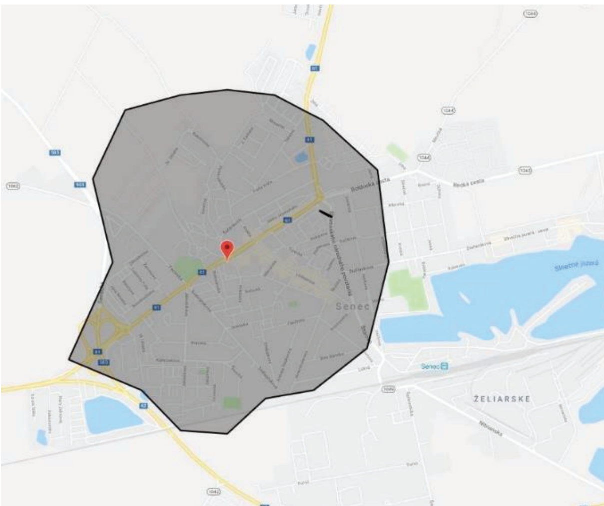

Fig. 5 Example of 15 min. walking distance to the railway Station

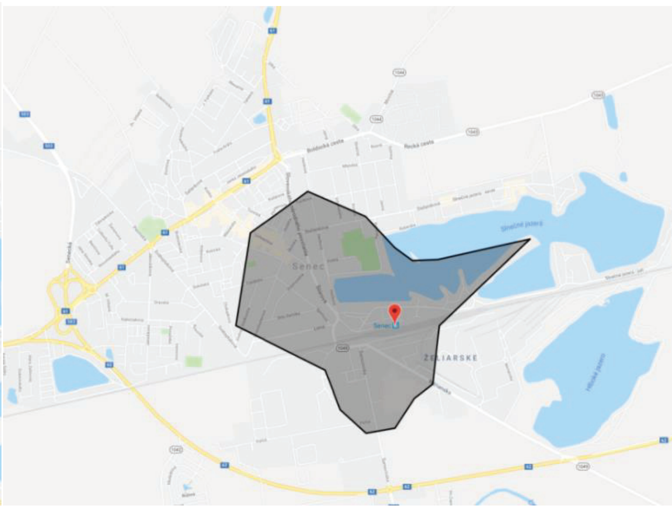

Fig. 6 Example of 15 min walking distance to the post office in the centre of Senec

In the case of the accessibility by vehicle, the situation is different, as expected, the coverage area is significantly larger, but it should be remembered that in the real situation (after taking into account time losses due to congestion) the accessibility by the vehicle will be considerably limited (Fig. 7) and such accessibility will be largely determined by the current traffic situation (Fig. 8).

Fig. 7 10 min. accessibility by vehicle (traffic restriction not considered)

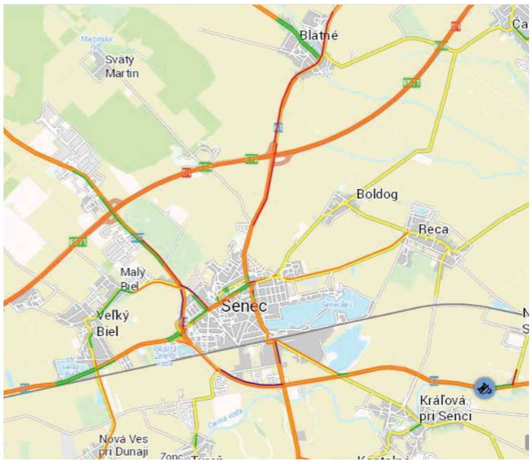

Fig. 8 Traffic congestion 28 January 2019 - NSDI

Size and terrain conditions show that the city has great potential in non-motorized transport. In the future, it is possible to assess the planned network of cycling routes as sufficient, but it is necessary to support pedestrian traffic, especially by removing collision points, which arise from the intersection of individual modes of transport (the main road passes through the city centre).

5. Conclusions

The analysis shows that the following aspects have a major impact on urban transport:

- high share of road traffic, the main road passes through the city centre;
- low frequency of train connections;
- non -competitive public transport in terms of time, and
- high proportion of economically active inhabitants who leave for work outside the town (approx. 85%) - to a large extent this is done by passenger cars, which also meet the needs of their family (transport of children) during the morning and afternoon rush hours.

In order to green transport, it is, therefore, necessary to develop public transport and adapt it to the needs of the inhabitants, to support the transition to alternative fuels (especially electric vehicles) and also to develop ecological modes of transport, especially non-motorized, i.e. walking and cycling, for which the city has suitable conditions.

In the following study, we will focus on the evaluation of the road network load. The traffic model (as part of the Transport Master Plan) and publicly available data (especially the National traffic information centre) will be used to monitor the traffic situation. Subsequently, the study of externalities will be proceeded.

Acknowledgement

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Study of air Pollution Reduction Possibilities of Post-Panamax Containerships in the Port of Klaipeda

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Abstract

This work aims to determine the air pollutant emissions of marine diesel oil and LNG-powered Post-Panamax container vessels that are accommodated by the Lithuanian joint-stock stevedoring company "Klaipedos Smelte". This study is based on the use of navigational simulator that enable to re-create the handling of containership and to perform a simulated task of sailing in the port of Klaipeda. With the use of this navigational simulator and the statistics of containers handling results in the "Klaipedos Smelte" container terminal (KSCT), there is estimated the amount of Post-Panamax containerships' emissions that reach the city of Klaipeda in this study. After this estimation there is provided the possibilities of air pollution reduction.
KEY WORDS: *Post-Panamax, containerships, emissions, air pollution reduction, port of Klaipeda*

1. Introduction

The Baltic Sea is one of the main transport corridors between Eastern and Western Europe. Over the last decade, maritime transport in the Baltic Sea region has changed considerably. The growth of container flow along the coasts of the Baltic Sea is particularly noticeable due to the strong growth of world trade, the growing service sector and the improvement of quality of life.

There is no exception in the port of Klaipeda either. Since the end of 2013, when an STS (Ship-to-Shore) type crane was installed for loading and unloading of containers to / from container vessels, and since the June of 2015, when there was opened "Klaipedos Smelte" container distribution centre (HUB), the port of Klaipeda became a popular port for Post-Panamax containerships. This sequence of terminal development caused the marked growth of containerships sails in the port of Klaipeda. Presently, 5000–7000 TEU capacity ocean going liners, carrying containers on "Australia Express" route and connecting Klaipeda with important transit European and Eastern seaports like London (England), Antwerp (Belgium), Valencia (Spain), Naples (Italy), King Abdullah (Kingdom of Saudi Arabia), Singapore, Colombo (Sri Lanka), Sidney (Australia) and others, are calling the container terminal of "Klaipedos Smelte" on regular basis once per week. The majority of these containers, that were carried by ocean going liners, are being transhipped by feeder ships – container carries to neighbouring seaports in Finland, Russia, Estonia and other countries [14]. This JSSC "Klaipedos Smelte" technical characteristic of being able to handle Post-Panamax containerships is very important as it is a recognition in a worldwide container vessel market and ability to handle larger quantities of containers.

However, growing environmental awareness and social challenges like air quality, climate change, and energy scarcity have resulted in the latest emissions legislation as set forth in the International IMO and US EPA regulations. Recent legislation covers the emission of NO_x (Nitrogen Oxides), SO_x (Sulphur Oxides), THC (Total Hydrocarbons) and PM (Particulate Matter). Implementation of a new text of Marpol Annex VI legislation had a dominating impact on the development of propulsion systems as it demands a significant reduction of the emissions of Nitrogen Oxides and Sulphur Oxides [8].

This implementation is equally important to the port of Klaipeda as its area is located near residential houses (about a couple hundred meters away from them), so that means the port contributes to the pollution of the city by most part which causes the dissatisfactions of residents. People know that air pollutant emissions negatively impact their health. These emissions can cause the reduction of oxygen delivery to the body's tissues and organs, which can induce asthma, bronchitis, heart failure and negative impact to central nervous system. Also, emissions of air pollutants at sea can exert an influence on vegetation and land-based objects many thousands of kilometres away [5]. This negative effects on local air quality and human health are largely dominated by the presence of NO_x, PM, acid deposition and nitrogen deposition, also by the emissions of sulphur and greenhouse gases (GHG) (e.g. CO2) that have a global impact on climate.

That is why there is a great demand to determine the air pollutant emissions that reach the city of Klaipeda, according to how many Post-Panamax container vessels are calling the container terminal of "Klaipedos Smelte" over the year. Therefore, with the use of navigational simulator "SimFlex4 Navigator" [2] and the statistics of containers handling results in the "Klaipedos Smelte" container terminal (KSCT), the more accurate diesel and LNG-powered containerships' emissions, that reach the city, are being estimated.

2. Situation Analysis of Post-Panamax Containerships Flow in the Port of Klaipeda

In the new political and competitive environment, the port of Klaipeda plays a very important role in the European trade and freight transport market. The port has become a significant in the transport and logistics sector following a variety of political and economic developments (the global economic crisis of 2008, and the weakening and geopolitical situation of Russia and Belarus). Being in a favourable geographical position for transit, the port is convenient for the Eurasian transport system connecting Russia and Belarus with European markets. Thus, not only local freight flows but also transit ones have contributed to a sufficiently intensive transport market in the port of Klaipeda.

There were handled 703 thousand TEU containers in 2019 in the port of Klaipeda [12]. JSSC "Klaipedos Smelte" handled around 36 % of the port total containers in 2019, i.e. total of 253489 TEU containers [11]. However, containers handling has not been entirely successful recently in KSCT. The turnover of containers in 2019 decreased by 34,5 % comparing with previous year (386982 TEU) [10]. The decrease of containers in 2019 was determined by a temporary suspension of regular arrivals of MSC ocean-going container vessels, carrying transhipment containers to JSSC "Klaipedos Smelte". In general, it is a still quite good annual turnover regarding that there were only handled 180094 TEU containers in 2017 in JSSC "Klaipedos Smelte" [9]. So, there still was a higher annual containers turnover in 2018 and 2019 than in 2017. This was mainly due to the changed taxation system for shipping lines and containerships in the port of Klaipeda – port fees became more attractive and flexible for customers and containerships. The other reason of increased quantity of containers was determined by regular calls of MSC ocean-going container vessels, carrying both import-export and transhipment containers to JSSC "Klaipedos Smelte", that started in May of 2018 [10].

According to containers statistics in 2019 and the condition that average capacity of Post-Panamax containerships, which are calling the container terminal of "Klaipedos Smelte", is 6000 TEU, it was determined that there should had been made around 4000–5000 loading and discharging movements per TEU. Such a conclusion was reached, because containerships usually enter other ports, like port of Gdynia or port of Gdansk, to load / discharge part of the containers there, before arriving in the port of Klaipeda. Therefore, on the basis of this finding and the fact that Post-Panamax container vessels are calling the KSCT on regular basis once per week, it was determined that there should had been accommodated about 57 of these container vessels in KSCT. Of course, this is not an accurate number because, as there was mentioned before, a temporary suspension of regular arrivals of MSC ocean-going (Post-Panamax) container vessels was made. That means it was decided to carry most of the containers by using 1400–2500 TEU feeder container vessels [13]. Even though these vessels are mainly used for further distribution by sea to St. Petersburg, Tallinn, Helsinki and other neighbouring ports after a short storage at "Klaipedos Smelte" container terminal, but it tends to be these feeder vessels were realigned for containers distribution from main hub ports, like Hamburg (Germany), Rotterdam (Netherlands) or Antwerp (Belgium), to the port of Klaipeda. Thus, there should had been less Post-Panamax containerships in KSCT in 2019.

However, in order to estimate the largest possible amount of air pollutant emissions that has been emitted by Post-Panamax container vessels, this study is based on maximum number of containerships that could had been arrived to / departed from the KSCT.

3. Methodology of the Study of Air Pollution Reduction Possibilities of Post-Panamax Containerships in the Port of Klaipeda

Emissions from the maritime transport sector represent a significant and increasing source of air pollution. This is most relevant for harbour cities because in these places ship emissions are often a dominant source of urban pollution and need to be addressed, in particular when considering sulphur oxides (SO_x), oxides of nitrogen (NO_x), fine particulate matter, carbon monoxide (CO) and dioxide (CO_2) as they are a side result of the fuel that is used to power ships.

The amount of gases emitted from marine engines into the atmosphere is directly related to total fuel consumption, which depends on different factors such as the hull shape, the loading conditions, the roughness of the hull, the condition of the engine, etc. Auxiliary engines also contribute to the total exhaust gas emissions. In general, ship emissions in port depend on manoeuvring time and cargo operations (vessel-type dependent) [1]. Focusing on all port operations and air pollution, the main factor to take into consideration is that each category – ocean / sea-going vessels, harbour craft, cargo handling equipment, trucks and locomotives – is mainly powered by diesel engines, which are significant contributors to air pollution [5], that can be detrimental to the natural environment and can contribute to many serious health problems. These negative impacts show the complexity of the situation and the urgent need for action to be taken. The increasing pressure of the maritime sector on the environment could be halved by adopting local and global emission restriction policies. So, the first step to take towards achieving this objective is to quantify the air emissions from the maritime transport sector.

For the evaluation of emissions arising from maritime transport, two dimensions have to be considered: the quantity of emissions produced and where they are emitted. For both dimensions, in this study, there is used full bottom-up approach which means air pollutants emitted by a ship in a specific position are calculated; aggregating these estimates over time and over the fleet gives an estimation of the total emissions [4]. With the help of navigational simulator "SimFlex4 Navigator", that enable to re-create the handling of containership and to perform a simulated task

of sailing in the specific port, and the statistics of total containers turnover, there can be easily identified total number of vessels, their characteristics (horsepower of the engines, fuel consumption, longitudinal speed) and geographical characterisation, that is: the actual sailing time in port (in hours and minutes) by vessels.

For commercial vessels, the methodology calculates the emissions from navigation by summing the emissions on a trip by trip basis. For a single trip the emissions can be expressed as [7]:

$$E_{trip} = E_{hotelling} + E_{manoeuvering} + E_{cruising} . \tag{1}$$

The total inventory is the sum over all trips of all vessels during the year. In practice it may be that data is collected for a representative sample of vessels over trips over a representative period of the year. In this case the summed emissions should be scaled up to give the total for all trips and vessels over the whole year [7]. However, as navigational simulator perfectly sums up vessels' characteristics during the passage, there is only estimated the manoeuvring and cruising of the particular ship through the port in this study, i.e. at the time of arrival and departure of the ship.

First of all, two different procedures should be used to estimate emission: fuel consumptions, on which depend the quantity of CO_2 and SO_x emissions, and engines power, on which depends CO, NO_x and PM emissions. When fuel consumptions for each phase is known, then emissions of pollutants, like CO_2 and SO_x, can be computed for a complete trip by using this formula [7]:

$$E_{trip,i,j} = FC_j \cdot EF_{i,j} , \tag{2}$$

where E_{trip} – emission over a complete trip, tonnes; FC – fuel consumption, tonnes; EF – emission factor (pollutant specific) in mass emitted per work output of the engine in manoeuvring and cruising mode, g/kWh; i – pollutant (CO_2 or SO_x); j – fuel type.

The fuel consumption is evaluated in the presence of navigational simulator's detailed information about fuel consumptions for a specific ship / engine type combination in the different navigation phases.

When fuel consumption per trip phase is not known, then a different methodology is proposed for computing emissions, based on installed power and time spent in the different navigation phases. Emissions of pollutants, like CO, NO_x and PM, can be calculated from a detailed knowledge of the installed engine power, load factor and total time spent, in hours, for each phase using the following equation [7]:

$$E_{trip,i,j} = P \cdot EF_{i,j} \cdot t , \tag{3}$$

where E_{trip} – emission over a complete trip, tonnes; P – engine power, kW; EF – emission factor (pollutant specific) in mass emitted per work output of the engine in manoeuvring and cruising mode, g/kWh; i – pollutant (CO, NO_x or PM); j – fuel type; t – time in manoeuvring and cruising mode, h.

CO_2 and SO_x emission factors are available for the individual fuel type combinations (marine diesel oil and liquefied natural gas (LNG)) are reported in Table 1 in a coefficient per tonne of fuel.

Table 1

Emission factors for CO_2 and SO_x for different fuel combinations [3, 6]

Emission	Marine diesel oil	Liquefied natural gas (LNG)
CO_2	3,2	2,1
SO_x	0,001	0

NO_x, CO and PM emission factors are available for the individual fuel type combinations (marine diesel oil and liquefied natural gas (LNG)) are reported in Table 2 in units of mass of pollutant per kWh.

Table 2

Emission factors for NO_x, CO and PM for different fuel combinations [6]

Emission	Marine diesel oil	Liquefied natural gas (LNG)
NO_x	10 g/kWh	4 g/kWh
CO	5 g/kWh	3 g/kWh
PM	0,5 g/kWh	0,1 g/kWh

As there is only studied total emission that occurs during the passage, the emission factors, shown in Table 1 and Table 2, are only related to fuel without engine of phase specification.

The debate on the evaluation of maritime emissions is still open and has resulted in several different estimations being made over the past decade. These are not all that easy to compare, since different contexts are analysed and different assumptions are made. However, using this mentioned methodology and navigational simulator, the air

emissions from the maritime transport sector can be easily estimated.

4. Research and Evaluation of Air Pollution Reduction Possibilities of Post-Panamax Containerships in the Port of Klaipeda

In order to determine the air pollutant emissions of marine diesel oil and LNG-powered Post-Panamax container vessels and to estimate the amount of emissions that reach the city of Klaipeda, there was made the passage of containership (Table 3) to KSCT by using navigational simulator “SimFlex4 Navigator”.

Table 3

Main dimensions of Post-Panamax container vessel, used in a navigational simulator [2]

Ship	Length, m	Breadth, m	Draught, m
Post-Panamax containership	331,00	44,00	12,50

In order to get more stable data, simulator was calibrated with fixed weather, swell, wind speed, wind direction and other values. The resulting containership movement trajectory is shown in Fig. 1.

Fig. 1 Post-Panamax containership movement trajectory in the port of Klaipeda

All necessary information about changes in engine power, fuel consumption, longitudinal speed during the passage and the actual sailing time in port is provided by the navigational simulator. The results are reported in Fig. 2.

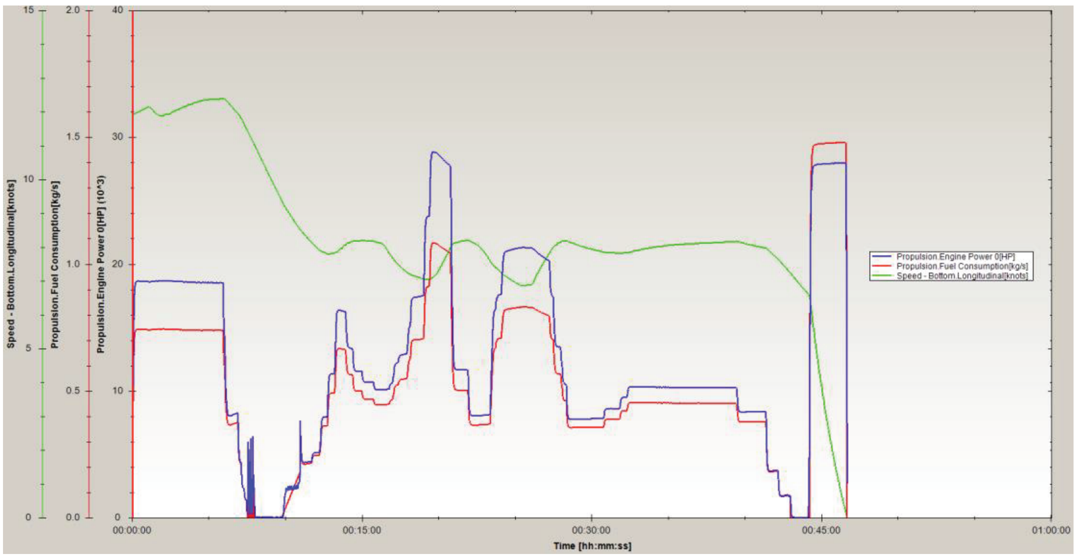

Fig. 2 The speed and propulsion characteristics of Post-Panamax containership during navigation

Data from this simulation concluded that there is direct relation between power used to manoeuvre the ship and fuel consumption (Fig. 1 and Fig. 2). Biggest spikes of used power and fuel consumption are visible at the start of manoeuvres when trying to reach permissible port speed (8 knots). Any sudden changes in power output (braking, speed increase) and ship control inaccuracies (manoeuvring) can lead to larger emissions. For example, manoeuvres can increase CO_2 and other emissions by up to 15–20%.

During the simulated passage, it was obtained that Post-Panamax container vessel consumed 1448,57 kg of fuel. During almost 47 minutes of voyage, the average engine power output was 8736 kW. Taking into account the fact that KSCT handles an average of 57 Post-Panamax containerships per year, the amounts of air pollutant emissions of marine diesel oil and LNG-powered Post-Panamax containerships are calculated when the ships make 2 voyages (arriving and departing from KSCT). These calculations are made by using aforementioned calculation methods – (2) and (3) formulas. The calculated results are shown in Table 4.

Table 4

The annual results of air pollutant emissions of marine diesel oil and LNG-powered Post-Panamax container vessels that arrive to and depart from KSCT

Emission	Marine diesel oil	Liquefied natural gas (LNG)
CO_2	528439,36 kg	346788,33 kg
SO_x	165,14 kg	0,00 kg
NO_x	7801,67 kg	3120,67 kg
CO	3900,84 kg	2340,50 kg
PM	390,08 kg	78,02 kg

In order to estimate the amount of emissions that reach the city of Klaipeda, it was assumed that 70 percent of the time the wind direction is toward the city. Thus, with this in mind, calculations were made which results are shown in Table 5.

Table 5

The annual results of air pollutant emissions that reach the city of Klaipeda

Emission	Marine diesel oil	Liquefied natural gas (LNG)
CO_2	369907,55 kg	242751,83 kg
SO_x	115,60 kg	0,00 kg
NO_x	5461,17 kg	2184,47 kg
CO	2730,58 kg	1638,35 kg
PM	273,06 kg	54,61 kg

The results can only be used as an estimate, because weather conditions, Post-Panamax containership size and other values may vary and have influence to overall fuel consumption and emissions of air pollutants. However, the results show that marine diesel oil powered containerships emit the most pollutants compared to LNG-powered containerships (about 1,5 times more than LNG-powered ones). In general, according to Table 6, CO_2 is the main source of the considered air pollutants during the Post-Panamax containerships' arrivals to and departures from KSCT, irrespective of the type of fuel used (Table 6).

Table 6

The percentage of air pollutant emissions that reach the city of Klaipeda

Emission	Marine diesel oil	Liquefied natural gas (LNG)
CO_2	97,733 %	98,428 %
SO_x	0,031 %	0,000 %
NO_x	1,443 %	0,886 %
CO	0,721 %	0,664 %
PM	0,072 %	0,022 %

Table 5 and Table 6 show that marine diesel oil powered containerships are more harmful to the environment than LNG-powered ones. Thus, it means that LNG-fuelled containerships could be used as an alternative to reduce air pollution.

5. Conclusions

Emissions from the maritime transport sector account for a significant portion of total emissions, affecting air quality and contributing to climate change and human health problems. Of course, ships are not the only cause of city pollution. Port equipment, land vehicles used to carry out port work, also emits significant emissions.

The estimation and geographical characterisation of maritime transport and with-it related equipment emissions are therefore important to the work of, for instance, atmospheric scientists or policy makers who try to analyse and address the problems associated with them. That is why the calculations were made in order to investigate the amount of Post-Panamax containerships' emissions that reach the city of Klaipeda, based on the maximum number of containerships that could have been arrived to / departed from the KSCT.

The results indicate that both CO_2 and NO_x are the major contributors to city pollution. One of the most effective ways to reduce these emissions is the transition from the use of marine diesel oil to the use of LNG fuel in containerships. This transition not only would eliminate SO_x emissions but also would significantly reduce emissions of other harmful air pollutants. Nonetheless, this solution requires large investments. Therefore, other options for reducing emissions from containerships are a selection of the optimal speed of a ship, optimal manoeuvrability of the ship in approaches to ports and in ports, use of shore energy sources in the ports, use of environmentally friendly fuels and combined energy (hybrid) sources. However, everyone would probably agree that air pollution reduction depends largely on operational options, which are based on qualifications of ships' crews, port pilots, port tugboat masters, port traffic control personnel, port mooring specialists and others.

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The Influence of Local Conditions on the Use of Cargo Bikes for Last Mile Delivery

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Abstract

Cargo bikes are transport means with specific operating demands. Factors that may not be important to other transport means may be critical to the use of cargo bikes. The use of cargo bikes for the last mile delivery is therefore not universally applicable.
Cargo bikes are currently operated in many cities with diverse geomorphologic, weather, and urbanistic conditions. Also, the infrastructure and its quality may vary. The article analyzes how local conditions can affect the operation of cargo bikes for last mile delivery. In response to this analysis, the conditions in selected cities in the Czech Republic are evaluated and compared.
KEY WORDS: *cargo bike, last mile delivery*

1. Introduction

Although the history of cargo bikes is almost as old as the bike itself, in Europe and the United States, modern cargo bikes have become to be used more widely only a few years ago [6, 3]. Cargo bikes can be used in various ways from commercial transport in courier, post and delivery services to personal logistics [8, 13]. Last mile delivery service is supposed to be quick enough and efficient. A cargo bike can fulfill these requirements if the conditions in the city are suitable. Cargo bikes are environmentally friendly transport modes. Conventional motor vehicles in last mile delivery systems produce large amounts of CO_2 [7], which can be reduced by supplementing the part of the total number of motor vehicles with the cargo bikes [17].

This article focuses on the analysis of predetermined conditions such as climate and terrain, characteristics and condition of the transport infrastructure and legislative measures. The cargo bike operator is supposed to adapt to these conditions, eg by selecting the suitable bike, the appropriate operating technology, the business model, etc…Demanding climatic and terrain conditions can place high demands on the physical condition of the bicycle driver. Unlike private journeys, the courier cannot decide not to ride in bad weather. These conditions can result in a lack of cargo bike drivers or a high turnover of bicycle drivers. Better conditions can be partially ensured by a suitable bicycle construction - from bikes with simple rain top covers [14] to fully covered electric multi-wheels bikes. The condition of the transport infrastructure and its characteristics can affect the speed and reliability of the delivery service. Narrow cargo bikes are more suitable for traffic in narrow streets in historic city centers, but they have a smaller loading capacity [1, 2, 12]. Local regulations and legislative measures can also affect the operation of cargo bikes. E.g. cargo bikes can gain an advantage of unrestricted entry in locations with limited motor traffic. Legislation in different countries may define e-bike within categories of road vehicles in different ways [12].

2. Analysis of Terrain and Climate Conditions

We analyzed local conditions in 126 cities with cargo bikes systems from 20 European countries. The map in Figure 1 shows both smaller cities and large urban areas with different terrain conditions. The cities with a population over 100000 represent the majority with a total of 73%. Only 16 cities (12%) are in the category of up to 50,000 inhabitants. Larger cities with a large group of potential customers are more suitable for the use of cargo bikes.

Cargo bikes are most used in the United Kingdom (21 cities). In another six countries, cargo bikes are operated in more than 10 cities (Spain, Belgium, Italy, the Netherlands, Germany, and France). These countries belong to areas with mild climate within Europe. A large part of the territory is flat and bicycle transport has a long tradition in these countries. Approximately 50% of the analyzed cities are located mainly in flat areas, only approximately 10% are cities with mostly hilly terrain in mountainous or foothill areas. Electric bikes are more suitable for areas with more demanding terrain conditions.

Climatic conditions are important especially in terms of the possibility of year-round cargo bikes use. The following climatic factors were assessed in the analyzed cities:

- average temperatures in January;
- average temperatures in July;
- annual total precipitation.

Fig. 1 Selection of European cities with cargo bike delivery service [5, 15, 16]

Figs. 2 and 3 show the number of cities according to the average temperatures in January and July. The year-round use of cargo bike in Europe can be influenced by weather fluctuations during the year. In winter, temperatures can drop below freezing point, it can be windy with snowfall. High temperatures in summer can also be a problem. Such conditions place high demands on the physical condition of the bicycle driver. The analyzed data show that in cities with cargo bikes, the average January temperatures are most often in the range of 0.5-5°C and the average July temperatures are in the range of 17-20.5°C. The average annual precipitation in the analyzed cities varies between 300 mm (Murcia) and 1738 mm (Donostia/San Sebastian).

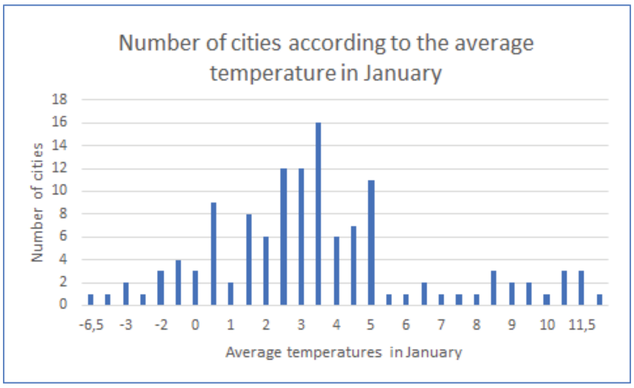

Fig. 2 Number of cities according to average temperatures in January

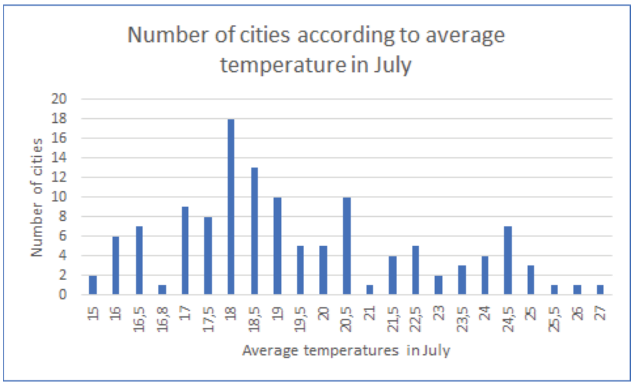

Fig. 3 Number of cities according to average temperatures in July

However, even in the case of less favorable conditions, it is possible to implement a successful system by choosing a suitable business model and the right type of bike. This is proved by examples from Sweden (Umea with January temperatures around -6.5°C) or Spain (Seville with very hot and dry summers).

The Czech Republic does not have typical conditions for the operation of cargo bicycles. The country is relatively mountainous with lower average January temperatures than in countries where cargo bikes are most common. However, there are cities where bicycle transport has a long tradition and local conditions are favorable.

3. Analysis of Transport Infrastructure and Legislation

The condition of the infrastructure and the traffic associated with it are important factors influencing the choice of transport means for the collection and distribution of small consignments. The road traffic rules in the Czech Republic are regulated by Act No. 361/2000 Sb. Technical standards and technical terms regulate the infrastructure parameters. Specifically, the infrastructure in the Czech Republic is regulated mainly by CSN 73 6101 Design of roads and motorways, ČSN 73 6102 Design of crossings on roads, ČSN 73 6110 Design of local roads.

3.1. Cargo Bikes in Relation to Transport Infrastructure and Legislation

Cargo bicycles that fulfill the terms of a bicycle can also use the infrastructure for cyclists, which is regulated by TP 179 Design of roads for cyclists [10]. Technical terms TP 179 define other related legal regulations, technical standards and technical regulations related to this issue.

But the question is: “When can a cargo bike be considered to be a (standard) bicycle?”. The concept of a bicycle,

or e-bike is not directly defined in the legal regulations of the Czech Republic. However, the Decree No. 341/2014 Sb., determines the technical requirements for bicycles (specifically in Annex No. 12 letter C - Technical requirements for the equipment of bicycles, cover vehicles and handcarts). If the vehicle (electric bicycle) fulfills all the requirements for fitting an auxiliary engine defined in section 8 of this Annex. and in the cases described in sections 9 and 10, it is still considered a bicycle with all consequences that relate to road traffic rules, especially resulting from Act No. 361/2000 Sb. Requirements for fitting an auxiliary engine determine that the load-bearing parts of the engine have not been tampered with and the auxiliary engine can be removed again at any time.

Other versions of vehicles referred to as e-bikes, which do not fulfill the terms defined in the above Decree (especially the auxiliary engine - the engine is already mounted directly from the manufacturer, so there is interference with the load-bearing parts, engine power exceeds 1 kW, max design speed exceeds 25 km/h, etc.), are assessed for classification according to Regulation No. 168/2013 of the European Parliament and of the Council on the approval of two- or three-wheel vehicles and quadricycles and market surveillance of these vehicles.

Technical terms TP 179 - Design of roads for cyclists summarize the rules and principles for the design of roads so that they are safe and comfortable for the use of bicycles:

- The scope of the scale is from the level of the basic spatial-operational concept to the detail of the measure;
- They apply to all roads, especially local roads;
- They specify in the detail the individual measures of the cycling infrastructure and the principles of their use;
- They specify the requirements of road solutions from the point of view of bicycle traffic;
- They are intended primarily for designers and other professions related to the process of assignment, preparation, approval and implementation of roads and public spaces in general.

Many cities have already learned to apply measures to support cycling. These measures include both building and transport organizational elements and measures that help to use bicycles safer and more comfortably. Roads for cyclists are being created in the main and associated traffic areas. However, these measures support "passenger" bicycle transport, and therefore the parameters of the roads correspond to the driving profile for single-track bicycles, or bicycles with a two-track trailer (especially for children).

For this reason, such an infrastructure may not always to fulfill the requirements of cargo bicycles, which have a wider riding profile due to their dimensions.

The operational-spatial character of the road should be "timeless" according to (TP 179), it determines the basic principles of access to this road, defines appropriate transport and organizational measures and ultimately defines the quality standard for users. Regarding the above mentioned, it is necessary to include the whole concept in the planning phase.

3.2. Cargo Bikes in Relation to Sustainable Mobility

Currently, larger cities in the Czech Republic (population approximately of over 40,000) are preparing sustainable mobility plans. These plans are a strategic tool for sustainable mobility planning. They are not only focused on the issue of transport, but they should also provide a framework and support for solving the urban mobility and meeting their needs. It is not only about the mobility of residents and visitors in the city, but also about the mobility of services and goods. It is also important to address the issue of city logistics already during the preparation of these plans. In the initial analysis, it is necessary to choose the users of the system and to invite their representatives as partners to the creative team. The analysis itself must target to supply and demand, the possibilities of transport space for the preference of cargo bicycles, etc. Specific measures should be reflected both in the design part and in the part of the action plan. After implementation, it is necessary to use the information obtained from the monitoring feedback in the evaluation of the entire plan. Unfortunately, the Methodology for the Preparation of Sustainable Mobility Plans for the Cities of the Czech Republic (X) deals with bicycle transport only as passenger transport.

As a part of urban mobility planning, cargo bicycles should be the preferred means of transport within city logistics. The adaptation of urban infrastructure should be the active preference. It is not possible to full use of the existing cycling infrastructure due to the wider driving profile of cargo bike, which depends on the size and design of the cargo space. Even so, their advantage in terms of size and environmental friendliness should be used to the full, as it is in the case of passenger cycling. The parameters of roads for cyclists should be based on the dimensions of the so-called standard vehicle, ie the largest bicycle for which it is proposed.

Significant roads, the so-called integrated corridors, should be accessible to cargo bikes through integration measures. These roads tend to be more congested with car traffic and public transport, but are inherently attractive in their straightforwardness, speed, and reliability. They also have an important transport function in addition to the service function (they can also contain sources and destinations for cargo bikes). The measures on these roads should be directed mainly to the main traffic area (e.g. different types of reserved lanes).

Quiet and calm roads and zones that are used for movement within the transport service area should also be accessible to cargo bikes. There is usually no need to create special measures on these roads. Measures for bicycle transport are applied as additional measures to ensure clarity and safety of the area. However, it is important to be aware of the wider passage profile in these cases so that the permeability is maintained also for cargo bikes (e.g. measures for two-way roads for bicycles).

The permeability of the cargo bike area should be maintained within the framework of protected cycling routes and connections. The parameters of roads for cyclists must be adjusted so as not to endanger the safety of movement of

pedestrians using the associated traffic area (separation of pedestrians and cyclists, adjustment of construction parameters, etc.).

4. Comparison of Selected Cities in the Czech Republic

Cargo bicycles are currently operated in the Czech Republic in Prague and České Budějovice. Courier services with standard and cargo bicycles are operated in Prague as part of a larger system of municipal courier services [9, 11]. Prague is the largest city in the Czech Republic with a relatively hilly terrain and intensive traffic in the center. The main advantage here is the existing wide number of potential customers, the operability of bicycles in normal traffic and the contribution of this system to environment in the city center. The city of České Budějovice belongs to the top ten largest cities in the Czech Republic according to the number of inhabitants. The terrain in the inner city is mostly flat, the climate is colder than in Prague. One cargo bike is operated here by a large delivery company [4, 11]. The city of Pardubice is also one of the top ten largest cities, the terrain here is mostly flat, the climate is mild. Cargo bikes are not currently operated here. Table 1 summarizes the observed factors for the above three cities.

Table 1

Local conditions in selected cities in the Czech Republic

City	Population	Average January temperature	Average July temperature	Average year precipitation	Terrain
Prague	1324277	-2°C	17,6°C	542 mm	partly hilly
České Budějovice	94463	-3,8°C	13,1°C	629 mm	mostly flat
Pardubice	91727	-3,9°C	15,3°C	599 mm	flat

We performed an analysis based on all the monitored factors from Chapters 1 and 2 for the city of Pardubice, where cargo bikes are not currently operated (Table 2).

Table 2

Analysis of local conditions in the city of Pardubice

Strengths	**Weaknesses**
- flat terrain - favorable temperatures and distribution of precipitation throughout the year - compact city - good transport accessibility of all city districts - distribution of individual transport modes within the modal split (representation of bicycle transport 14%) - connection of surrounding villages by means of cycle paths	- traffic intensity in the city center - insufficient parameters of the cycling infrastructure for cargo bikes - lack of (insufficient) measures to restrict car entrances to the city center - absence of internal and external bypasses (routes for internal transit through the city center)
Opportunities	**Threads**
- existence of unused commercial space in the center - a growing range of bicycle types suitable for last mile delivery - support of bicycle transport by the city authorities (solution of city logistics within the emerging SUMP) / region	- insufficient set of end customers - operation of bicycles together with other modes of transport - natural obstacles in the development of infrastructure (Elbe, Chrudimka)

The city of Pardubice is currently preparing a SUMP, within the action plans concerning the city logistics are also created. Not only experts in spatial planning, traffic engineers, etc. are involved in the creation of this strategic document, but also representatives of companies, enterprises, and services in the city. This can be very important for the creation of own concept of logistics.

The city of Pardubice has very favorable terrain and climatic conditions, the parameters of the transport infrastructure are here the problem factor. Although Pardubice is a city of cyclists and has a good infrastructure for cyclists, which continues to develop, this infrastructure is not always suitable for cargo bikes. Especially larger cargo bikes could have a problem moving in the associated space due to their wider driving profile. Congestion, which arises, among other things, due to inappropriate internal transit tracing, will prevent smooth movement in the main traffic area together with other vehicles during peak periods. Unfortunately, the routes currently lead through the city center. The city has not got a bypass, which would also connect the individual parts of the city. The development of transport infrastructure is limited by the flow of two rivers, which must be crossed, and by the very limited size of available areas in the city center. In practice, it is therefore possible, especially in the city center, only to redistribute the area for the benefit of individual users. However, this cannot be done without compromise and a change in the thinking of all

involved subjects.

Recently, the local authorities efforts to reduce the traffic load on the city center, especially the private motor vehicle transport (new parking policy, the realization of the first P+R parking lot on the south side of the city, etc.) have begun to emerge. It will be possible to further develop these efforts also thanks to the analyzes that arise within the activities for SUMP, and thus to guide the personal mobility of residents and visitors to the city. This also creates scope for "managing" freight mobility and the use of more environmentally friendly modes of transport here as well. The cargo bikes can be one of the ways. Right now, the city has the opportunity to use the cooperation of individual subjects and thus create a system for the delivery of small consignments using the type of transport, which has been proving itself in passenger transport in Pardubice for many decades.

5. Conclusions

The decision to use a cargo bike system for last mile delivery depends to a large extent on external factors, which are predetermined. Unlike conventional modes of transport, the importance of these factors can be crucial in decision-making. A detailed analysis of climatic conditions, terrain, infrastructure, and legislation can help the cargo bicycle operator in deciding on the operation model. It can be the basis for creating a suitable business model and for choosing the right type of bike. At present, regional authorities place great emphasis on sustainable mobility within urban agglomerations, which also includes the organization of city logistics processes. Cargo bicycle is an ecological and flexible means of transport that can complement the conventional last mile delivery systems in cities with suitable conditions.

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Analysis of Maritime Transport Activity Factors Influencing Global Warming

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Abstract

Over the last decades, global environmental degradation and climate changes have led to concerns about the continued use of fossil fuels. Maritime transport is not only an important element of the global energy supply chain but by itself is a global consumer of energy, contributing to climate impact. To reduce the impact of shipping on the global environment, the International Maritime Organization has established new regulations on emissions from ships. A large number of potential solutions are announced and developed as a means to minimize emissions onboard ships, such as LNG, LPG, methanol, hydrogen, ammonia or to use electric batteries, etc. The article encloses the main factors of international maritime transport activity contributing to global warming, offers a look at the fuel usage for shipping as a sequential element of energy chain following his particular life cycle.
KEY WORDS: *maritime transport, ship propulsion system, fuel, greenhouse gases, emissions, life cycle, energy chain*

1. Introduction

The direct climate forcing to global warming (also termed “radiative forcing”) is related to changes in the atmospheric global excess of long-lived, well mixed greenhouse gases (GHG), in particular carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halogenated compounds (mainly CFCs) [1].

It found that there is a near-linear relationship between cumulative CO_2 emissions and the global temperature response, while international shipping is also a contributor to anthropogenic GHG emissions, and CO_2 in particular [2-4]. But at the same time UNCTAD statistics definitely show that maritime transport is vitally important for humans, as the backbone of globalized trade and manufacturing supply chain, when more than four fifths of the world merchandise trade by volume is carried by sea [5]. Shipping remains irreplaceable as the carrier of the world trade.

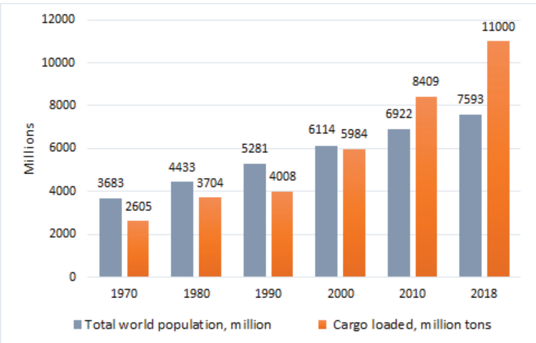

Fig. 1 World population and international seaborne trade loaded millions of tons per selected years. Data sources: for world population - [6], for international seaborne trade - [5]

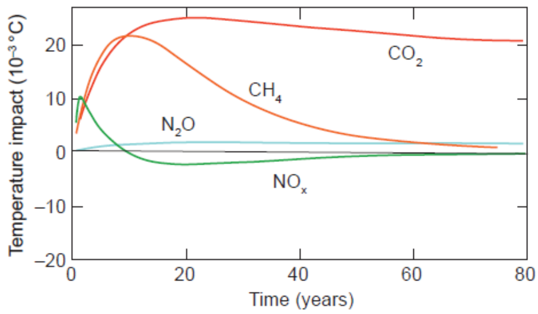

Fig. 2 The importance of greenhouse gas lifetimes on global temperature [9]

The main drivers of a rise in world trade are increasing population and a growth in a global production and corresponding transportation of required resources. Fig. 1 shows the change in international seaborn trade and the growth in population per selected years during period from 1970 till 2018. Global population grew by a factor of 2.06 from about 3683 million people in 1970 to 7593 million in 2018 [6]. Whereas a growing world population needs more resources, the seaborn trade has continuously expanded to satisfy the increasing demands. The world seaborne trade during the same period, growing in line with developments in the world economy, reached 11.0 billion tons in 2018 [5], demonstrated grew by a factor of 4.2, it is growing twice as fast comparing with world population.

In order to meet needs of the world seaborne trade, the world commercial fleet on 1 January 2019 consisted of 95,402 vessels, with a combined tonnage of 1.98 billion dwt [5]. At the same time the world maritime transport is not only important element of global supply chain, but by itself is a global consumer of energy, contributing to climate impact.

The article offers a look at the fuel usage for shipping as a sequential element of an energy chain, enclosing main international maritime transport activity factors, contributing to global warming through GHGs and in particular CO_2 emissions.

2. GHG Radiative Forcing Mechanism

Carbon dioxide, methane, nitrous oxides, and chlorofluorocarbons (CFC or “Freon”) are commonly referred to as “greenhouse gases” because they let in most of the incoming solar radiation that heats Earth's surface and prevent part of the outgoing thermal radiation from escaping to space, thus trapping some of the surface heat energy. Increases in the amount of atmospheric water vapor, under warmer conditions, reinforces the heat absorption by the other greenhouse gases [7]. Without naturally occurring greenhouse gases, Earth's average temperature would be near -18°C instead of the much warmer +15°C.

Human emissions of greenhouse gases have increased global temperatures by around 1℃ since pre-industrial times [8]. Most greenhouse gases are anthropogenic and comprise additional forcing factors. The water vapor, which, despite being the most important greenhouse gas, is *not* a forcing factor because its atmospheric concentration is not controlled by human activities or other factors external to the climate system [9].

Each gas has a specific global warming potential (GWP). The GWP is an index, based on radiative properties of the GHG. It measures the radiative forcing from the emission of 1 kg of the GHG in the atmosphere relative to that from 1 kg of CO_2. The GWP values of different GHGs are different as gases absorb different amount of infrared radiation and stay for different time in the atmosphere. Emissions of different quantities of GHG are then converted into CO_2 equivalents based on these factors. This is integrated over a specific time horizon such as 20, 100 or 500 years for calculating the impact over different time periods [10].

The importance of greenhouse gas lifetimes on global temperature is reflected in Fig. 2. Here the plot compares the long-term impact on global temperature of a hypothetical, one-year emission pulse equivalent to emissions in 2008 for greenhouse gases with various lifetimes. Shown are CO_2 (very long lifetime), CH_4 (lifetime = 9.1 ± 0.9 years), N_2O (lifetime = 131 ± 10 years), and NO_x, which initially affects temperature by increasing the production of ozone [9]. Indeed, 20 to 35 percent of CO_2 may remain in the atmosphere for 2,000 years, and 7 percent may remain after 100,000 years.

The atmospheric CO_2 because of it’s rising amounts and long lifetime is recognized as the most important present-day radiative forcing factor.

3. Maritime Transport Contribution to Emissions of Anthropogenic GHG and CO_2 in Particular

Anthropogenic greenhouse gases, carbon dioxide (CO_2), nitrous oxide, methane, and others GHGs are generated as a result of different processes and technologies and the contribution to their emission is unequally distributed among the sectors of human activities.

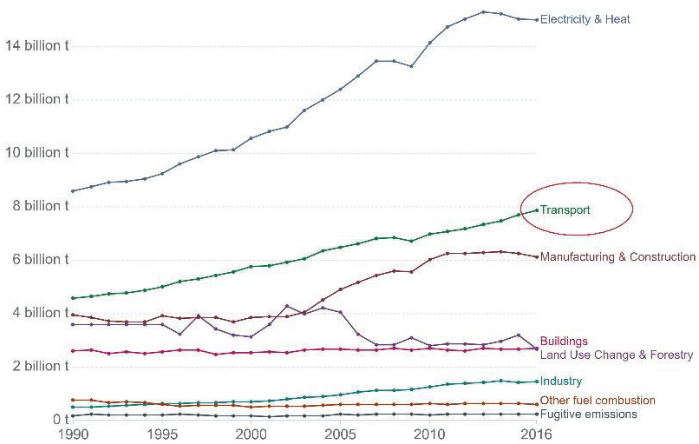

Fig. 3 Greenhouse gas emissions, measured in tonnes of carbon dioxide-equivalents by sectors (CO_2e) [8]

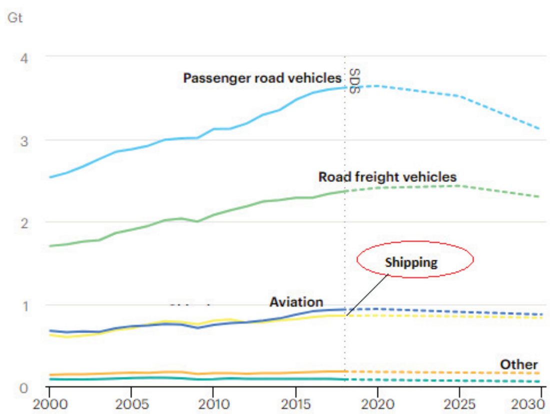

Fig. 4 Global CO_2 emission by transport mode according to IEA [4]

Greenhouse gas emissions, measured in tonnes of carbon dioxide-equivalents by sectors (CO_2e) are presented in the Fig. 3. CAIT detailed data reveals [8] that GHG carbon dioxide (CO_2) emissions are generated mostly by electricity and heat, then transport, having almost twice as smaller impact, after that manufacturing and construction and other sectors, whereas these emissions are a result of fossil fuel burning. While agriculture is responsible for almost all emissions of methane (CH_4) and to a large degree for nitrous oxide (N_2O).

According to IEA global energy-related CO2 emissions formed in 2019 at around 33 Gt (here giga is a metric definition of billion, auth.), following two years of increases [4]. Transportation in general is responsible for 24% of direct CO_2 emissions from fuel combustion. Road vehicles – cars, trucks, buses and two- and three- wheelers – account for nearly three-quarters of transport CO_2 emissions (Fig. 4), and emissions from aviation and shipping each reaches one million Gt [4].

In the Third IMO GHG Study the international shipping impact to the total global anthropogenic emissions estimation was presented [11]. Total shipping year emissions were approximately 938 million tonnes CO_2 and 961

million tonnes CO_2e for GHGs combining CO_2, CH_4 and N_2O. International shipping accounts for approximately 2.2% and 2.1% of global CO_2 and GHG emissions on a CO_2 equivalent (CO_2e) basis, respectively. The fourth IMO GHG Study expected to be published in 2020.

In recent years, environmental sustainability has become a major policy concern in global maritime transport. Environmentally driven regulations are increasingly affecting shipping market dynamics. By Hinchliffe [12] the main feature for shipping for the next 20 years would be the costly implementation of regulations focused on environmental protection, notably reduced air emissions, ballast water treatment, safer recycling of ships and, most likely, reduced emission of noise into the ocean.

4. IMO Legislative Regulations for the Prevention of Air Pollution from Ships

In 1997 the International Maritime Organization (IMO) has adopted well known Regulations for the Prevention of Air Pollution from Ships (MARPOL convention Annex VI) seek to minimize airborne emissions from ships: SO_x, NO_x, ozone depleting substances (ODS), volatile organic compounds (VOC), shipboard incineration and their contribution to local and global air pollution and environmental problems. Annex VI entered into force on 19 May 2005 and a revised Annex VI with significantly tightened emissions limits was adopted in October 2008 [13] and entered into force on 1 July 2010.

IMO regulations to reduce sulphur oxides (SO_x) emissions from ships first came into force in 2005, under Annex VI. Since then, the limits on sulphur oxides have been progressively tightened [14]. From 1 January 2020, the limit for sulphur in fuel oil used on board ships operating outside designated emission control areas is reduced to 0.50% m/m (mass by mass). This will significantly reduce the amount of sulphur oxides emanating from ships and should have major health and environmental benefits for the world, particularly for populations living close to ports and coasts, but does not matter for GHG.

The Energy Efficiency Design Index (EEDI) is mandatory for new ships, providing a specific figure for an individual ship design, expressed in grams of carbon dioxide (CO_2) per ship's capacity-mile [15]. The regulations entered into force on 1 January 2013 and apply to all ships of 400 gross tonnage and above, irrespective of flag and ownership. These very important measures are the first ever mandatory global GHG reduction regime for entire maritime industry sector.

The Paris Agreement, which entered into force in 2016, sets the ambitious climate change mitigation goal of limiting the global temperature increase to below 2°C and ideally 1.5°C [16]. Reflecting to this challenge in April 2018, the International Maritime Organization agreed to reduce GHG emissions by at least 50% by 2050 compared to 2008 with carbon intensity reduction targets across international shipping by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008 [17].

5. Ship's Propulsion and Power Energy Systems

The ship energy system consists of two fuel-consuming energy-converting systems: propulsion system and electric power plant. The function of the propulsion system is to generate ship towing power - thrust, which enables the ship to move at the desired speed. The electric power plant converts energy of fuel into auxiliary electric energy for ship operational needs and for hotel services and general support. On board conventional ship energy consumption for propulsion needs depends on voyage phase and for container ship accounts for approximately 90 – 85 percent of general consumption, depending on the ship size. The propulsion system is the most important energy consumer on board.

The propulsion system generally consists of three main components: prime mover, transmission and propulsor (Fig. 5). The electric power plant usually consists of four main components: prime mover, generator, main electric energy distribution and conversion into secondary electric energy elements and users (Fig. 6).

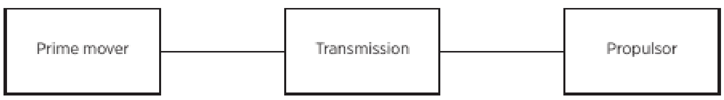

Fig. 5 Main components of a ship propulsion system [18]

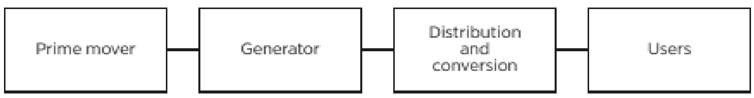

Fig. 6 Main components of a ship electric power plant [18]

On board contemporary ships, both systems usually have interfacing energy flows, either through an electric shaft generator, auxiliary shaft machine (electric motor/generator) or waste heat recovery gas or steam turbine electric generators. In case of contemporary hybrid power plant [19] new things such as power storage elements (batteries, flywheels or super capacitors) or new type converters, such as electrochemical power supply fuel cells could appear.

6. Conventional Ship Propulsion System Structure

Conventional ship generalized propulsion system with geared mechanical transmission is shown in the Fig. 7.

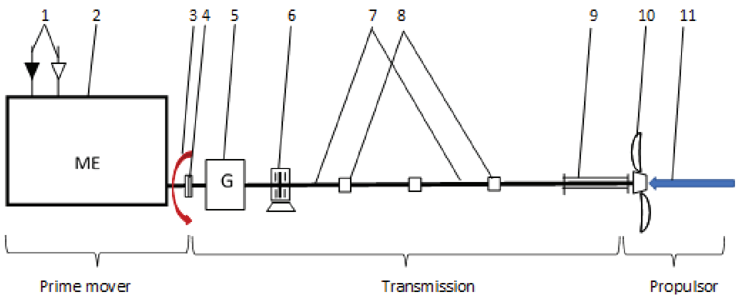

Fig. 7 Conventional ship propulsion system, generally consisting of prime mover, transmission and propulsor

In the above scheme fuel and air (*1*) enters the main engine (*2*), where chemical fuel energy converts to mechanical rotating energy (*3*). In case of mechanical drive main engine flange (*4*) could be directly coupled to the shaft (direct drive, the most efficient one) or to the gear (*5*) in geared drive case (presented in the figure). There may be also a case of electrical drive, equipped with generators, cables, switchboards and electric motors, or in some cases hydraulic drive. Intermediate shafts (*7*), supported from below by shaft bearings (*8*) transfer energy via tails shaft, supported by sterntube (*9*) to propeller (*10*). The propeller (the most efficient and popular type of propulsor) converts mechanical rotating energy received from the shafts to thrust – water reaction force (*11*). The thrust power from propeller via shafts comes back to thrust bearing (*6*), which transfers it to the ship structure and forces the ship to move, overcoming the resistance of the medium.

7. Ship's Propulsion System Efficiency

7.1. Ship's Propulsion System Energy Conversions

Ship's propulsion system generally consists of components that actually form a sequential energy chain, consisting of energy converters and transmitters. For today in maritime transport major primary energy is a chemical energy of various fossil fuels, such as gasoil, residual fuels or LNG. The energy stored in the bonds of chemical compounds of the fuel hydrocarbons, releases in the form of heat during an exothermic reaction of fuel compounds oxidation. The primary energy in a prime mover is transformed to a secondary energy. Depending on propulsion system composition secondary energy could be mechanical, electrical, thermal or hydraulic.

During every conversion output energy at a new form is always lower than input, because every process is accompanied by energy losses and process efficiency is estimated by conversion efficiency coefficient, determined as useful energy obtained and expensed energy ratio [20].

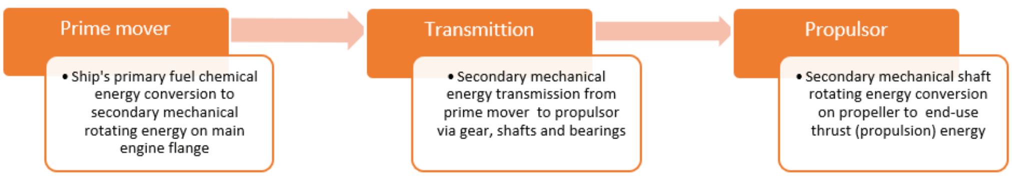

Fig. 8 Ship's propulsion system energy chain in case of mechanical drive

7.2. Efficiency of the Energy Conversion in a Prime Mover

Chemical energy conversion to mechanical in heat engines efficiency referred to as a thermal efficiency. Theoretically, the general Carnot cycle efficiency can reach 80 – 85% [18].

Calculations of a steam turbine simple cycle, when maximum temperature of steam before turbine is 600°C and the temperature of saturated steam condensation from 25° to 35°C, the unit thermal efficiency can reach 44.2%. The maximum theoretical thermal efficiency of the gas turbine simple cycle with gas temperature before turbine 1200°C and pressure ratio of the turbine 12 can reach 46%. Combined cycle estimations show possibility to reach higher efficiency due to cycle waste energy utilization [10, 21, 22].

The ideal Otto (premixed combustion) cycle efficiency with typical compression ratios in the range of 8 – 10 can reach maximum thermal efficiency 60%. The efficiency of the ideal Diesel cycle depends not only on the compression ratio, but also on the cut-off ratio – the ratio of the volume after combustion to the volume before combustion. Calculations indicate that the efficiency of the ideal Diesel cycle is less than the efficiency of the ideal Otto cycle for any given compression ratio [19].

In practice, however, the efficiency of thermodynamic conversion is much less due to the temperature limits and different additional losses. This is illustrated by the following overview of the practically achieved prime energy converters thermal efficiencies [18]:

Marine steam turbine	25 – 30%
Marine gas turbine (simple cycle)	28 – 34%
Diesel engine (medium speed, turbocharged)	38 – 52%
Stirling engine	40 – 50%

Another related aspect is that the shore power plants electricity production efficiency is in the range from 30% for coal fired conventional plants based on Renkine cycle to 48% for ultra- supercritical plants [10]. Notable that hydro kinetical power of water conversion to electrical efficiency is in the range 80 – 95%.

7.3. Efficiency of the Energy Transmission on Board a Ship

Mechanical energy is transmitted, or converted by shafting systems accompanied by friction losses. Example of geared mechanical transmission on board a ship is presented in figure 7. The transmission efficiency of a such shaft systems and gearboxes is at 96-99% [18].

7.4. Efficiency of the Energy Conversion in a Propulsor

The propeller efficiency η_0 is related to working in open water, when the propeller works in a homogeneous wake field with no hull in front of it. The propeller efficiency depends, especially, on the speed of advance, the thrust force T, the diameter d, and on the design of the propeller, such as the number of blades, disk area ratio, and pitch/diameter ratio. Depending on the propeller loading and design, an efficiency of η_0 = 0.55 - 0.70 is typically attained [18, 23].

7.5. Estimation of the Ship Propulsion System General Efficiency

Whereas the ship propulsion system elements are connected one after the other in a sequential manner, the system general efficiency could be determined as multiplication of the elements efficiency coefficients:

$$\eta_{propulsion\ system} = \eta_{prime\ mover} \cdot \eta_{transmission} \cdot \eta_0 \,. \tag{1}$$

We can roughly estimate that only 20 to 36 percent of the energy contained in the fuel is effectively used for propulsion of the ship and the most energy wasting propulsion system elements are prime mover (main engine) and propulsor (propeller). Fossil fuel hydrocarbons inefficient consumption is directly affecting excessive CO_2 emission.

8. Elemental Composition of Fossil Fuels Influence to GHG Emissions and Alternative Fuels Development

Primary energy is the energy extracted or captured directly from the environment: non-renewable energy (fossil fuels): coal, crude oil, natural gas, nuclear fuel and renewable energy: hydropower, biomass, solar energy, wind, geothermal, and ocean energy. It is generally accepted that non-renewable energy sources or fossil fuels (except nuclear) are formed from the remains of dead plants and animals by exposure to heat and pressure in the earth's crust over the millions of years and contain high percentages of carbon and fewer percentages of hydrogen [20].

Hydrogen and carbon have different characteristics (Table). Since hydrogen atomic mass is much lower than carbon atomic mass and hydrogen calorific value is much higher, fuel having higher H/C ratio, has lower density, but higher calorific value and vice versa.

Table

Hydrogen and carbon properties

Chemical element	Atomic mass	Calorific value, kJ/kg
Hydrogen, H	1.00794	143 000
Carbon, C	12.011	32 700 (graphite)

In ideal situation the combustion of a hydrocarbon fuel and release of its energy a hydrocarbon fuel converts fully to the ideal combustion products CO_2 and H_2O. Emissions of CO_2 from fuels depend primarily on their carbon content and their hydrogen–carbon ratio. The higher the H/C ratio, the higher the energy efficiency of the fuel and the lower the CO_2 emissions from its combustion [20, 24]. Thus, fossil fuel with a higher H/C ratio is more environmentally friendly and more desirable.

Of pure hydrocarbons methane has the highest H/C ratio (4:1). Particularly interesting is that LNG, the current social media favourite, does not have as strong an impact on GHG emissions as some other options; it still is a fossil fuel and produces CO_2 when combusted, but it is the cleanest of the fossil fuel options [25]. LNG carbon content makes up 0.75, while heavy fuel oil – 0.85 [15].

DNV GL in their presented Energy Transition Outlook [26] indicated development steps for alternative

fuels (fig. 9). Not all alternative fuels have the potential to reach the deep-sea stage, due to limited energy densities. Hydrogen and ammonia are still on the first steps of the stairway, while HVO and battery electric power have seen their first commercial short-sea applications. Furthermore, each alternative fuel must overcome different technological and financial barriers.

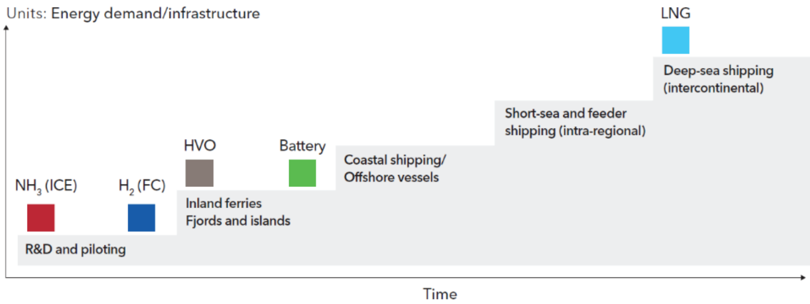

Fig. 9 Current development stage for selected alternative fuels [26]: NH_3 (ICE) – ammonia burned in internal combustion engines; H_2 (FC) – hydrogen in fuel cells; HVO – hydrotreated vegetable oil; Battery– full electric with batteries; LNG – liquefied natural gas

As we can see, among presented alternative fuels only LNG is non-renewable prime fuel, or prime energy source, captured directly from the environment. All other fuels indeed are secondary fuels, or "energy carriers", that require a prime energy source to produce them. To understand and evaluate true alternative fuels effectiveness, it is necessary to apply life cycle or so called "well-to-wheel" analysis principle, assessing their life cycle inventory, energy and material flows and the environmental impact throughout all their lifetime.

Alternatives like nuclear and hydrogen can achieve up to 100 per cent of carbon dioxide (CO_2) emission reductions. It is highly unlikely there will be a return to the age of sail, which would deliver up to a 32% reduction in shipping CO_2 emissions [25].

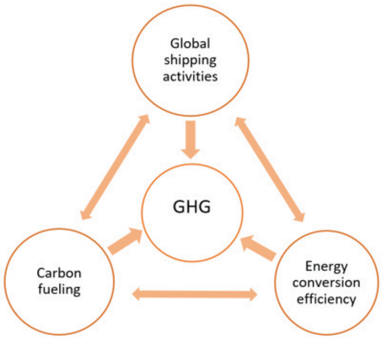

Fig. 10. Main interrelated factors of international maritime transport activity

The graphical expression of the conclusions, presented in the Fig. 10, demonstrates main interrelated factors of international maritime transport activity, contributing to global warming through GHG and in particular CO_2 emissions.

9. Conclusions

The analysis indicates that these factors are three following: rapidly growing world seaborne trade, promoting transport activities and especially maritime shipping; low energy conversion efficiency in ships energy systems and burning of fuels with a high content of carbon in these systems.

In general, the maritime transport is vitally important for humans as the vital element of globalized trade and the manufacturing supply chain, where more than four fifths of world merchandise trade by volume are carried by sea. At the same time the world maritime transport is not only an important element in the global supply chain, but by itself is a global consumer of energy, contributing to climate impact.

Transportation in general is responsible for 24% of direct CO_2 emissions from fuel combustion. International shipping accounts for approximately only 2.2% and 2.1% of global CO_2 and GHG emissions on a CO_2 equivalent (CO_2e) basis, respectively. The atmospheric CO_2, because of its rising amounts and long lifetime, is recognized as the most important present-day radiative forcing factor.

Analysis of conventional propulsion unit's efficiency indicates that only about 20 to 36 percent of the energy contained in the fuel is effectively used for propulsion of the ship and the most energy wasting propulsion system elements are prime mover (main engine) and propulsor (propeller).

IMO legislatively formulated challenges to promote investigations of alternative fuels with less carbon content, but for their objective evaluation necessary to apply life cycle analysis principle, assessing fuels life cycle inventory, energy and material flow and the environmental impact throughout all lifetime. Among developing maritime alternative fuels only LNG is non-renewable prime fuel (prime energy source), captured directly from the environment. Other

investigated alternative fuels really are secondary fuels ("energy carriers") that require a prime energy source to produce them.

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Training of Specialists in the Field of Railway Signalling using Modern Railway Devices Simulators

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Abstract

The constant development of computers and existing possibilities of creating realistic images make it possible to make simulators of technical devices and use them in the process of training specialists, e.g. from the field of railway signalling. The need for safe operation and management of railway traffic requires the use of ever newer solutions for signalling devices and systems. Such a place is the Local Control Centre, in which railway signalling systems fulfilling various functions are integrated. Moving from the mechanical and electromechanical systems to the hybrid and computer systems resulted in necessity for a new approach to practical education. The article also presents a modern base of laboratory and research, which exists currently at the Faculty of Transport, Electrical Engineering and Informatics on University of Technology and Humanities in Radom. A series of simulators and models of railway signalling devices used in the didactic and training classes for specialists in the field of railway signalling were presented.
KEY WORDS: *transport, railway signalling devices, training, laboratory, simulators*

1. Introduction

In the area of teaching and further training, computer simulators are increasingly used. The typical cases of their usage can be identified as below:

- training or skills improvement regarding technical devices handling, where the simulator reproduces a real situation in the most realistic way;
- practising of the operator's behavior in extreme situations that may occur and require immediate reaction;
- checking of the effects and practicing of the behavior, e.g. in the army, where the usage regarding certain types of weapons is not possible without the necessary need, as well as developing the soldier's reaction in the crisis situations, etc.

Nowadays, the usage of computer simulators in the training process is a part of the whole complex of modern tools and didactic methods, called e-learning.

The computer simulation regarding railway traffic and operation of railway signaling devices is used in the designing and testing of the devices as well as in the staff training which handles them. The manufacturers of new railway devices often prepare their own simulators, which are used to learn how to operate and handle these systems and devices. Due to the differences occurring in the structures of subsequent generations regarding railway signaling devices, it is also necessary to provide comprehensive training for specialists in this field using the computer simulators.

Faculty of Transport, Electrical Engineering and Informatics, Kazimierz Pulaski University of Technology and Humanities in Radom has a modern and developed laboratory base. This laboratory was realized thanks to cooperating university with many Polish railway companies, for example: Bombardier Transportation (ZUS) Poland from Katowice, KOMBUD from Radom (Poland) and Scheidt & Bachmann Poland from Luboń [5].

2. Equipment of the Modern Railway Traffic Dispatcher's Stands

The railway traffic dispatcher has the management capabilities at the Local Control Center equipped with various functional control and railway traffic diagnostics systems. From the level of the Local Control Center, it is possible to manage the so-called remote control of railway traffic on the selected railway line sections. This makes it possible to running the trains at the distance from the Local Control Center in the area of several adjacent railway traffic posts as well as railway lines of the monitored area (Fig. 1) [11, 13, 14].

The principle of remote control consists in transmitting controlling commands and reports between remote railway control traffic rooms and objects. The commands are coded and sent to the remote control objects, where they are decoded by the interface and transmitted to the control devices at the railway traffic station [6, 9].

Fig. 1 View of the dispatcher's stands in the Local Control Center in Wroclaw [17]

3. Device Simulators Adapted for the Railway Transport Needs

A typical simulator consists of two basic parts, i.e. physical and graphic. The physical part reflects physical devices, e.g. railway signalling or cabin of a rail vehicle. The graphic part is the image on the monitor displayed. Its task is to provide the highest possible realism of simulation and create the impression of full realism [1, 3, 7, 10].

The growing possibilities of generating the digital 3D images have contributed to the abandonment of video solutions and the implementation of simulators based on virtual three-dimensional environment. Although initially they were characterized by relatively poor graphics quality, they are currently able to display a 4K image quality. In some cases, there is even higher quality. They are limited by the capabilities of modern LCD and LED type screens [17, 19].

The artificially created driving environment was also used. It contributed to the change of approach in reference to the typical trainings on simulators. There was obtained a tool which allows to the dynamic simulation of events related to the selection of any rolling stock, railway line and traction instead of the static train passage. In order to raise a realism, there was started a usage of selected devices on a platform with six degrees of freedom (Fig. 2). Due to the application of this solution, any changes in the speed of train or lateral acceleration associated with cornering were felt in the simulator just like in a real vehicle [18].

a

b

Fig. 2 The locomotive simulator EP 09 by produced of the Autocomp Management [18]: a – mechanism of movement simulation with six degrees of freedom; b – interior of the engine-driver's cab

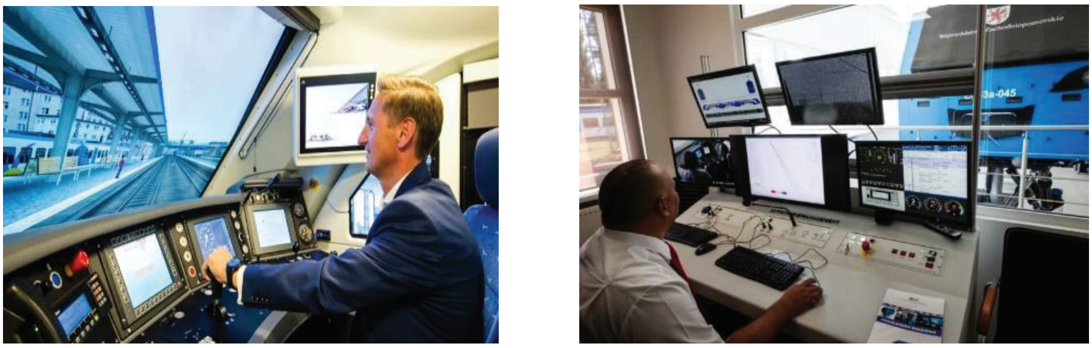
The assembly of such a simulator requires a large space, not only a place for the engine-driver's cab, but also extensive computer facilities and a room for instructors supervising the trainings.

The simulators using virtual reality are very new solutions. Some manufacturers prefer full simulation in virtual reality (railway vehicle control devices, railway traffic control devices), while others use real and physical devices such as the railway drive or the track sensors. This allows for greater immersion and precision of the simulation. These solutions lead to limit the space for the simulator and at the same time to provide the greatest possible immersion. The simulator classes allow for placement of several or even more training stands within a common space under the supervision of one instructor. In this way, the engine-driver's training process is simplified. The cost is reduced and the engine-drivers are trained in a uniform and more effective way [1, 7, 12, 16, 18, 19].

In June 2018, as a part of the Engine-drivers Training Centre in Szczecin, a special driving simulator for engine-drivers training was put into operation. It will allow to train candidates for engine-drivers and it will make them better prepared to drive the railway vehicles [15].

The simulator is designed to give the impression of running a real railway vehicle. The look of the cabin interior was made in close collaboration with the manufacturer of traction units. As a result, it is equipped with a Man Machine

Interface the same as the one used in IMPULS II trains (Fig. 3, a). It considers not only the devices mapping, but also weather conditions including blinding during the drive to the sun. The simulator uses a spatial sound system that reflects all the sounds produced by the instrumentation and on-board equipment as well as by the vehicle dynamics and its surroundings.



a b

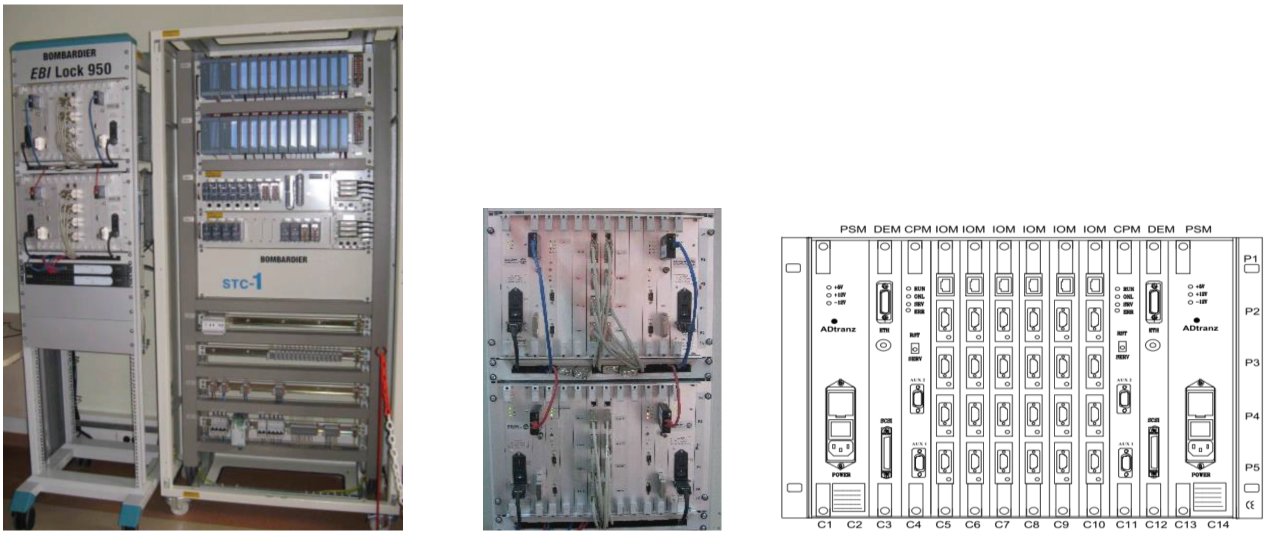
Fig. 3 View of a modern simulator for engine-drivers in reference to driving training developed by Autocomp Management [15]: a – interior of the engine-driver's cab (IMPULS II train); b – instructor stand for setting of selected track and weather parameters as well as specified scenarios regarding train traffic routes.

The applicants for engine-drivers can practice four important railway routes. The simulator has been programmed to reflect the topographical conditions prevailing on the railway sections in Poland (Fig. 3, b): Szczecin-Poznań, Szczecin-Świnoujście Port, Szczecin-Kostrzyn and Szczecin-Słupsk [15].

4. Analysis of Selected Simulators and Models of Railway Signalling Devices Located in the Laboratories at the University of Technology and Humanities in Poland in Radom

Data from real railway signalling devices included in the simulators of the corresponding devices significantly improve the accuracy of the simulation and reflect real situations in the control of train traffic.

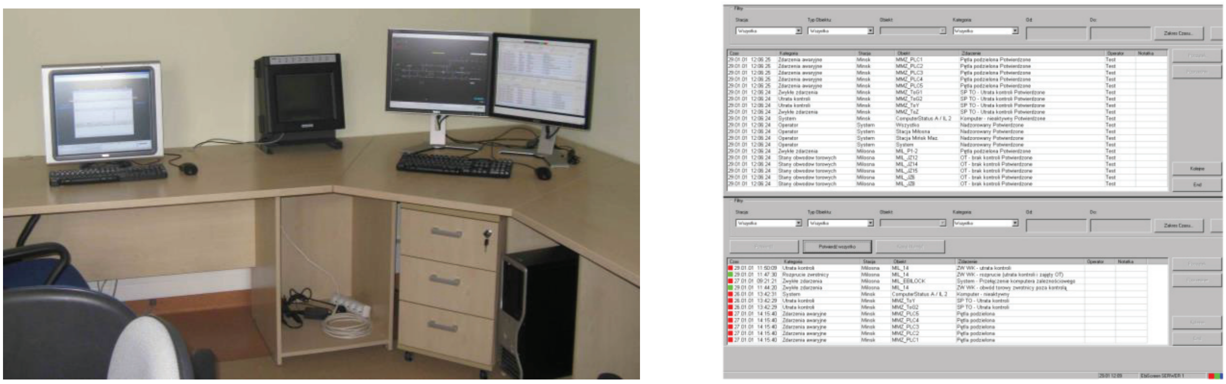
The EbiLock 950 system, whose model is shown in Fig. 4, a, is responsible for the correct control of train traffic at the railway station. The IPU 950 dependency unit operates on the basis of the ILC 951 (Fig. 4, c) dependency computer. It performs dependence functions in the EbiLock 950 system in cooperation with the superior system. To increase the certainty of the system operation, it was assumed that the ILC 951 unit contains two industrial computers. The first computer is active and it carries out all the system functions, the second one remains in a hot reserve state and it is ready to take over the system functions (Fig. 4, b) [4, 8].



a b c

Fig. 4 Model of the control system at the railway traffic station EbiLock 950 type: a – with the stand of STC object controllers [own elaboration]; b – Configuration of the IPU 950 dependency system [own elaboration]; c – The mechanical design of the dependency computer type ILC 951 [2], where: PSM – Power Supply Module, DEM – Module of Mass Memory and Network, CPM – Central Processing unit Module, IOM – Input/Output Module (Interface)

The stand of traffic dispatcher for railway station EbiScreen type (Fig. 5, a) was designed for the exemplary LABORATORY railway station. The EbiScreen system is an interface between the operator and the railway traffic station Ebilock 950 type dependency system. The executive elements of the traffic control at the railway station have been included in the computer application simulating railway signalling devices.



a b

Fig. 5 Model of the EbiScreen system stand for running train traffic at a railway station [5, 8]: a – View of the entire simulation stand; b – The monitor screen with events and alarms windows [2]

The TD 950 simulator (Fig. 6) allows you to: simulate railway station objects and enables changing their state and simulate train movement (route, length, speed, etc.). The simulator programme is loaded into one of the dependency computers and emulates the events on the railway station object [6, 20].

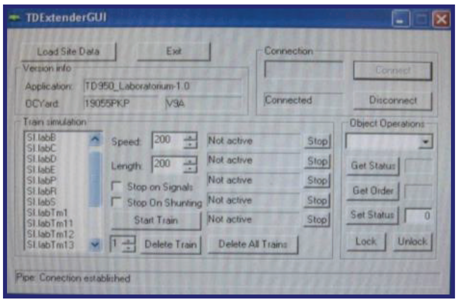


Fig. 6 The TD 950 simulator window for running trains in a railway station [5]

The computer SHL-12 line block system is designed for automatic regulation of train consequences on the railway line. Under laboratory conditions, the function of the actual steering panel is taken over by a computer programme simulating the operation of the SHL 12 line block system. It is possible to carry out train running tests through the railway route in both directions using the simulator of railway axle counters (Fig. 7, a) [9]. A diagnostic panel of type EZG 2101 is used to present information on the physical and logical status control points on the SHL-12 railway line block system (Fig. 7, b).

a b

Fig. 7 View of the laboratory stand of the railway line block system SHL-12 type simulator [own elaboration]: a – Computer simulator of axle counters occurring at consecutive intervals of the railway line; b – EZG 2101 type diagnostic panel and signalling lights simulators of consecutive blocks on the railway line

The train driving involving axle counters simulator can be carried out in three ways:

– automatic driving;
– driving manual setting – adding and subtracting one axes train entering and leaving the zone consecutively;
– manually according to the assumed number of train axes, after entering even number of axes in appropriate fields of particular active zones covered by CAN transmission.

Simulators of railway signalling devices used in the laboratory cooperate with physically existing and currently used railway traffic control devices, among which it is necessary to mention (Fig. 8):

– EAA-5 type railway switch drive;
– EHA-22 type 5-chamber trackside signal light;
– RSR-180 type wheel sensor;
– EHZ-7 type traffic signal light warning of drivers before entering on the level crossings;
– EHZ-5000 type warning target for engine-driver used at a level crossing.

a b c d

Fig. 8 Physically existing railway signalling devices located in the Laboratories at the University of Technology and Humanities in Poland in Radom [own elaboration]: a – EAA-5 type railway switch drive; b – EHA-22 type 5-chamber trackside signal light; c – RSR-180 type wheel sensor; d – EHZ-7 type traffic signal light and EHZ-5000 type warning target for engine-driver used at a level crossing

5. Conclusions

The process of training regarding railway signalling professionals is particularly important for the safety of railway transport. It allows to develop previously gained skills and behaviours. It increases also the level of efficiency in relation to the activities performed by the employees.

In the paper author presented the selected railway signalling devices simulators introduced for needs of specialists' training. The article contains the construction and operation descriptions of modern railway devices selected simulators, mainly the railway signalling. All simulators and device models collected in the railway signalling laboratories at the Faculty of Transport, Electrical Engineering and Informatics at the Kazimierz Pulaski University of Technology and Humanities in Radom correspond to real devices operated on Polish railway lines.

The simulators of railway signalling devices presented in the publication have been designed and manufactured in such a way as to provide a training base for railway traffic dispatcher's or other employees in the field of railway traffic control.

The advantage of the railway signaling devices simulators characterized in the paper is the fact that they are supplemented with an accurate model of the train traffic. It will allow students to become more familiar not only with the principles regarding operation of the particular railway signaling devices (also the devices used in the subway or trams), but also with the entire process of railway traffic conduction with their usage.

The latest solutions of simulators of transport devices use the virtual reality and a virtual three-dimensional environment. Virtual reality solutions also allow to significantly reduce space for the simulator.

The railway signaling devices simulators can be used in a wide range of scenarios, from training for railway traffic dispatchers to the introduction of new technic solutions. They enable realization of scenarios in many difficult situations related to exploitation of devices and railway traffic control. By using such simulators, it is possible to check whether planned upgrades of devices or investments will increase safety and bring expected results [1, 3, 16, 19].

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Investigation of the Model of Functioning of Production and Technological Potential of Subway Power Supply Departments

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Abstract

Management of production processes of the power supply system is a multidimensional task that implements various strategies for the use of production and technological potential and its efficient use. Carrying out organizational and technical measures to effectively solve the applied problems of the power supply system, it is necessary to use the assessment of the competitiveness of services of economic units that supply the subway with electricity. This is done through media analysis, which is part of systematic analysis and includes the business activities of departments. Depending on the volume of production, management policy, goals, objectives and many other factors, system requirements are formed for the management and provision of production and technological capacity of units that provide capacity. The study of the model of functioning of production and technological potential of these units as a subject of project management, maintaining the proper state of the power supply system, is the basis for formulating and solving the system unity of many problems of power supply processes. On the basis of the researched problem the possibility of development of models and methods of the decision of problems of maintenance of necessary level of efficiency of use of production and technological potential of subway divisions which supply the electric power is developed that will allow to construct corresponding algorithms of work.
KEY WORDS: *production and technological potential, information, model, methods, system analysis, algorithms, process*

1. Introduction

The main laws of construction, operation, development and adaptation of subdivisions of production and technological potential (PTP) of the subway electricity industry should be based on the principle of functional unity of their objects of system analysis: <PTP objects> - <PTP processes that provide the required state of the objects. The system that implement the corresponding PTP processes>. The efficiency of PTP largely depends on a comprehensive solution of many problems Z_{jk}, which are focused on achieving high end results of the subdivisions of the subway electricity industry (SSEI) with the rational use of labor, material and financial resources.

The set of tasks of Z_{jk}, aimed at ensuring the required level of efficiency and quality of operation of SSEI, should be formed taking into account the organizational, technological, technical, economic and social aspects of the subdivisions [1].

Organizational aspects of SSEI activities include the level of organization of labor and production. Technological aspects of the divisions of this farm necessitate the search for new technological solutions for production processes in order to intensify the use of production and technological potential of SSEI. Theoretical aspects of activity characterize the technical equipment of production processes of equipment subdivisions, buildings, structures, etc. Economic aspects characterize the efficiency of use in the production of all types of resources and the ultimate effectiveness of subdivisions [2, 3].

2. Research Materials and Results

Setting a set of tasks Z_{jk} ensuring the required level of efficiency of the **SSEI** must comprehensively take into

account all aspects of its activities.

The set of problems Z_{jk} can be divided by decomposition into two subsets:

$$\begin{aligned} & Z_{jk} = Z_{jk}\left\{Z_{jk}{}^{1}, Z_{jk}{}^{2}\right\}; \\ & Z_{jk}{}^{1} \cup Z_{jk}{}^{2} = Z_{jk}; \\ & j = 1,2,...,J; k = 1,2,...,K, \end{aligned} \tag{1}$$

where $Z_{jk}{}^{1}$ – a subset of tasks, the solution of which ensures the achievement of the required level of quality of the production processes of SSEI; $Z_{jk}{}^{2}$ – a subset of tasks that solve the rational use of resources; j – types of resources used to solve new optimization problems; k – stages of the life cycle of SSEI.

The main criteria for the systematic solution of many problems: the quality and efficiency of the SSEI processes, taking into account all aspects of its activities [4].

System criteria for the functioning of SSEI are formed on the basis of system analysis: quality and efficiency

Based on the system criteria, a set of tasks is formed, which ensure the optimization of the relevant processes and the final results of the operation of the SSEI.

The main purpose of the operation of the SES can be represented as:

$$\max_{U_i \in U} Y = \max_{U_i \in U}\left[X_i - \left(\sum_{j=1}^{J} R_{wi} + R_{oi} + R_{di}\right)\right], \tag{2}$$

where $\max_{U_i \in U} Y$ – maximum profit for the i-th period of time with the rational use of labor, material and financial resources; X_i – revenues of the enterprise for the *i*-th period of time; R_{wi} – labor and material resources spent on the operation of production processes SSEI in the i-th period of time; R_{oi} – overhead for the i-th period of time; R_{di} – depreciation for the full restoration of fixed assets.

Depreciation is mostly used to form the investment fund needed for modernization and technical re-equipment of units.

Overheads ensure the efficiency of SSEI management system.

Maximization of expression (1) is provided by solving the set of the problem.

Given the complexity of SSEI production processes, the mathematical model of SSEI operation can be represented as:

$$\begin{aligned} & F_{SES} = F_{SES}\left(F_{1i}, F_{2i}, F_{3i}, ..., F_{qi}\right); \\ & i = 1,2,...,N; q = 1,2,...,Q, \end{aligned} \tag{3}$$

where F_{SES} – mathematical model of functioning on the i-th period of time; F_{qi} – mathematical model of functioning of separate SSEI production processes on the i-th period of time.

Models of functioning of separate production processes of SSEI can be set on set of problems Z_{jk} the decision of which in system unity on the basis of wide application of modern methods and information technology provides achievement of high results of activity of divisions.

In general, you can write:

$$F_{qi} = f\left(Z_{jk}^{(1)};\ q = 1,2,...,Q; i = 1,2,...,N; j = 1,2,...,J; k = 1,2,...,K\right). \tag{4}$$

Consider the formation of problems for different hierarchical levels of PTP SSEI, the solution of which at different levels of hierarchies PTP involves the formation of appropriate system requirements, which are based on a comprehensive consideration of all objects and processes of PTP.

Comprehensive consideration of objects and processes of PTP involves their identification, which provides a formalized description. Identification of PTP can be carried out by means of system model which has to consider various aspects and properties of its functioning [5-7].

All tasks related to the functioning of PTP SSEI should be set and solved comprehensively, taking into account the functional relationships in accordance with the systemic purpose of the SSEI. According to the formula of system analysis we will write down:

$$\begin{aligned}
&D_{si} \to D_{jk}\left\{d_{jk} : d_{jk} \in D_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\};\\
&D_{ji} \to Z_{jk}\left\{z_{jk} : z_{jk} \in Z_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\};\\
&Z_{ji} \to M_{jk}\left\{m_{jk} : m_{jk} \in M_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\};\\
&M_{ji} \to A_{jk}\left\{a_{jk} : a_{jk} \in A_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\};\\
&A_{ji} \to P_{jk}\left\{p_{jk} : p_{jk} \in P_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\};\\
&P_{ji} \to S_{jk}\left\{s_{jk} : s_{jk} \in S_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\};\\
&S_{ji} \to H_{jk}\left\{h_{jk} : h_{jk} \in H_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\},
\end{aligned} \tag{5}$$

where, D_{si}, D_{jk} – system and local goals of SSEI operation in the i-th period of time; Z_{jk} – a set of tasks that need to be set and solved in a given period of time to ensure the required level of efficiency of the SSEI; S_{ji} – a set of systems (subsystems) that implements many tasks in a given period of time; P_{jk} – software and methodological tools for solving problems; M_{ji} – many methods of solving problems; A_{jk} – a set of algorithms for solving problems; H_{jk} – the results of solving the set for a given period of time.

The system model of SSEI operation can be written on a set of tasks.

The logical structure of the set of problems Z_{jk} is formed individually for each SES, taking into account its specifics [8].

The condition of system efficiency of solving a set of problems Z_{jk} is described:

$$E_s = \min_{\forall R_{jk}^{(i)}} \sum_{i=1}^{I} e_{jk}^{(R)} \wedge \max_{\forall O_{jk}^{(i)}} \sum_{i=1}^{I} e_{jk}^{(O)}, \tag{6}$$

where $e_{jk}^{(R)}$, $e_{jk}^{(O)}$ - respectively, the effectiveness of certain tasks that affect resource costs and the quality of operation of facilities and processes of PTP.

The structure of problems Z_{jk} can be represented in the form of an oriented graph:

$$G_{jk} \to G_{jk}\left(Z_{jk} : N_{jk}\right); j = 1,2,....,J; k = 1,2,....K; N_{jk} : Z_{jk} \to Z_{jk}, \tag{7}$$

where N_{jk} is the set of edges of the graph $G_{jk}(Z_{jk}N_{jk})$ that connect the individual problems and characterize the relationship between them and the priority of their solution [9].

An oriented graph $G_{jk}(Z_{jk}N_{jk})$ can be constructed using a matrix of adjacency of vertices $V = \left\|V_{jk}\right\|$, in which $V_{jk} = 1,0$, if the graph contains an edge (jk) and $V_{jk} = 0$ vice versa.

An oriented graph $G_{jk}(Z_{jk}N_{jk})$ can be constructed using an incidence matrix $W = \left\|\omega_{jk}\right\|$ in which:

$$\omega_{jk} = \begin{cases} 1,0; \text{if } j \text{ is the initial vertex of the edge } k;\\ \text{-1,0; if } j \text{ is the final vertex of the edge } k;\\ 0; \text{if in the opposite direction.} \end{cases} \tag{8}$$

The graph is constructed on the basis of such an algorithm [10]:

1. Selecting and setting the set tasks are solved by hierarchy levels PTP and ensure the implementation of local objectives T_{jk} that:

$$T_{jk} \to Z_{jk}\left\{z_{jk} : z_{jk} \in Z_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\}. \tag{9}$$

2. The choice of methods for solving many problems:

$$Z_{jk} \to M_{jk}\left\{m_{jk} : m_{jk} \in M_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\}. \tag{10}$$

The choice of methods for solving the tasks can be represented as a problem:

Given a set of tasks $Z_{jk} \to Z_{jk}\left\{z_{jk} : z_{jk} \in Z_{jk}\right\}; j = 1,2,...,J$ and a category $M_{jk} \to M_{jk}\left\{m_{jk} : m_{jk} \in M_{jk}\right\}$; $M_{jk} \in Z_{jk}; k = 1,2,...,K$. Any enterprise M_{jk} of category M_{jk} is called a covering of a set:

$$\bigcup_{j=1}^{k} M^{r} = Z_{jk} . \qquad (11)$$

A set of $M^{r}{}_{jk}$ is called a set that covers. If each $m_{jk} \in M_{jk}$ is set to the corresponding efficiency E_{jk}, then the problem of choosing methods for solving problems is formed as follows:

Find the set $M_{jk} \to M_{jk}\left\{m_{jk} : m_{jk} \in M_{jk}\right\}; j = 1,2,...,J$ that covers the set Z_{jk} with maximum efficiency $E_{jk} \forall Z_{jk}$. The problem can be solved by the method of linear programming.

3. Formation of algorithms for solving problems $M_{jk} \to A_{jk}\left\{a_{jk} : a_{jk} \in A_{jk}; j = 1,2,...,J; k = 1,2,...,K\right\}$. On the basis of the received algorithms A_{jk} information technologies of their realization which include corresponding software and methodical means and automated systems are developed.

4. Construction of a matrix of contiguity $V = \left\|V_{jk}\right\|$ and incidents $W = \left\|\omega_{jk}\right\|$.

5. Construction of an oriented graph $G_{jk}(Z_{jk} N_{jk})$, which characterizes the logical-functional relationship between problems. When constructing a graph G_{jk}, special attention is paid to the hanging vertices of the graph, which correspond to the input problems. You can find hanging vertices on a graph using the adjacency matrix $V = \left\|V_{jk}\right\|$ of the graph $G_{jk}(Z_{jk} N_{jk})$, which is used to determine the vector $V(l)$ with components for each vertex $l = (l = 1, L)$.

$$V^{l} = \sum_{k=1}^{L} V_{kl}; V_{l} = \sum_{j=1}^{L} V_{jl}; L = \sum_{j=1}^{J} Z_{jk} . \qquad (12)$$

According to (12) V_l is the sum of the elements of the l-th row and V^l the l-th column of the adjacency matrix $V = \left\|V_{jk}\right\|$. The value V_l determines the number of edges coming from the vertex l, and V^l - the number of edges entering it. The edges coming from the top V_l indicate that the solution of the problem Z_{jk} is necessary to solve other problems, and the edges included in it indicate the need to solve the corresponding problems. The results are basic for solving problems Z_{jk}. And if $V_l = V^l = 0$ then the vertex will be isolated, if $V_l = 0$ - then the vertex will be deaf, if $V^l = 0$ - then hanging. It can be concluded that the graph $G_{jk}(Z_{jk} N_{jk})$ is a logical-functional and information model for solving many problems Z_{jk} to ensure the efficient operation and use of production and technological potential of SSEI.

6. Determining the diameters of the model for solving problems Z_{jk}, which describes the length of the maximum path (d_{jk}) between the hanging and deaf vertices:

$$d = \max_{j,k} d_{jk}, j \in J; k \in K, \qquad (13)$$

where the length d_{jk} between the hanging j and deaf k vertices is equal to the number of edges that create this path, and characterize the set of problems, the solution of which ensures the achievement of the system goal T_s. Determining values d_{jk} is reduced to the standard problem of finding the shortest path in a graph for each pair (j,k), such that $j \in J, k \in K$. This problem can be solved by the method of dynamic programming.

7. Optimization of the model of problem solving, which consists in building an optimal model by the criterion of structure $G_{jk}(Z_{jk} N_{jk})$. The criterion for optimal construction of the model can be either a mathematical expectation of the values the indicators of target $T_s(T_{jk})$, which are obtained on a given structure $G_{jk}(Z_{jk} N_{jk})$, or the probability that the values of these indicators will satisfy the given values.

Construction and optimization of the model $G_{jk}(Z_{jk} N_{jk})$ provides a systematic solution to the problem of achieving the required level of efficiency of operation and use of production and technological potential of SSEI.

3. Conclusions

Due to the systematization of the main criteria for the effectiveness of management of the use of production and technological potential of the departments of the energy sector of the subway, we can begin to implement a system model for optimizing the required level of use of production and technological potential.

This model reflects the entire life cycle of formation and management of production and technological potential, allows us to conclude that each process is responsible for obtaining inputs and production results, maintaining the proper

state of the power supply system, is the basis for formulating and solving system unity of many power supply processes.

It is determined that the quality of technological equipment of production and technological processes affects the level of use of production and technological potential for repair and maintenance of subway energy facilities. A set of measures to optimize technological and production processes leads to a reduction in labor intensity, increase productivity and rational use of labor, material and financial resources.

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Logistics Potential of the Railway as a Key for Sustainable and Secure Transport Development

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Abstract

The railway should be considered as a basis for a sustainable and secure society. More than ever, rail proves to promote economic development, sustainable mobility, environmental protection and international integration. Logistics potential is one of the defining features of railway transport. Logistics potential is a system of complementary components that characterize the capabilities of the investigated object and can be used to justify strategic directions for development. The research goals include justifying and interconnections building for a system of indicators forming enterprise logistics potential to help with decision making considering sustainable and secure transport. The paper presents a comprehensive component interconnections system for the logistics potential of railway enterprises. Logistics potential assessment allows identifying reserves for efficiency and effectiveness improvement for the railway enterprises and the railway industry as a whole; influences the development prospects for the industry in the light of current trends.
KEY WORDS: *sustainable transport, secure transport, railway enterprises, logistics potential of the railway, Enterprise logistics potential index (I_{ELP})*

1. Introduction

The sustainable and secure society development is considered a high priority throughout the world. World-famous European Horizon 2020 program is one of the tools to ensure a sustainable and secure society [1]. This initiative supports research and innovation aimed at developing a sustainable and secure society. One of the contemporary societal challenges highlighted in this program is smart, intelligent, green, secure and integrated transport creation. This, in turn, will ensure a competitive European transport system creation that will incorporate resource efficiency, environmentally friendliness, security and integration for the benefit of the economy and society as a whole. The railways should be considered the heart of the transport system for a sustainable and secure society. In line with the vision developed in Horizon 2020, rail in a safe and sustainable society has the following basic qualities:

- competitive in the price-quality ratio;
- eco-friendly (key for environmental issues addressing: greenhouse gas emissions problem, air pollution reduction, energy security achievement);
- primary in other transport types interaction chain;
- indispensable for economic growth supporting;
- the largest socially responsible employer;
- progressive in digitalization area.

Considering the railways importance for a sustainable and secure society ensuring, the question of finding ways for making strategic, rational decisions is urgent. One of the defining methods is logistic potential assessment. The logistics potential assessment practice is widely used at the macro level for countries, regions, supply chains and industries assessment, but it is equally important for the micro level as well, namely for the enterprises evaluation. Studies demonstrating some issues regarding logistical capacity assessment: country [2, 3], region [4, 5], supply chains [6, 7], enterprises [8, 9]. However, many problematic provisions have remained out of the researchers' scope, and therefore require further research. The available logistical potential magnitude measuring issues and the level of its usage by enterprises have not been sufficiently developed.

2. Research Methodology

Alternative methods for evaluating logistics potential include expert, rating, index and statistical ones. There is an international system for evaluating the logistic efficiency index used to evaluate the logistics services market development level - Logistics Performance Index (LPI) [10]. The expert method was used as a basis for this study. Top countries in this rating use more sophisticated statistical and dynamic methods for logistics potential assessment locally. Taking into account the peculiarities of railway enterprises, the authors propose a method of logistics potential evaluation that incorporates statistical and expert estimations. Logistics potential evaluation method for railway transport enterprises is proposed and described in detail by the authors in the article [11]. In the study a system approach was used to represent railway enterprise logistics potential index as a coherent system, and component interrelations for this index system have been substantiated.

3. Results

Railway enterprises logistics potential evaluation system is a complex and composite process involving a set of interrelated and complementary elements including: subject; object; purpose; principles, criteria; indicators; units (scales) of measurement; methods; evaluation decisions; results.

Schematically, a railway enterprises logistics potential evaluation system is presented in Table.

Table

Railway enterprises logistics potential evaluation system

System components	The issue to address	Characteristics
Subject	Who needs an indicator assessment?	Business owners; Enterprise Management; Cross-industry competitors; Investors; Business partners; Transport industry participants; State leadership; International organizations.
Object	What to evaluate?	Railway enterprises logistics potential
Purpose	What is an evaluation purpose?	Obtaining practical tools for making sound management decisions.
Information support	What information sources are to be used?	Internal (enterprise reporting); External (expert assessments, public reports, transportation journals)
Principles	What principles are prioritized in the evaluation process?	Systematicity; Objectivity; Complexity; Consistency; Informative unity; Accessibility; Simplicity; Hierarchy; Integrity; Specificity; Effectiveness.
Methods	What methods are to be used?	Formalization; Analysis; Synthesis; Statistical studies; Expert Surveys.
Indicators	What to use for evaluation?	Quantitative: absolute, relative, complex, statistical; Qualitative: expert assessments.

Railway enterprises logistics potential evaluation system components integrity and coherence is highly important for the interpretation of the correct results. Logistics potential components reflect permanent significant cause and effect relationships. All the constituent elements interact and influence each other. The components interconnections system for the railway enterprises logistics potential is represented schematically (Fig. 1).

Components interconnections detailed explanation for the railway enterprises logistics potential.

K1-K1: The technic- technological component is the basis for enterprise competitiveness ensuring based on the technical and production potential development. This component implies stable engineering and technical support operations, which together form up the enterprise material and technical base and provide all the requirements for its work. State of technical and technological support, in particular the number of rolling stock in operation, the number of active railway stations and terminals, modern information technologies affect the actual transportation possibilities, their intensity and the maximum possible transportation distances.

K1-K2: High performance of the technic-component ensures positive results for the economic component. Sufficient rolling stock and proper operation of railway stations, improvement of equipment performance and quality, use of advanced materials and processing technology improvement - all these factors make it possible to maximize demand, affect the profit making process and contribute to investment climate improving.

K1-K3: The rolling stock condition and railway stations have an impact on environmental performance: pollution and traffic safety. Outdated rolling stock provide negative environmental pollution and traffic accidents high likelihood. Railways transport is considered to be one of the most environmentally friendly compared to other transport types, but the technic-technological component state requires modernization to reduce noise, vibration and pollution of air, water

and soil.

K1-K4: High-tech enterprises require appropriate competencies from employees. Modern rolling stock, technology upgrades, IT solutions require new competencies for employees to operate, maintain and repair properly.

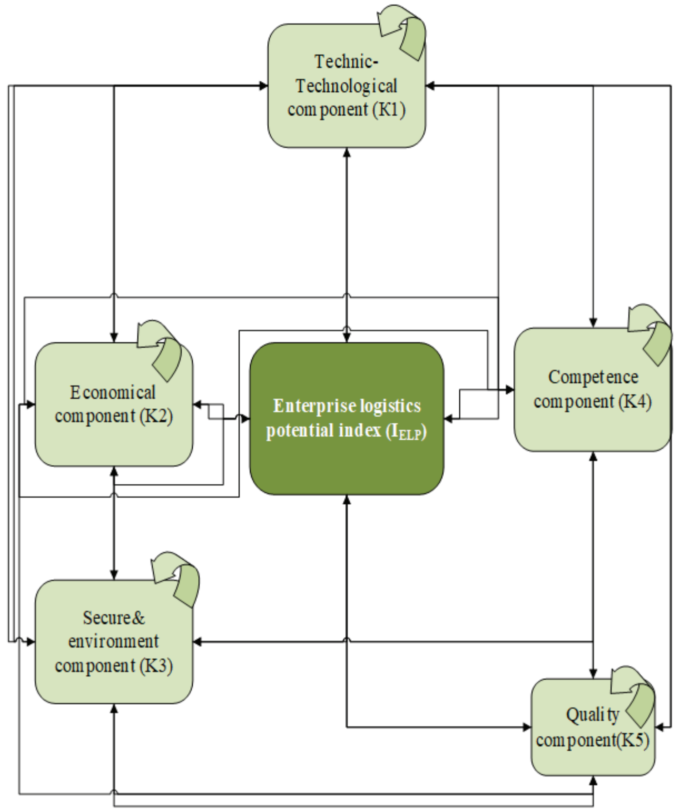

Fig. 1 The components interconnections system for the railway enterprises logistics potential

K1-K5: The rolling stock condition, its reliability and quantitative support, optimal transportation routes, well-organized work of stations and technological support of transportation have an impact on the company quality indicators, namely services provided timely, fully implemented and without errors.

K2-K2: Railway transport development is the basis for country's transport system, is a prerequisite for all sectors of the economy effective functioning and contributes to economic growth. The economic component prioritizes the state of the enterprise and reflects the main purpose of any profit-making enterprise. It also determines the pace of enterprise development, its level of competitiveness, investment climate. Economic indicators determine the future expansion or production modernization conditions, the creation of industrial, social infrastructure, opportunities for the personnel competencies development, servicing conditions quality improvement, the enterprise eco-responsibility promotion.

K2-K1: All technic-technological solutions (updating and modernization for rolling stock, railway stations, terminals, etc.) require investments attraction and proper development. The greater the investment and profit of the enterprise, the greater the opportunity to improve the technic-technological component state.

K2-K3: The enterprise high economic results make it possible to invest more in environmental solutions. The enterprise high economic results indicate large transportation volumes, therefore the harmful impact on the environment increases. The purpose of the company is to strike a balance between economic and environmental components.

K2-K4: First thing to consider: the company is under the person's leadership. Performance, enterprise development influences the employees development, expansion and improvement of their competencies. Businesses should create working conditions that would ensure a rational work organization, take into account the personnel health and safety conditions, and enhance the employees' professional competences. Costs that contribute to improving human productivity can be considered as investment for the enterprise itself.

K2-K5: An enterprise with positive economic indicators, attracted investments, provides quality services accordingly.

K3-K3: Innovative technologies in the field of ecology are increasingly taking precedence over the consumer's attitude to the environment on the railways. The environmental component involves the complete transformation for enterprise strategies, processes, and supply chain participants structures in accordance with resource-saving, energy-efficient and environmental technologies. Key guidelines for railway enterprises include providing smart, safe, sustainable and green transport. Rail transport is in dire need of innovative technologies that would improve environmental safety, quality and reliability of operation, and traffic safety. Greening is the railway enterprise ability to ensure rolling stock, infrastructure and resources usage while preserving the natural environment and reducing the

transportations negative impact on it.

K3-K1: Eco-solutions introduction require enterprises technic-technological component modernization and updating and introduction of resource-saving and energy-efficient technologies. For example, the atmospheric emissions reduction from diesel locomotives can be achieved by railway sections electrification (switching from diesel locomotive traction to electric), noise and vibration reduction through rolling stock and infrastructure upgrades.

K3-K2: Achieving a balance between economic and environmental components is the goal of modern businesses. Adherence to international environmental standards increases the investment attractiveness of the enterprise. Environmental focus is a trend today that affects reputation and therefore directly affects economic performance.

K3-K4: One of the most important problems for the environmental component is the lack of qualified specialists in the area. New trends and eco-solutions introduction require specially trained employees in the field: green logistics, sustainable and safe transport. It is necessary to improve employee skills in the field of environmental protection and use of natural resources. In addition, the positive environmental component results imply moral and material incentives for employees for environmental protection activities.

K3-K5: Environmentally safe services provision.

K4-K4: In the context of railway reforming, the competencies of logistics and Supply Chain Management specialists are extremely important; they can take rail to a new level. The basic standards of professional competence are described in the European Qualification Standards for Logistics Professionals, developed by the European Logistics Association (ELA) and recognized worldwide [12]. ELA standards are updated regularly to meet new market trends. When competence component is analyzed, the basic principles of ELAQF Qualification Standards for logistics competence were used.

Investments in human capital development are actions that enhance workers professional skills and productive abilities and thus affect labor productivity. In the long term, employees receive greater income and greater job opportunities from upgrading their skills. Concerning the enterprise benefits, they include competitive employees, introduction of new technological, environmental solutions, improvement of economic results and services quality.

K4-K1: The components relationship is characterized by the principle understand the impact of technological innovation on supply chain design. investment in human capital is a qualitatively new workforce creation with a high level of qualification, knowledge of modern technologies and ability to perform work of greater complexity. Specially trained employees easily master and implement new technic-technological solutions.

K4-K2: A potential attention is given to the principle understand leading and lagging Key Performance Indicators (KPIs). The human capital improvement and development is a key for enterprises economic situation improvement. Railway workers who are highly skilled, flexible, ready to develop their lifelong competencies and able to adapt to different production conditions are a necessary element for economic goals achieving both for railways and the country as a whole. Costs for human capital development should be considered as investments because such expanses will result in increasing future revenue.

K4-K3: The primary principle is Implements sustainable transportation management programs and understand how sustainability might impact on the supply chain. Highly qualified ecology workers introduce modern eco-solutions, adapt world eco-practices to national rail transport. Ecological control over production processes and industrial zone conditions is carries out in each subdivision.

K4-K5: The principles of customer service are followed, in particular understand use social media in customer service processes. The current quality management system has significantly changed the educational requirements and employee competencies. Employees who do not cease to develop and improve their professional competencies implement modern effective solutions in the company, timely and clearly carry out their direct responsibilities, help to improve general level of stuff effectiveness.

K5-K5: The rail transportations quality is considered as a combination of entities and objects of rail transportation throughout the transport chain to meet the needs of consumers.

K5-K1: Meeting the international and domestic service quality standards requires an appropriate level of technical and technological support. Rail transportations quality is determined by the compatibility of infrastructure, rolling stock and information technology.

K5-K2: Quality services ensure high economic results in the enterprise.

K5-K3: Modern quality services are not only technologically clear and effective, but also those that meet environmental standards and requirements.

K5-K4: The highest quality requirements for employees: understand customer service procedures; Use Key Performance Indicators (KPIs) to measure customer service; understand multichannel communication with the client; understand the basic functions of customer relationship management (CRM).

K1-I_{ELP}: Technical and technological provision as a whole ensures all the enterprise operation.

K2-I_{ELP}: Ensuring the economic situation of the industry and the market as a whole.

K3-I_{ELP}: Environmental safety prioritizing and adherence to environmental norms and standards in transport, promotion of energy-saving technologies.

K4-I_{ELP}: Personnel potential is an indispensable component in achieving positive performance.

K5-I_{ELP}: The qualitative indicators system characterizes the efficiency level of the logistics system.

I_{ELP} –K1: Opportunities for upgrading / updating technic-technological components.

I_{ELP}–K2: Impact on enterprise economic performance, investments attraction, usage of transport resources in accordance with market demands.

I_{ELP} –K3: Adoption and implementation of international environmental standards.

I_{ELP} –K4: Perspective of the entire industry and, accordingly, the growing weight of the professional competencies in logistics and Supply Chain Management.

I_{ELP} –K5: Meeting the demand for providing quality of logistics activities.

The logistics potential evaluation system interconnections for railway enterprises have been fully identified and described.

4. Conclusions

Among all the components of the railway enterprises logistics potential Secure&environment component (K3) should be considered a key one for sustainable and secure transport development. However, the pairwise interconnections for all the components identified in the study testify to the coherence and integrity of the railway enterprises logistic potential system. In the economy, such connections generate synergy - the various components and metrics so greatly affect each other that they can achieve more in a complex than their individual usage with the same purpose. The synergism presence and the ability to manage these effects creates a specific competitive advantage that is implemented at the enterprise or industry level as a whole. Such a compatible impact must be taken into account in the enterprise management system and adjusted to the enterprise's strategic goals, so research plays an important role in building an effective enterprise management system.

Considering the fact that a combination of elements and components is used for railway enterprises logistics potential evaluation, the synergistic effect is of strategic importance here.

Therefore, the manifestation of a synergistic effect in logistics potential evaluation for railway undertakings means that the level of logistics potential (I_{ELP}) is provided by:

- opportunities realization for new technologies implementation;
- long-term economic results;
- sustainable and secure transport development;
- demanded professional competencies in logistics and Supply Chain Management;
- continuous improvements affecting services quality - the key to success in competition.

When railway enterprise logistics potential is evaluated, a properly organized system approach is of great importance: some set of components that are focused on achieving one common goal is to be identified, connections are to be evaluated, a system is to be build, for which a principle of synergy is applicable and result in a qualitative increase in logistics potential.

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Conceptual Design to Reduce Slush Accumulation in the Wheel Arches of Passenger Cars

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Abstract

Vehicle movement in the autumn-winter-spring period is conditioned by local atmospheric conditions. Increased intensity of rainfall, and at negative snow temperatures reduces the coefficient of adhesion. In addition, the accumulation of a layer of snow causes the possibility of slush formation on the road. Slush, a mixture of snow, ice, sand and chemicals, e.g. salt, directly affects road safety and the obtained acceleration values in driving processes. In such environmental conditions, the accumulation of slush occurs between the wheel and the wheel arch of the vehicle, resulting in increased resistance to motion and increased loads on the suspension and steering system. The article presents the conceptual concept design of the slush removal system from the wheel arches of a passenger car.
KEY WORDS: *vehicle traffic safety, slush, slush removal system*

1. Introduction

In winter, environmental and surface features have an impact on road safety [1-4]. Acceleration values obtained in given conditions determine the driver's behavior and decisions that affect the dynamics of vehicle movement [5-7]. In winter, the adhesion coefficient can change its value in a fairly wide range from close to zero, on an ice-covered road, even to a value above 0.7 for clean and dry surfaces [8-10].

Lowering temperatures below 0°C may cause a number of phenomena that adversely affect the vehicle's traction. If the wheel moves on a layer of snow, as a result of the flakes sticking to the tread surface, the tire surface association may occur in ice - ice or snow - snow pairing. Snow occurs in many different varieties depending on the temperature, layer thickness, retention time, traffic intensity, air humidity and other factors. It should be remembered that the deterioration of traction conditions in winter is caused by the introduction of additional environmental factors to the tire surface, snow or ice. In this situation, the adhesion between the tire tread and asphalt is significantly weakened or completely disappeared, and the friction resulting from hysteresis becomes dominant.

In given environmental conditions, the surfaces are covered with running melting snow, slush (Fig. 1). These conditions of interaction of the tire with the road surface directly affect the safety of the vehicle movement, and drivers must quickly and confidently make decisions and strategies for dealing with the conditions on the road.

Fig. 1 View of the surface covered with slush

The scope of vehicle traffic safety also depends on the possibility of slush accumulation or snow itself between the wheel and wheel arch (Fig. 2). Freezing slush in the wheel arch can cause mechanical damage to the steering system, suspension or the tire itself [11]. Slush is not only melting snow, but also various chemicals and a large amount of salt. Currently, slush is removed from cars in two ways:

- mechanically - by the user using the strength of his own muscles and / or tools;
- thermal - the car is parked in a heated garage or the air temperature increases spontaneously.

Fig. 2 Photographs showing the problem of retaining mud in wheel arches

The constant development of the automotive industry has contributed to the fact that currently motor vehicle users have at their disposal a whole range of facilities that care for both safety and comfort of travel, and car manufacturers are constantly adapting to the needs of customers and are introducing new innovations in their products. This is due to advances in technology and the introduction of innovations on the automotive market. Safety systems such as seat belts, airbags, ABS or ESP have significantly reduced the number of victims and injured in car accidents. The trends of introducing individual equipment elements affecting the scope of safety of the driver, passengers and the environment are presented in Table 1.

Table 1

Numerical results of individual elements of additional equipment in passenger cars [12]

years of production	total number of cars	manual air conditioning	automatic air conditioning	electric windows	ASR	ABS
until 1989	2037	174	91	448	50	413
from 1990 to 1994	3719	582	430	1840	313	1936
from 1995 to 1999	21313	6766	6492	16424	5195	16650
from 2000 to 2004	66076	22631	30933	58755	29402	60264
from 2005 to 2009	86852	27049	47978	79631	50777	82209
since 2010	85901	23281	50425	76311	58790	79506

In each subsequent age group of vehicles, their number increases, as well as the number of individual elements of additional equipment. Observing the indicated trends, it can be assumed that customers buying passenger cars attach more and more importance to additional equipment, and the vehicle manufacturers themselves are willing to retrofit their cars with new, innovative systems. The launch of the new accessory system is also an extremely important achievement for the car manufacturer. In such a situation, it is important for manufacturers to offer as many different accessories as possible, including innovative ones, to attract customers. Design innovations [13-16], development of used materials [17, 18] and skills of operators [19, 20] can contribute to increased operational safety [21] and environmental protection. One of such systems may be an innovative slush removal system from car wheel arches. The article presents an conceptual concept design of a slush removal system from the wheel arches of a passenger car.

2. Construction Assumptions

When designing additional equipment, pay attention to the requirements in accordance with PN-S-76001 for four aspects: mechanical, electrical, operational and economic:

“1) from the mechanical point of view: material compliance with standards, compliance of main and assembly dimensions, mechanical strength especially in rotating elements, selection of appropriate anti-corrosion coatings, resistance to vibrations, shocks and moisture, resistance to low and high temperature , durability, a certain degree of noise at work;

2) from the electrical point of view: sufficient insulation resistance, electrical strength, minimum transition resistance at the contacts, sufficient electrical overload, allowable temperature increases of individual components (windings, contacts, commutators, etc.);

3) from the operating point of view: fire, explosion and service safety, operational reliability and quick readiness for work, simplicity of assembly and operation, durability and easier access for inspection and maintenance;

4) from an economic point of view: low manufacturing costs, interchangeability of parts, possibly small dimensions and low weight”[22].

The project assumed that:

- system operating temperature range is from -40^{o}C to + 20^{o}C;
- the system will be resistant to vibrations and atmospheric conditions;
- the system will be resistant to chemicals encountered on the road;
- the system will be electrically powered.

3. Place in the Wheel Arches of a Passenger Car

To assess the applicability of the slush removal system, it is necessary to analyze the place in the wheel arch of a selected passenger car. It is necessary to recognize the suspension type and body type. After theoretical analysis, it is necessary to assess the actual clearances between the wheel and wheel arch. An example diagram of the self-supporting body skeleton is given in Fig. 3, and the result of the analysis of the space between the mounted car wheel and the wheel arch is shown in Fig. 4. An example of the passenger car on which the analysis was carried out was Ford Focus manufactured in 2016 equipped with 205/55 R16 tires.

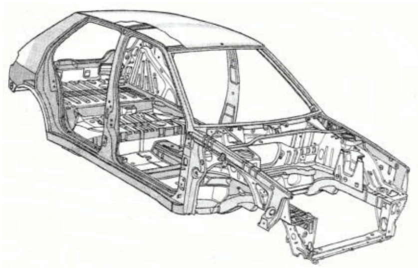

Fig. 3 An example of the body structure of a self-supporting modern passenger car [23, 24]

Fig. 4 Photograph showing the amount of space in the right wheel arch of a passenger car when turning the wheel left (left) and right (right)

When determining the amount of available space in the wheel arch of a passenger car for the right wheel, the distance between the tire and the nearest vehicle element was obtained. Extreme values were measured in three different configurations. The test was carried out with the steering wheel turned to the maximum left, with the wheels set straight ahead, and with the steering wheel turned to the right. For the first setting this value was 80 mm, for the middle setting 70 mm and for the third setting 60 mm. The obtained results allow estimating the amount of free space when the vehicle is stationary. However, one should take into account the possibility of reducing these values due to the work of the suspension when overcoming unevenness, vibrations, as well as due to the change in the size of the wheel size by the car user in relation to the series mounted.

4. System Construction

The slush removal system should be characterized by short operation time, energy efficiency, low cost of performance, reliability, no impact on the vehicle during breakdowns and universality. In addition, the developed structure must fit into the skeletons of car bodies used so far. The proposed construction of the slush removal system are heating mats installed in the wheel arch of the car.

The task of heating mats is to generate heat. Similar items of equipment are already used in passenger cars. An example of the use of electric heating is electric seat heating, heating the rear and windshields, and mirror heating. Such a design solution reduces the production costs of the system, and the operation and possible failure of the system used to remove slush does not adversely affect other passenger car systems.

The advantages of this design are simple design, low cost of manufacture, as well as the possibility of using it in any vehicle that is equipped with a 12 V electrical system. An additional advantage is the ability to operate at any time, regardless of the warming of the engine unit and the coolant. The use of heating mats means that the dimensions of the system used will be small, and their shape can be easily adapted to any type of wheel arch. The disadvantage is the slow operation and consumption of electricity to generate the temperature necessary to remove slush, and thus the use of such a system generates costs for the user.

4.1. Heating Element

Electric heating mat working on 12V power supply is an element that can be freely shaped in terms of size and profile. In order to protect against mechanical damage, moisture and other factors affecting the heating mat, it was decided to cover it with an additional element. The cover should be designed of durable material that is chemically resistant and will be resistant to impact and other random external factors. Another requirement is the need for heat conduction.

The material that meets the accepted requirements is steel. The assembly of the executive system next to the engine compartment means that we can assume temperature values from -40 to 125°C. The type of location also affects the occurrence of chemicals and a large amount of moisture in any form. The most difficult task is to determine random factors such as stone impacts, the pressure of the pressure washer and other unpredictable events. Using the Newton's second law, the necessary thickness of the heating element shell was calculated. The calculations assumed the possibility of a perpendicular impact with a stone with a mass of $m = 50$ [g], which was accelerated by the wheel of a vehicle traveling on the highway at the maximum speed allowed in Poland. After analyzing the requirements, it was decided to use 2H13 stainless steel. After calculations it was shown that the thickness of the shield with the assumed impact force $F = 200$ [N] must be at least 2.8 [mm]. The safety factor has been taken into account in the calculations [25]. Taking into account the obtained result, it can be assumed that the thickness of the entire heating system including assembly should not exceed 5mm. Bearing in mind that the minimum amount of free space between the wheel and wheel arch was 60 [mm], it can be stated that the executed method allows the system to be used without changes in currently used constructions. For further calculations, the thickness of the heating mat cover $g = 3$ [mm] was assumed.

4.1.1. Heating Mat Power

For calculations, it was assumed that the cover of the heating mat will have dimensions of 430 × 120 × 3 [mm]

and its mass will not exceed 1.3 [kg]. It was also assumed that the task of the heating mat would be to reach a temperature of + 20°C, which was considered sufficient for melting slush. The scope of work was set at temperatures from -40°C to + 20°C.

$$Q = m \cdot c\left(T_2 - T_1\right), \tag{1}$$

where Q – energy necessary to change the temperature of the cover; m – sheath mass; c – specific heat of steel $c = 460 \dfrac{J}{kg \cdot k}$.

$$Q = 1{,}3 \cdot 160\left(20 - (-40)\right) = 35880\left[J\right]. \tag{2}$$

Assuming the time needed to warm up the heating mat and cover and the efficiency of the heating element at 85%, you can estimate the power of the slush removal system in winter conditions (Table 2).

Table 2

Calculation results

t_1 = 120 [s]	t_2 = 300 [s]	t_3 = 600 [s]
$P_{t_1} = \dfrac{Q}{t_1 \cdot \eta} = \dfrac{35880}{120 \cdot 0{,}85} \approx 352\left[W\right]$	$P_{t_2} = \dfrac{Q}{t_2 \cdot \eta} = \dfrac{35880}{300 \cdot 0{,}85} \approx 141\left[W\right]$	$P_{t_3} = \dfrac{Q}{t_3 \cdot \eta} = \dfrac{35880}{600 \cdot 0{,}85} \approx 71\left[W\right]$

In order to check whether the obtained power of the heating elements would not affect the battery operation, calculations were made for the heating time of the 300 [s] mat.

$$Q = P_{t_2} \cdot t_2 = 141 \cdot 300 = 42300\left[J\right]. \tag{3}$$

The capacity of currently used batteries in modern passenger cars is about 75 [Ah]. Assuming the use of two heating elements at the same time, the absolute proportion of the battery load by the heating mats was calculated.

$$Q_A = q \cdot U = 270000\left[As\right] \cdot 12\left[V\right] = 3240000\left[\mathrm{J}\right]; \tag{4}$$

$$q = 75[\mathrm{Ah}] = 75*3600[\mathrm{As}] = 270000[\mathrm{As}]; \tag{5}$$

$$\frac{2 \cdot 42300\left[J\right]}{3240000\left[J\right]} \cdot 100\% \approx 2{,}6\%. \tag{6}$$

The level of utilization of the sample battery capacity in a passenger car when using two heating mat systems is at the level of 2.6%. Comparing the power of the proposed systems to the power of commonly used dipped headlights in passenger cars, it can be seen that it is at a similar level (dipped headlights consume from 110 W to 120 W). Lighting in the car alone can draw up to 400 W. This means that an additional power consumption of 300 W for 5 minutes will not be dangerous for the car's electrical system and the battery.

Taking into account the supply of the heating mat directly from the alternator, the necessary current and the absolute load of the heating mats were calculated. In the case of an example car - Ford Focus 2016, the alternator has a charging current of 150A [26].

$$P = U \cdot I; \tag{7}$$

$$I = \frac{P}{U} = \frac{2 \cdot 141\left[W\right]}{12\left[V\right]} = 23{,}5\left[A\right]; \tag{8}$$

$$\frac{23{,}5\left[A\right]}{150\left[A\right]} \cdot 100\% \approx 15{,}7\%. \tag{9}$$

It can be considered that it is possible to use a slush removal system in an electrical system with a modern alternator.

A heating time of 5 minutes is optimal for system operation, as it ensures both sufficient response time and moderate use of the alternator and battery. However, in cars more frequently used in extremely winter conditions, a system with a longer operating time or with stronger heating mats should be used, while in cars with weaker alternators it is possible to extend the system's operation time with a decrease in the power of heating elements.

Fig. 5 presents the views of the 3D model made.

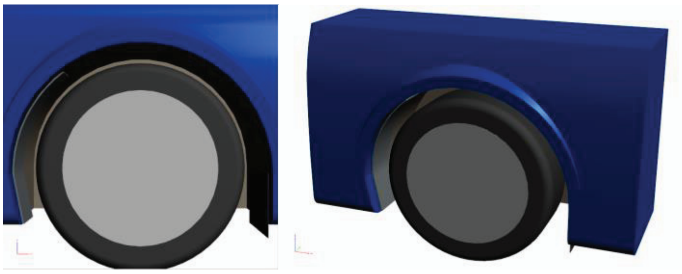

Fig. 5 An example of placing the heating mat in the wheel arch - 3D model

The designed 3D model shows the front right wheel arch of a passenger car along with the executive system of a slush removal system in accordance with the adopted concept based on the use of heating mats.

5. Conclusions

The proposed conceptual concept design of the slush removal system could be an optional additional equipment for vehicles increasing the scope of traffic safety in the autumn-winter-spring period. The low weight and dimensions allow free installation in the free space between the wheel and the wheel arch of the vehicle. The use of the system would minimize the possibility of the accumulation of slush or snow itself, resulting in reduced steering and suspension loads. The resistance to motion would be reduced [27, 28], and the possibility of mechanical damage to tires would be reduced.

The proposed variant using heating mats can also be used in the wheel arches of the rear wheels and in the chassis of a passenger car. This can significantly reduce the problem of snow accumulation and slush sticking to the vehicle during its movement. An important factor in this case will be the proper placement of heating mats and ensuring a sufficient amount of electricity in the vehicle.

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Perspectives on Small and Medium-Sized Enterprises' Participation in Public Procurements of Innovation in Klaipėda Port

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Abstract

Innovation is one of the most important factors for the economic growth of a country, as well as it has a direct impact on the society and the private sector of a country and still limited used in the port of Klaipėda. The Innovation Union initiative of the EU is one of the seven objectives of the Europe 2020 strategy for ensuring a smart, sustainable and inclusive economy. Small and medium-sized enterprises (hereinafter 'SMEs') account for about 99.5% of the total business in Lithuania and are one of the main factors of the economic growth of the country. The value added of SMEs in Lithuania amounts to 69.9%, compared to 56.8% EU average. These companies create three quarters of jobs in Lithuania and two thirds in the EU. The port and the enterprises related to its operations provide more than 58,000 jobs and 6.13 % of the Lithuanian gross domestic product (GDP) (more than 800 economic agents).
KEY WORDS: *public procurement, innovation, innovative, management, small and medium-sized enterprises*

1. Introduction

Right from the beginning of the legal regulation of public procurement procedures, the arrangements for the procurement of goods, services or works have been the subject of public criticism due to inadequately high prices of goods, services or works paid by contracting authorities (hereinafter 'service recipients') from the taxpayers' money. Another problem is insufficiently secured conditions for the fair competition between suppliers (hereinafter 'service providers') as regards contracts, and the transparency-related issues. Public procurement is a relatively new practice for public sector agencies that is linked to the ideas of the new public management to take over business management principles and apply them to the activities of public institutions, thus saving public funds, allocating them more efficiently and promoting the cooperation between the public and private sectors. In 2013, Lithuania chaired the activities of the European Public Procurement Network and identified the dissemination of good public procurement practices and the resolution of practical problems as the major priorities during its chairing. Public procurement has been identified as one of the instruments that could contribute to the priorities of the Europe 2020, a strategy for smart, sustainable and inclusive growth [13; 32].

Each country can make different decisions in order to increase the efficiency of public administration based on country's individual historical experience and ability to adapt to a rapidly changing global society. In Western Europe, the widespread application of innovation policies to public procurement in cooperation with SMEs allows to see the practical advantage of the new public management to the public interest [9]. The arguments for public procurement as a separate tool to promote innovation policy at both the EU and national level, as well as the importance of innovation policies for improving the management of the public procurement process, can be observed in the works of the researchers since 1970. However, it has been only since 1990 that innovation policy has been perceived as a means to act on and improve the performance of the innovation system [5]. In Lithuania, public procurement of innovation is not a debated topic in researchers' work, and, it is noteworthy, that public procurement, as a tool for promoting innovation in the activities of service recipients and, thereby, of service providers, has been the main research object of foreign researchers and practitioners for more than a decade now [2; 5-7; 9; 30]. One of the reasons for the low demand for public procurement of innovation in Lithuania is the narrow and legalistic understanding of the public procurement process.

F.Y.Y.Ling having analysed tendering practices in Australia, Canada, Saudi Arabia, Singapore, the United Kingdom and the United States, has concluded that, in government projects, the selection of service providers based on certain different types of procurement is mandatory in accordance with procedures established by law. A study on the transparency of public procurement in Italy has shown that non-fulfilment of contractual obligations by service providers is a topical issue and that non-compliance with technical and quality requirements, etc. was identified within over one third of the public purchase and sale contracts signed, while sanctions were imposed only on 3.4% of the breaches of the purchase and sale contracts. The main reasons: misuse of position and bribery in order to simplify the public procurement process [24; 31]. This is what represents the dysfunctions of the new public management.

In the United Kingdom authors found that collaboration between service recipients leads to greater efficiency and a joint negotiation power in communication with service providers. The authors specify the importance of the existence of a buyer-buyer relationship [39]. Public sector organisations presumably have similar objectives and tasks when organising public procurements. Interinstitutional cooperation reflects the closeness of the buyer-buyer relationship and is much more important than the use of management techniques in a buyer-supplier or supplier-buyer

relationship. The scientific literature does not analyse the buyer-buyer relationship in public procurement, however, in assessing the results of the research carried out, it is necessary to note the importance of the existence of this relationship. Summarizing the scientific literature, it is possible to generalize the conceptual model of the new public management in public procurement (see Fig. 1) [28].

Prior to reforming the management of the public procurement process in a country, it is first important to identify the key elements of the conceptual model of the new public management. The concepts of efficiency and effectiveness presented in the figure reflect real situations in the public procurement process management. The concept of efficiency encompasses the achievement of an objective, i.e., the implementation of a public procurement carried out in accordance with the terms and conditions set out in the tender materials, as well as the implementation of the public purchase and sale contract signed. Efficiency in public procurement could be defined as the effectiveness of the use of resources (tangible and intangible), where the objectives of the public procurement policy are achieved at the lowest cost. In other words, the maximum possible result is achieved at the lowest possible cost. However, it is worth adding that the new public management also incorporates the concept of effectiveness. The essence of the effectiveness: the better the value for money, the greater the effectiveness of the public procurement process. The lowest price, as an award criterion widely used in public procurement, may not necessarily be efficient and effective from the perspective of the new public management.

2. Opportunities for Innovative Practices in Public Procurement

The new public management is inherent in qualitative expression, when applying the elements of usefulness and sustainability in decision-making and implementation processes. Value creation in public procurement could be assimilated to longevity, where the thing that matters is not just the fact of the implementation of a public procurement but also its enduring value and practical application. The provision of usefulness rejects the need for the lowest price criterion in the evaluation of public procurement tenders and encourages the search for new management solutions. One of these is the establishment of a minimum number of public procurement specialists (e.g., one or more) when forming public procurement commissions even before the start of a specific tendering process. The existing social and/or economic situation makes impact on the identification of the need for public procurement, where, according to the objectives, input, activities and output of an organisation, the relevance of public procurement is determined based on categories such as economy, efficiency, cost-effectiveness, usefulness and sustainability, and effectiveness. From the point of view of the new public management, the cost-effectiveness in the public procurement process refers to the need for the necessity of the costs incurred by the service recipient or the effectiveness of the costs. The expected final result is the satisfaction of the public interest. It should be noted, that the application of these elements by a specific organisation would ensure the efficiency of public procurement and give a sense to the practical application of the new public management.

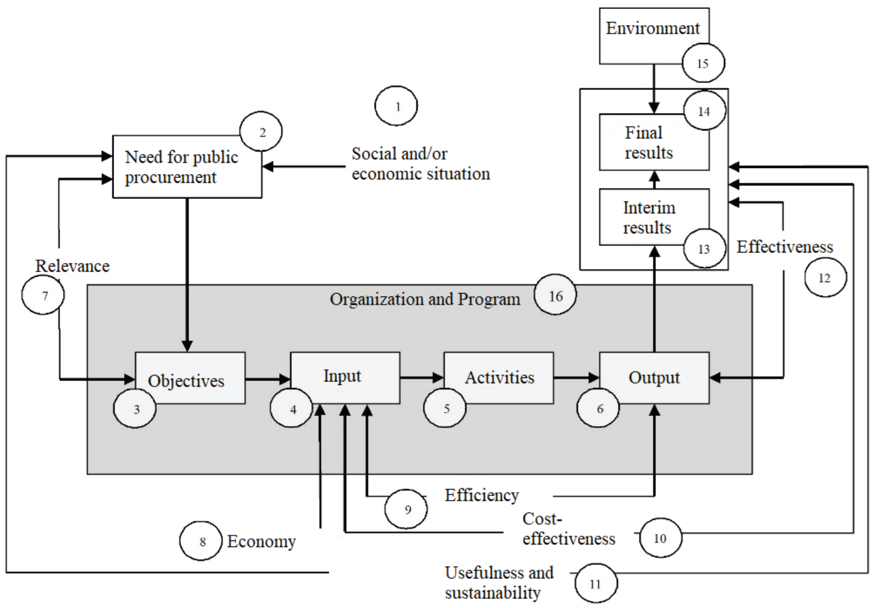

Fig. 1 Conceptual model of the new public management in public procurement [28]

Based on EU directives of 2014, the European Commission, along with the Procurement of Innovation Platform, has developed the Guidance for Public Authorities of Public Procurement of Innovation for service recipients. The Guide on Dealing with Innovative Solutions in Public Procurement – 10 Elements of Good Practice developed by the European Commission back in 2007 still remains the objective for service recipients in the context of modern public governance (meta-governance) (see Table) [4; 13-16; 23; 37].

Table

Analysis of innovative elements of public procurement

Criterion	Element	Result	Measures/Tools	Authors
Organisational structure	Competent authorities	Cooperation	Electronic document management system	[3, 6, 9, 11, 12, 17]
			Mediation to increase demand for innovation	
Aesthetic and / or functional characteristics	Consultations with the market	Open dialogue	Telecommunication equipment, technologies	[6, 8, 9, 22, 35]
			Promoting participation of SMEs	
Quality	Involvement of key stakeholders	Involvement and participation	Human Resource Management System	[3, 6, 12]
Deadline for completion	Quality solutions for the market	Ask the market instead of prescribing	Variable message signs	[9]
Price	What matters is the value for money, not the lowest price	Saving resources	Application of the most economically advantageous tender evaluation criterion (set of criteria)	[3, 9, 17, 25]
Time	Use of electronic means	Electronic public procurement	EU TED and SIMAP portals	[27, 36]
Security	Risk management	Identification, planning, risk owner identification	Electronic signatures	[2, 3, 8, 9, 35]
Technical support	Use of contractual arrangements	Energy saving procurements	Ensuring intellectual property rights	[7, 9]
			Incentives for innovative solutions in the contract	
Operating costs	Preparation of implementation plan	Measuring performance and / or results	Planning structure and resources, monitoring	[5, 6, 9, 25]
Effectiveness	Learning for the future	A learning organization open to innovation	Support for mutual learning	[2, 7, 9, 17, 38]
		Establishing evaluation and review procedures		
Environmental protection characteristics	Sustainable development	Sustainable public procurement	Green public procurement	[1, 10, 18-21, 25, 26, 29, 33, 34, 38]

Different authors analyse the public procurements that can be used as an instrument to increase the demand for innovation in the country and the port of Klaipėda. The importance of procurement value in the perspective of innovation policy development should be emphasised as one of the procurement evaluation criteria, which should not be limited to the lowest price of the object to be procured. This encourages state policy and its priorities to be geared towards obtaining maximum returns and achieving maximum productivity, which directly reflects the principles of modern public governance. As a part of sustainable development, sustainable public procurement is often used to reduce the negative environmental impact associated with production and consumption. While sustainable development encompasses environmental protection, economic and social development, green public procurement emphasises only one of these areas, i.e., the importance of environmental protection requirements. The analysis of the scientific literature on sustainable public procurement was focused on identifying specific obstacles to the implementation of sustainable public procurements [1, 10, 18, 21, 26, 29, 39 and others].

The United Nations (hereinafter 'UN') 2030 Agenda endorsed by world leaders in 2015 is the new global agenda for sustainable development, which sets out 17 goals for sustainable development. It is a commitment to eradicate poverty and ensure sustainable development worldwide by 2030, leaving no one behind [13]. The EU has a solid foundation in the field of sustainable development and, together with its Member States, is strongly committed to leading the way in the implementation of the UN 2030 Agenda. Sustainable development goals are included in all of the ten priorities of the European Commission. EU law establishes equal rights and opportunities for service providers to tender. Service recipients cannot create exclusive conditions for SMEs and, in specific ways, give this type of enterprises a preferential right to participate and, possibly, become a winner in a particular public procurement.

3. Conclusions

Summarizing the results of the research, one of the advantages of including SMEs in the public procurement of innovation is that SMEs tend to grow much faster than large companies, take advantage of innovative financing tools and a more favourable business environment created by institutions. The above authors maintain that, were contracts are awarded to SMEs, the revenue of the government, along with its innovativeness, increases, as well as this promotes entrepreneurship and contributes to creation of jobs and economic development. The service providers' opportunity to participate in public procurement of innovation is primarily determined by their experience, interest in demand for innovation, focus on scientific research, planning opportunities for entrepreneurship development, and the emphasis on access to financial support. The key management tools that create a supportive environment and increase the role of public procurement as a separate instrument to drive demand for innovation in the port of Klaipėda include: (1) centralized control, risk mitigation and emphasis on transparency, as well as financial support to innovative service providers; (2) deregulation when implementing specific public procurement characteristics: e.g., purchase value results are often tend to be used for transferring decision-making power to service recipients, their managers, agendas of politicians, expectations of service providers, the media and the community.

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Analysis of the Impact of Human Factors on the Occurrence of Rail Accidents

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Abstract

Rail transport, like other modes of transport, seeks to ensure the safety of travelers and transported goods. This is due to the fact that accidents that occur in rail transport are usually very spectacular, they carry the death of many people and large material damage. The causes of accidents can be divided into four groups: human factor, technical factor, organizational factor and environmental factor. Statistical data indicate that the main source of rail accidents is the human factor. The authors of the paper conducted an analysis of the impact of the human factor on the occurrence of rail accidents in the European Union and discussed the causes of human errors. The need to assess human reliability, taking into account qualitative and quantitative methods, was also pointed out as a method leading to ensuring the required level of railway safety.
KEY WORDS: *human factor, human reliability analysis, rail accidents, safety culture*

1. Introduction

As the users of technical objects and systems, especially those that have an impact on safety, people want them to be reliable, i.e. to be able to perform planned functions under specified conditions and for a defined period of time. While constructing systems, due to human participation in the process of exploitation of technical systems, it is necessary to include man as an important element of the system man-technical object and to estimate the risks resulting from any possible errors. The authors of this paper to analyze the causes of the accidents that occurred on the European railways in the years 2013-2018 have used UIC Safety Report [17] and Eurostat statistics [6]. In conducted analysis it was noted that for a significant part of accidents and events the direct or indirect perpetrator is a human. It was an additional motivation to analyze a group of methods qualitative and quantitative methods used to assess the potential contribution of the human factor to safety, called Human Reliability Analysis (HRA) methods [13].

2. The Analysis of Rail Accidents Causes

EU Member States are obliged to continuously monitor the safety level of their railway systems [3, 5, 10], including monitoring the achievement of the Common Safety Targets (CSTs), defined in a quantitative and qualitative manner [2, 4, 14, 15]. The conducted analysis has taken into account data on accidents and incidents on the rail network from Eurostat [6], which were reported by individual Member States as well as data from the Safety Database (UIC-SDB) [17] provided by members of the International Union of Railways (UIC). The data collected in both sources are acquired from infrastructure managers, who are obliged to report serious accidents and incidents in rail transport.

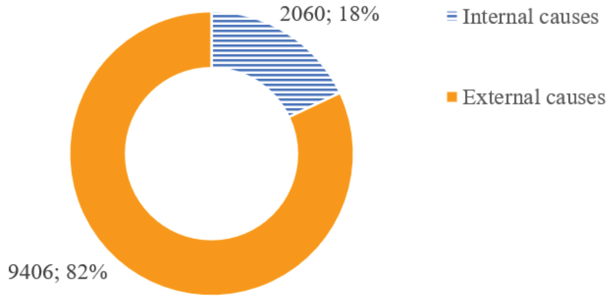

Fig. 1 Accidents per internal/external cause between 2013 and 2018 [6, 17]

In the UIC SDB database, the causes of accidents are divided into two main categories: internal causes (human factors, railway users, infrastructures, rolling stock) and external causes (trespassers, level crossing users, other and unclassified, weather & environment), where the majority of accidents (82%) is made by external (Fig. 1).

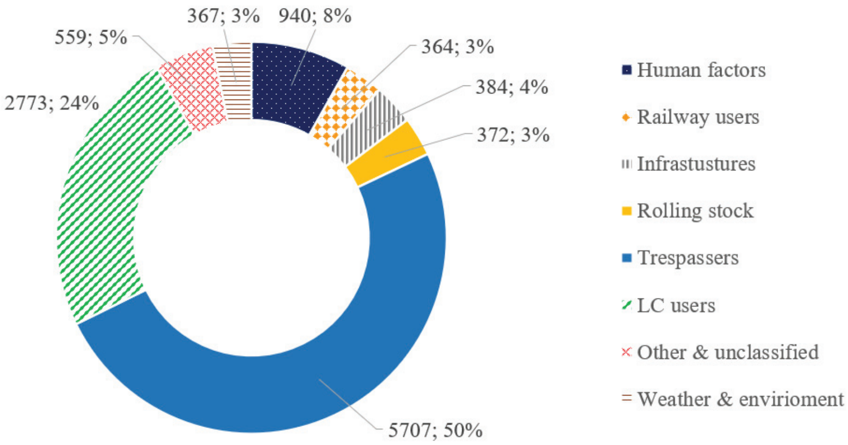

Fig. 2 Rail accidents per its causes between 2013 and 2018 [6, 17]

Both main categories include accidents involving people. These are accidents in the following categories: human factors, railway users, trespassers, level crossing users, which together account for 85% of all accidents in the analyzed time period (Fig. 2) and include 93% of victims (fatalities and serious injuries) (Fig. 3). Fatal accidents represent half of all significant accidents and this proportion is stable along the analyzed years.

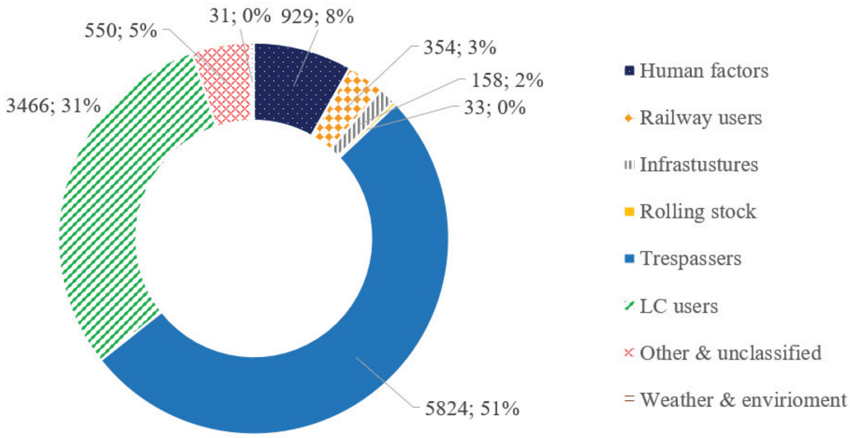

Fig. 3 Victims of rail accidents per its causes between 2013 and 2018 [6, 17]

In the analyzed period, 38% of accident victims were passengers, 11% staff and 51% third parties. Fig. 4 shows a split of victims of rail accidents caused by third parties using the data from 2017. It should also be noted in the analysis, that the steady trend of safety improvement and decreasing the number of accidents and their victims, observed on rail until 2015, in later years clearly stagnated and the improvement in the number of accidents and victims is minimal (Fig. 5). Similar observations concern the change in the number of accidents at level crossings and their victims. Despite extensive legal, educational and technical activities [3, 9, 10, 12], the trend of safety improvement visible until 2015 was halted, and the number of incidents and victims at level crossings in 2018 is similar to that of 2015 (Fig. 6). However, it still decreased by 21% over the whole analyzed period, and the number of incidents and accidents involving pedestrians and cyclists decreased by 26%.

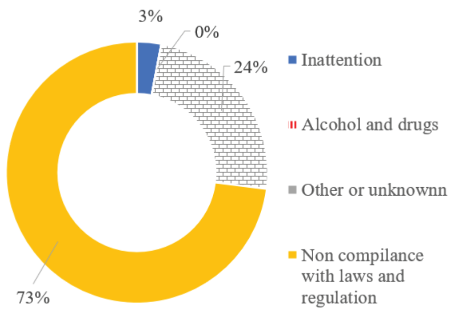

Fig. 4 Split of victims of rail accidents caused by third parties per cause 2017 [17]

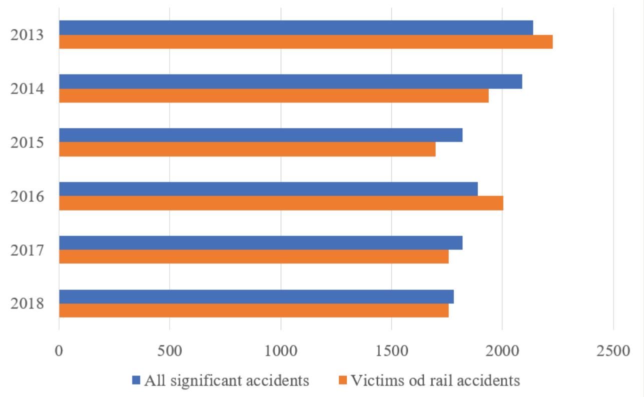

Fig. 5 Significant rail accidents and rail accidents victims between 2013 and 2018 [17]

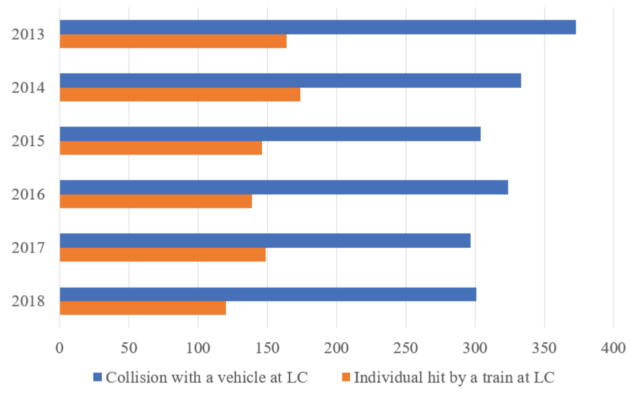

Fig. 6 Significant rail accidents at level crossings between 2013 and 2018 [17]

In all the analyses conducted by the authors, it can be observed that human behavior and actions are a significant cause of rail incidents and accidents. In the process of admission and placing railway systems into service and operation, a lot of attention is paid to reliability estimation and analyses concerning technical and organizational elements of rail system. Human reliability is usually omitted in the conducted analyzes, however, according to the authors, it should be an integral part of system reliability testing.

3. The Impact of Human Factors on Railway Safety

When assessing the human impact on safety in rail transport, it is necessary to take into account the specific characteristics of the human, including his subjectivity. Human pursues his goals in a conscious manner and thus is able to perceive the hazards and consequences of errors. In addition, he has the ability to learn and make rational decisions in unpredictable situations. Unfortunately, as mentioned before, people still remain a source of many rail incidents and accidents, which is due to many reasons. Therefore, it is necessary to conduct scientific research aimed at the classification of human errors, discovering the reasons for their occurrence and finding the methods of preventing their occurrence. Currently, the main causes of errors include [13]:

- communication problems;
- loss of awareness of existing risks and hazards as a result of routine and repetitive tasks over a long period of time;
- gaps in knowledge and competencies;
- distraction and a tendency to distract attention and mind chaos;
- lack of cooperation in a team, due to lack of definition of common objectives, inappropriate leadership style or communication methods;
- exhaustion that is not noticed at the right time;
- resource, tools and materials shortages as well as poor working conditions;
- pressure from superiors and coworkers due to lack of time resulting from poor task scheduling;
- lack of assertiveness consisting in accepting impossible or high-risk tasks;
- stress - caused by a competition, new activities, a modification of scope of duties or private causes;
- carelessness that results from incorrect evaluation of the possible consequences of an action;
- facilitation by accepting exceptions from applicable instructions or standards.

HRAs (Human Reliability Analysis) methods are helpful in investigating the causes of potential human impact on rail transport safety. Among them the most popular are:

– HEART (Human Error Assessment and Reduction Technique) - method defines 9 Generic Task Unreliability to which they relate nominal values of Human Error Potential (HEP). This method takes into account 38 conditions badly influencing human activity - EPCs (Error Producing Conditions). For each task shall be assigned the HEP, dependent on the EPC rates [8].

– THERP (Technique for Human Error Rate Prediction) – allows to determine the probability of human error and estimate their consequences. It consists of four stages [8]: problem identification and recognize, quality assessment, quantity assessment as well as research and utilization of results.

– ASEP (Accident Sequence Evaluation Program) – includes the following procedures [7]: pre-accident tasks, post-accident tasks, screening and nominal human reliability analysis.

– SPAR-H (Standardized Plant Analysis Risk-Human reliability analysis) – in this method, the HEP probability is the sum of the nominal values of the error probabilities at the diagnosis stage and the action stage. They are calculated taking into account 8 impact factors, called Performance Shaping Factors (PSF), that determine human efficiency [1]: time available, stress, complexity, experience and training, ergonomics including Human-Machine Interface (HMI), procedures, fitness for duty, work processes.

– ATHEANA (A Technique for Human Error Analysis) - method designed to identify plausible Errors Forcing Context (EFCs) to estimate human error probabilities (HEPs) in risk assessments [13, 16].

– CREAM (Cognitive Reliability and Error Analysis Method) - method distinguishes [11]: 9 phenotypes such as timing, duration, force, distance, speed, direction, wrong object, sequence, quality/volume and 3 genotypes such as human factors, technical/environmental factors and organizational factors. In the analysis, successive phenotypes that are characteristic for human error are selected, and then the genotypes that best correspond to the phenotype are selected. The final estimation of error possibility is obtained by taking into account one of nine Common Performance Condition (CPC) levels [11].

4. Conclusions

Rail transport is related to the provision of passenger and goods transport services, and thus plays an important role in the national and international economy, influencing the proper functioning of the states. Rail transport safety systems should therefore operate at the highest possible level. The analysis of rail incidents and accidents indicates that the human factor is a significant cause of their occurrence. Statistical data indicate that since 2015 any significant improvement in rail safety has not been seen. According to the authors of the paper, along with the growing requirements related to the safety assessment of technical solutions, it is necessary to pay more attention to the human factor. Safety level estimation methods that take into account human reliability may be helpful in this. Only then a proper risk and hazard assessment can be obtained, which will ultimately allow to make the right decisions in the safety management process. Ultimately, this should lead to the creation of individual and group values, attitudes, competences and patterns of behavior that will help to form of safety culture in rail transport at high level.

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Fiberglass Coating of Railway Culvert Pipes

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Abstract

The culvert pipes in the railway roadbeds are an important element of the infrastructure. The pipes are subjected to chemical and electrochemical attack, the influence of frost and groundwater. Aggressive medium causes a negative change in a concrete structure and metal and results in pipe destruction. A glass-reinforced plastic band is proposed for internal and external protection of the pipes. The pipe construction, known as “pipe-in-pipe”, has been obtained by the winding of the outer fiberglass layers at an angle of 45° to the longitudinal direction of the pipe. Then the pipe samples have been placed on a test stand to determine the presence of deformations. The experimental results showed that the glass-reinforced plastic band possesses the necessary physical and mechanical properties. It can be used for spiral reinforcement of the pressure concrete pipes instead of metal reinforcement. Replacement of steel reinforcement with fiberglass allows creating a pipe design for laying in the places with increased corrosive effects of groundwater, as well as in soils with a significant value of leakage currents and stray currents.
KEY WORDS: *culvert pipe, fiberglass coating, strength, deformation*

1. Introduction

Protection of railway infrastructure objects against destruction is one of the main problems in the railway industry. Such objects are culvert pipes in the railway embankments. The pipes are subjected to the effects of various loads and aggressive mediums. Due to corrosion, the pipe operational life is far less than the calculated one. There are many studies are devoted to the enhancement of the metal and concrete constructions by an external layer [1-4]. To manufacture composite pipes in [1], glass fibre is dipped into a resin solution and wound around a core pipe. Hybrid nanoparticles, modified by epoxy resin and applicable for the filament winding process, were studied in [2]. However, toxic vapours and low productivity under high temperature conditions are serious problems connected with the usage of the epoxy resin. A new non-toxic composition material has been proposed in [3]. This waterproof composition contains an acrylic polymer and a filler. More effective protection has been offered in [4]. It consists of the fibreglass plastic that is wrapped around pipes and gives them bigger strength and corrosion resistance.

The multilayered filament wrapped composites are widely distributed for strengthening and protection of the different constructions [5-7]. The Optimization of filament winding parameters for the design of a composite pipe is performed in [5]. This paper presents the design stages for the selection of the optimal fiber, matrix, volume fraction, and winding angle θ. Based on analytical estimations, the authors [5] found the optimal technological parameters with volume fraction 40% ÷ 60% and winding angle $\pm 44.5° < \theta < \pm 52.5°$. From these considerations, they suggest a customization in the pipe production, based on the estimated axial loads in exercise. The paper [6] presents the design optimization of filament winding composite cylindrical shell under hydrostatic pressure to maximize the critical buckling pressure. The design variables are fiber orientation and the corresponding number of layers. Results show that filament winding angles have a more significant effect on the critical buckling pressure than the number of layers. In paper [7], an analytical model is proposed to calculate the winding process-induced residual stresses for the multilayered filament wound composite parts. In the modeling the winding process, the contribution of the highest winding tension to the residual stresses of previously wound composite layers is calculated. Then, the value of complete residual stresses is obtained based on the principle of elastic superposition. The proposed analytical model is of high accuracy and can be used to calculate the residual stresses due to winding tensions for the multilayered filament wound composite parts.

Based on the winding and curing process, an analytical model of residual stresses was established in [8]. This model can be used to analyse the stress state of a composite cylinder before and after removal of a mandrel. The degree of shrinkage deformation and the coefficient of thermal expansion are introduced as controlled variables to develop a model of residual stresses. The numerical simulation and slitting experiment for composite wrapped cylinder after mandrel removal are investigated. The analysis shows that the maximum difference of radial stress between the model

and the experiment is 0.14 MPa around the neutral axis. In this case, the maximum difference of hoop stresses is 2.6 MPa which occurs along the outer radius. In addition, the corresponding errors hoop and radial stress are 9.0% and 7.7%, respectively. The result indicates that this model can be used to predict residual stresses and the winding tension to guarantee that the hoop wound cylinder with an inner liner has a uniform residual hoop stress. The new high-strength composite fibrous materials, such as fiberglass, basalt fiber reinforced polymers, carbon-filled plastics, proved to be quite perspective in the manufacturing of multilayer products and constructions. In this study, a pipe construction is offered which consists of an internal pipe (metal or concrete), a glass-reinforced plastic band, a heat-insulation layer (if necessary), and a second glass-reinforced plastic band (Fig. 1). The acrylic powder-liquid type plastic is applied as the binder to provide the adhesion strength between the pipe and the band. Powdered component (polymer) is a high-molecular methyl methacrylate-based substance. Liquid component (hardener) of acrylic plastic is methacrylic methyl ester (methyl methacrylate monomer). The pipe construction, known as “pipe in pipe”, has been obtained during winding of the outer fiberglass band at an angle of 45° to the longitudinal direction of the pipe. After curing, the pipe samples have been placed on the test stand to determine stress and deformations (Fig. 2).

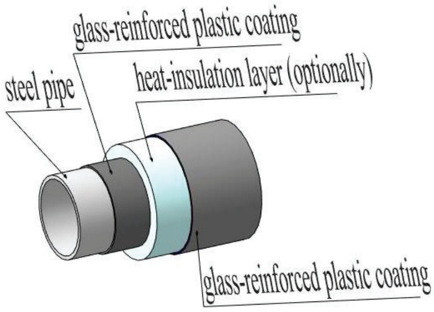

Fig. 1 The pipe construction

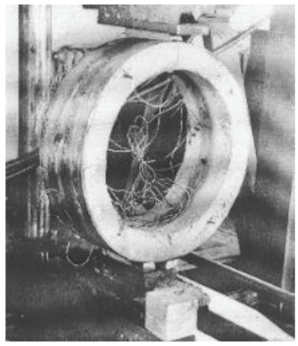

Fig. 2 The pipe testing

The aim of the test is to find out the maximum value of critical stress for the band during its pre-tensioning and winding process. The complexity of this challenge is the definition of the stress value which depends on the loading speed of the band. It necessitates a lot of test samples, a special test stand, stability of the test conditions, and long testing time. We applied the rapid test method which is as follow.

2. Theoretical Study

As has been shown in [4], the increase of a pipe diameter does not lead to the corresponding increase of its strength. The reason is the insignificant participation of external layers of concrete or steel in taking up loads. A needed effect can be reached by multilayer winding of prestressed steel wire or strip on a cylinder. The idea to form compound cylinder constructions is used extensively in civil engineering for manufacturing of the high-strength constructions. In this case, a brittle construction material obtains additional strength and plastic properties in the conditions of compressive three-dimensional stress. Using this effect, known “a hoop effect”, a number of ways to reinforce concrete were developed: concrete in a steel wire coil, concrete in a pipe, concrete with tubular steel reinforcement, etc. High strength properties of such constructions made it possible to decrease the proper weight of constructions and save the construction materials (steel, cement, etc.). The developed new high-strength composite fibrous materials, such as fiberglass, basalt fiber reinforced polymers, and carbon-filled plastics, proved to be quite promising in the manufacturing of multilayer high-strength items and constructions.

There is an increase of deformations observed under a constant load. This increase stops when the load is below a certain limit. In this case, elastic deformations disappear immediately after load is removed. The plastic deformations remain. If the load is over a certain limit, the deformations grow until sample is destroyed. The maximum stress, which does not cause sample destruction regardless of load application time, is referred to as limit of long-term resistance. There are following principles that are applied to define the long-term resistance.

1. There is a linear dependence between a rate of the plastic deformation growing and the critical stress, which causes plastic deformations to appear.
2. The critical rate of growth the deformation corresponds to the critical stress.

The critical stress is considered to be a constant of the material under static loading. In dynamic tests the critical stress depends on the strain rate, the method of load application, and is not constant. The problem lies in the following question: what can be considered to be the dynamic strength of the material, and how to predict the ultimate strength characteristics under dynamic effects. The second problem is a stress relaxation in the glass-reinforced plastic band. The winding of every next layer of the band leads to decrease of the stress in the layer beneath. In Fig. 3 it is shown how the stress changes under winding of the band made of an isotropic material (nickel) and an anisotropic material (fiberglass plastic).

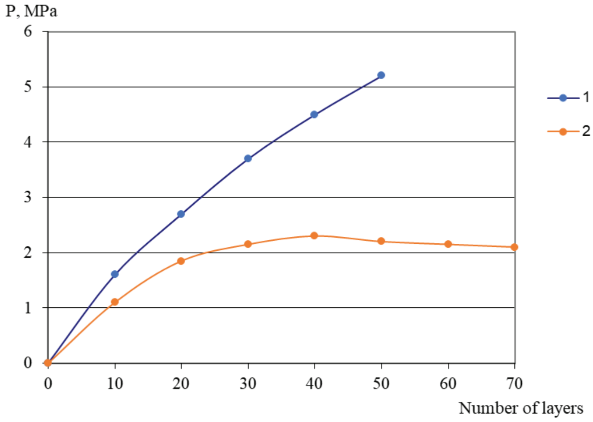

Fig. 3 The stress change under winding of the band made of an isotropic material *1* and an anisotropic material *2*

As can be seen in Fig. 3, the decrease of the prestressing force does not occur under the winding of the isotropic material. It means that the pressure grows in proportion to the number of layers. In opposite, this dependency becomes nonlinear for the anisotropic material even under a small number of wraps (Fig. 3, curve *2*). The fiberglass layers must work evenly in the thickness of the band. For this, the needed prestressing force must be provided in every band layer.

3. Experimental Study

To solve this problem the following approach has been applied. Based on the experimental results with samples that have different rates of deformation, dependence can be found between the critical stress and the rate of increase of the elastic deformation, which is simultaneously the growth rate of the plastic deformations. Three groups of the fiberglass band have been tested under the following deformation rates: $0.75 \cdot 10^{-5}$ s^{-1}, $1.25 \cdot 10^{-5}$ s^{-1}, $1.75 \cdot 10^{-5}$ s^{-1}. The band was stretched until broken. The experimental results are shown in Fig. 4. The stress increases linearly until a certain value. Then, increase slows down a bit while the destruction process develops in the sample. According to Fig. 4, the critical stress σ_s have been determined which corresponds to the transfer from elastic deformation to the plastic one for each of the three deformation rates. After that, the diagram has been plotted to show the dependency between the critical stress and the rate of its growth (Fig. 5). The critical deformation value ε_s is represented by dark dots. Tangents to respective curves are drawn for each dot. These dots correspond to the critical stress σ_s. These tangents cross an axis of abscissas at angles α_1, α_2, α_3, respectively. The slope of each tangent is equal to the rate of the growth of the critical elastic strain that corresponds to the found critical stress.

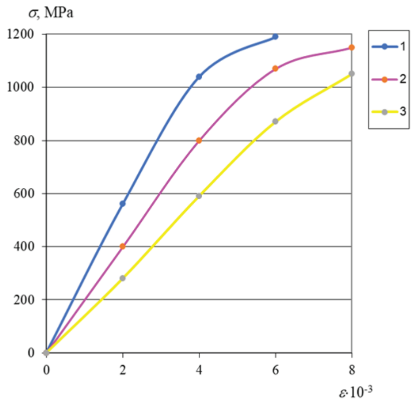

Fig. 4 Stress - deformation variation curve for deformation rates: *1* – $0.75 \cdot 10^{-5}$ s^{-1}; *2* – $1.25 \cdot 10^{-5}$ s^{-1}; *3* – $1.75 \cdot 10^{-5}$ s^{-1}

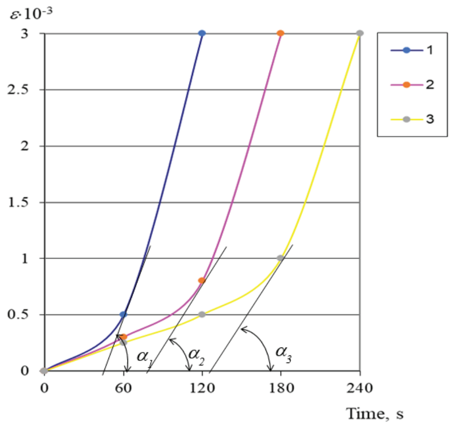

Fig. 5 Deformation - time variation curve for deformation rates: *1* – $0.75 \cdot 10^{-5}$ s^{-1}; *2* – $1.25 \cdot 10^{-5}$ s^{-1}; *3* – $1.75 \cdot 10^{-5}$ s^{-1}

The next step is to plot a graph which shows a dependence between the critical stress σ_s and the critical rate v_s (Fig. 6, line *1*). To find out the limit of long-term resistance, a straight line is drawn through the obtained points σ_s. This line is drawn until it intersects the y-axis. The point of intersection is the value of critical stress when the rate of growth of elastic strain is equal to zero (Fig. 6, line *2*). This point is the value of the limit of long-term resistance sought for the fiberglass band. These test curves (Fig. 4 and Fig. 5) are obtained in experiments with the strain rate that varies from experiment to experiment. So, they are reference curves for a mathematical model of the dynamic deformation of materials. Based on this method, software will be developed for calculation of the critical stress.

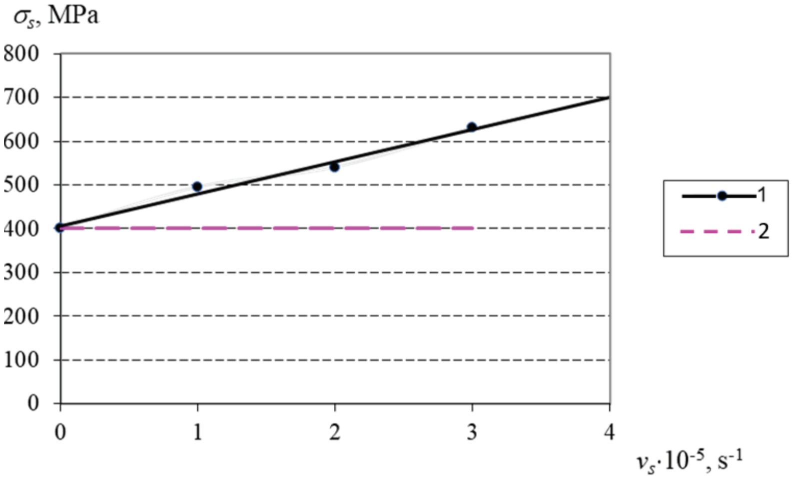

Fig. 6 Critical stress – critical rate dependency

At this critical stress of 400 MPa, the reinforcement band must be winded to provide the necessary compression stress in the pipe. Also, the plastic deformations will not appear under any winding rate at this critical stress. The critical stress is referred to as an important characteristic along with such parameters as the winding rate, a step and angle of an over-wrap, the tension force, etc. The change of the over-wrap direction, relative positions of the wrap, and the fiberglass tension has been made the management of the anisotropic properties for the building products and constructions possible.

4. Conclusions

Experimental data show that the stresses in the fiberglass coating depend on the winding rate. Also, it has been observed that the decrease of the prestressing tension happens due to stress relaxation and plastic strains. To prevent the appearance of plastic deformations, the critical stress value has been determined to be 400 MPa. This critical stress value is used to create prestressing tension of the glass-reinforced plastic band at any winding rate without the appearance of plastic deformations. It is a technological base for directed reinforcement of the products and constructions with the usage of the continuous filament winding method. This method allows:

- to create the effective type of the non-metal reinforcement;
- to execute biaxial and triaxial compression of the elements;
- to obtain the reinforcement that corresponds to an operational stress state;
- to develop a continuous reinforcement method for the constructions of any shape;
- to wrap a required number of layers for protection against corrosion.

According to physical and mechanical properties, the developed fiberglass plastic coating is a potential protective and strengthening material which allows creating the corrosion-resistant and durable materials.

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Research of the Strained State in the "Subgrade – Base" System at the Variation of Deformation Parameters

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Abstract

When building the railway lines, there are several cases of the subgrade construction, which in the future is the cause of poor operation. It lies in the fact that "diseases": defects and deformations emerge in the subgrade and the base on which it is built. These phenomena are due to the fact that, firstly, the quality of the subgrade is not consistent with the normative deformation parameters, and secondly, the soil foundation of the subgrade is weak. The purpose of this research is to obtain the strained state of the "subgrade – base" system at the variation of the deformation parameters of its elements. For this, finite-element models were developed, in which the track superstructure with assembled rails and sleepers, the subgrade and its base were reproduced. Numerical analysis was carried out in the static position on trainloads. The obtained results of the strained state of the models are components of horizontal and vertical displacements. The results of the research show that the impact of the base with lower deformation parameters is greater than in the subgrade with a reduced, unlike regulatory, the elastic modulus.
KEY WORDS: *subgrade, base, track superstructure, finite-element models, deformation parameters, horizontal and vertical displacements*

1. Introduction

When building the railway lines, there are several cases of the subgrade construction, which in the future is the cause of poor operation. It lies in the fact that "diseases": defects and deformations emerge in the subgrade and the base on which it is built. These phenomena are due to the fact that, firstly, the quality of the subgrade is not consistent with the normative deformation parameters, and secondly, the soil foundation of the subgrade is weak. The purpose of this research is to obtain the strained state of the "subgrade – base" system at the variation of the deformation parameters of its elements.

2. The Current Status of the Issue

From the experience of operating the domestic railways, which is enshrined by regulatory documents, the deformation parameter (elastic modulus) of the subgrade is the value within 30000…40000 kN/m^2, the rational value is 35000 kN/m^2. The subgrade on the operated lines is most often not characterized by normative deformation parameters, since in the process of dynamic impact from trains they decrease. Therefore, the value of the elastic modulus for the subgrade, which is being operated and has already been repaired or reconstructed, ranges from 20000…25000 kN/m^2 (and sometimes less than 20000 kN/m^2).

However, even if the subgrade is constructed with the proper elastic modulus (30000…35000 kN/m^2), which requires constant compaction control and the appropriate effective technologies for its implementation, the problem arises on the other side. The subgrade with the normative parameter of the elastic modulus has a soil foundation which undergoes minimal construction impact during building or stabilization. In this case, the value of the elastic modulus of the base might not only not reach the normative module of the subgrade or also be much smaller (weak foundations with the elastic modulus of 10000…15000 kN/m^2).

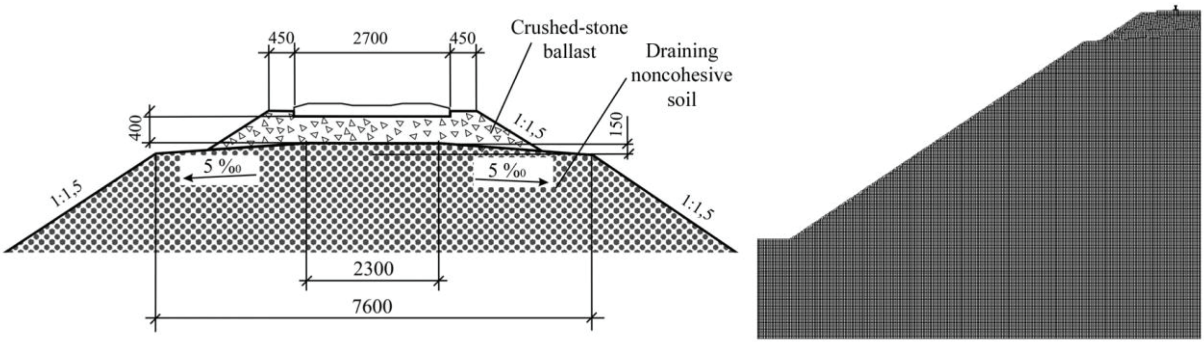
Thus, in the subgrade constructed with the normative value of the elastic modulus, the foundation subsidence with smaller deformation parameters can occur very actively. This leads not only to defects and deformations of the subgrade but also to more serious cases of a decrease in slope stability [1, 2], penetration of a ballast section and the emergence of plastic deformations of the soil requiring operative procedures (repair or reconstruction) [3-5].

The "subgrade – base" system, even with perfect construction or repair works, cannot be completely homogeneous. The track superstructure provides it with heterogeneity, in which there is its own interaction between rails, fastenings, reinforced concrete sleepers, and ballast section [6-11] and its features in case of irregularities [12-14]. Therefore, to investigate how the variation of the deformation parameters in the "subgrade – base" system affects the overall strained state is an important scientific and technical task. Its solution provides an opportunity to evaluate and predict the development of deformations for the "subgrade – base" system with knowledge about the deformation

parameters of parts in the system.

3. Simulation of the "Subgrade – Base" System by the Finite Element Method

The purpose of this research is to obtain the strained state of the "subgrade – base" system at the variation of the deformation parameters of its elements. For this, finite-element models were developed, in which the track superstructure with assembled rails and sleepers, the subgrade for a single-track embankment and its base with the dimensions, indicated in Fig. 1, a. were reproduced. The reference option is the non-reinforced subgrade without a protective layer, which is made of draining noncohesive soil of sufficient bearing capacity (Fig. 1, b). This type of subgrade is the basic one in construction and repair, and it is adopted for simulation of the "subgrade – base" system by finite element method in SCAD software package [15].



a b

Fig. 1 The subgrade design for single-track embankment (a) and finite element model for the "subgrade – base" system (b)

Four options were developed for the calculation, in which there is a difference between the elastic modulus of the subgrade E_S and base E_B. They are presented in this form: 1) option 1 ($E_S = 20000$ kN/m^2, $E_B = 30000$ kN/m^2); 2) option 2 ($E_S = 30000$ kN/m^2, $E_B = 30000$ kN/m^2); 3) option 3 ($E_S = 30000$ kN/m^2, $E_B = 10000$ kN/m^2); 4) option 4 ($E_S = 30000$ kN/m^2, $E_B = 20000$ kN/m^2). The reference Option is Option 2.

Other strain characteristics are given in Table 1.

Table 1

Strain characteristics of finite elements of the model

Model element name	Elastic modulus, kN/m^2	Poisson's ratio	Bulk weight, kN/m^3
Sand	50000	0.2	20.0
Crushed stone	100000	0.2	20.0
Sleeper	$3.91 \cdot 10^7$	0.2	24.5
Rail	$2.1 \cdot 10^8$	0.3	77.0

The "fixing" of the model was conducted around its perimeter. On the left side (Fig. 1, b) only nodes of the base are fixed on the horizontal and longitudinal axes, on the right side nodes are fixed on the horizontal axis at all height, and motions in all directions are completely forbidden at the bottom. Numerical analysis was carried out in the static position on trainload of 150 kN per wheel (300 kN per axle) [16-18]. The deadweight of the subgrade and the base in all options were not taken into account.

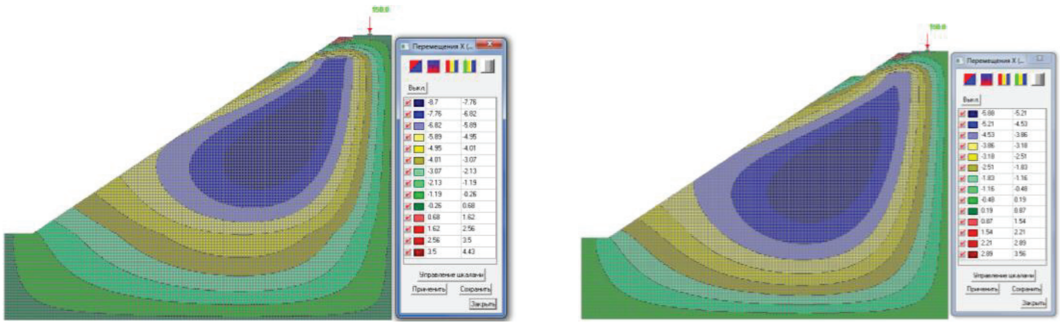
4. Analysis of the Calculation Results

After setting all necessary parameters, the options were calculated using the multifrontal method. In the end, a report (SCAD protocol) on the successful completion of the work was provided in the calculation protocol, after which the calculation results were thoroughly analyzed.

For options 1-4, Fig. 2-3 show a characteristic distribution of the strained state (horizontal displacements) when changing the elastic modulus of the subgrade and the base due to the action of the trainload.

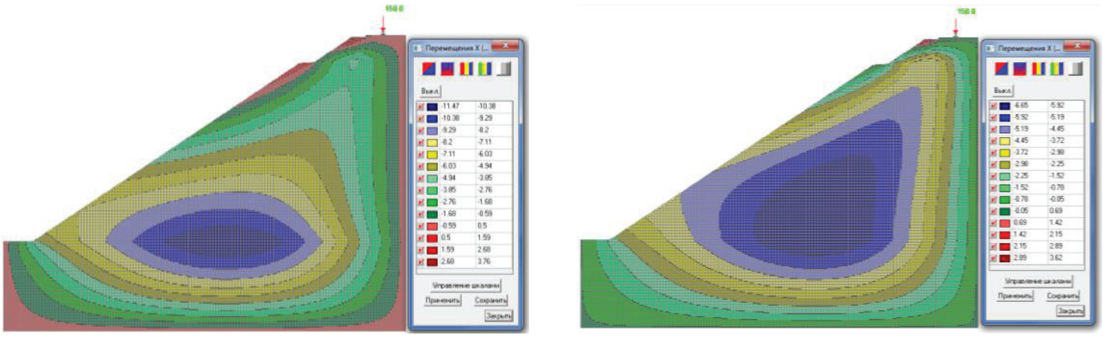
The analysis of the qualitative picture of the strained state shows that in the subgrade with a smaller value of the elastic modulus (Option 1) the horizontal displacements are concentrated in the subgrade (Fig. 2, a).

In Option 2 (reference), there is a surge in the core of displacements on the slope, but the values are minimal (Fig. 2, b).



a b

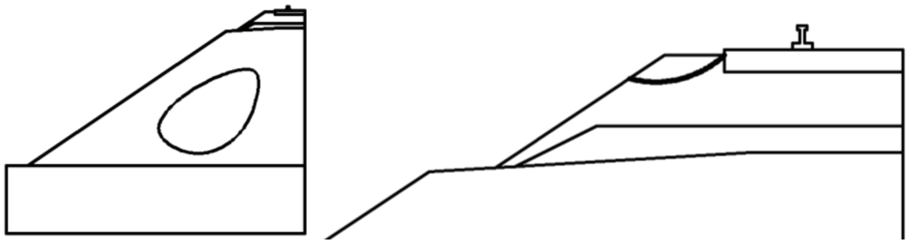
Fig. 2 Strained state (horizontal displacements) of the finite element model of the subgrade and the base: a – Option 1; b – Option 2



a b

Fig. 3 Strained state (horizontal displacements) of the finite element model of the subgrade and the base: a – Option 3; b – Option 4

In Option 3 (a weak base) the horizontal displacements are maximum and are located at the interface between the elements of the "subgrade – base" system (Fig. 3, a). This can lead to the active displacement of the outer layer of the subgrade and, accordingly, the possible emergence of slope defects. The core of the negative displacements is located in the subgrade (Fig. 4, a) and the epicenter of the positive displacements is located at the top of the ballast section (Fig. 4, b).



a b

Fig. 4 Schematic diagram of the core location of negative (a) and positive (b) horizontal displacements

Table 2

The results in changing the horizontal displacements in accordance with the strain characteristics

Option No.	Maximum horizontal displacements, mm	
	Negative	Positive
1	-8.7	4.43
2	-5.88	3.56
3	-11.47	3.76
4	-6.65	3.62

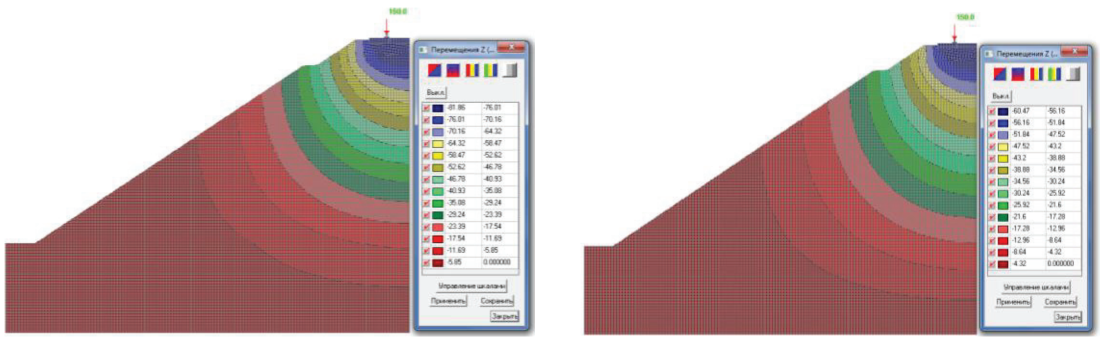
The core of maximum negative displacements (Table 2) is located closer to the ballast section in a model with a low (unlike the base) elastic modulus of the subgrade. Also, in this case, there is an evident flattening of isolines and their clearly visible distortions at the intersection between the ballast section and subgrade (Fig. 2, a and Fig. 3). The

"subsidence" of isopoles beneath the base is observed on these three Options, as well as bending of isolines in the joint places of the subgrade and the base.

Particularly characteristic (from the viewpoint of distribution of the horizontal deformation) is Option 4, in which, at the normative value of the elastic modulus of the subgrade and sufficiently strong base, their core has an exit on a slope (Fig. 3, b).

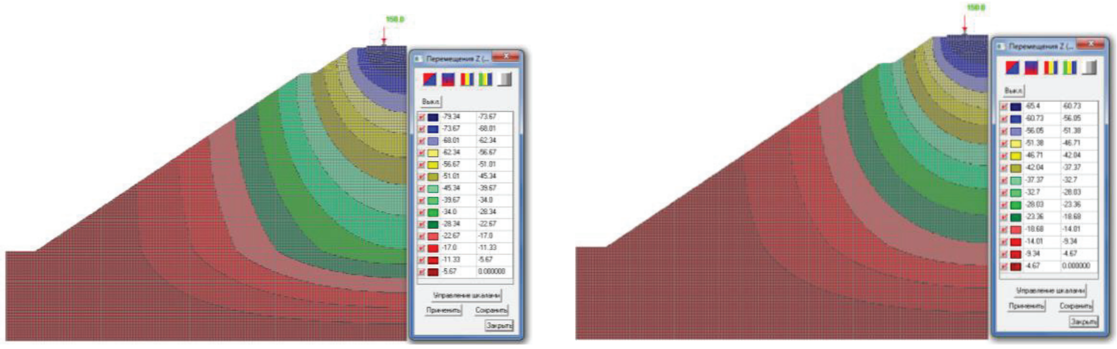
At a low elastic modulus of the base (Options 3 and 4), the distortion of isolines at the subgrade/base intersection (Fig. 3) is clearly seen. With a larger elastic modulus, such fractures are barely noticeable, and in Option 1 they are completely absent. With a weak elastic modulus of the base from the core of negative displacements, a large layer of displacements is distributed, which is more evenly distributed throughout the massif as it increases.

Figs. 5-6 show the characteristic distribution of the strained state (vertical displacements) from the action of the trainload when changing the elastic modulus of the subgrade and the base.



a b

Fig. 5 The strained state (vertical displacements) of the finite element model of the subgrade and the base: a – Option 1; b – Option 2



a b

Fig. 6 The strained state (vertical displacements) of the finite element model of the subgrade and the base: a – Option 3; b – Option 4

In Options 3 and 4, there is explicit refraction of isolines in the zone of connection between the base and the subgrade (Fig. 6). In models with a higher elastic modulus, the uniform spacing of isopoles of displacement is observed throughout the entire massif. The epicenter of negative displacements is at the place of load application and it uniformly decreases towards the subgrade (Fig. 7).

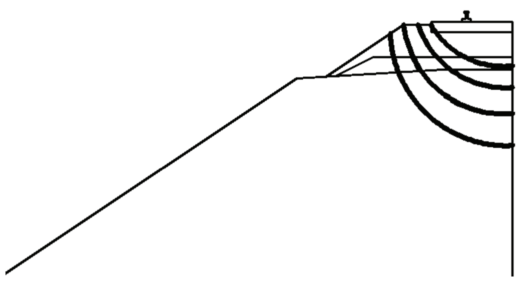


Fig. 7 Scheme of characteristic distribution of vertical displacements

The analyzed results of the calculation for Options of finite element models allow us to conclude about the greater part of deformation of the base in the overall deformation in the “subgrade – base” system with a significant difference between the modules of the subgrade and the base. Quantitative analysis shows that negative displacements

are: Option 1 is 81.86 mm; Option 2 is 60.47 mm; Option 3 is 79.34 mm; Option 4 is 65.4 mm. So, the least strained is Option 2 (reference).

Other analyzed options with variation of deformation parameters indicate that the most strained is Option 3 (E_S =30000 kN/m^2, E_B =10000 kN/m^2). Moreover, the maximum displacements of Option 3 occur in both horizontal and vertical directions, which allow predicting complex operation.

However, the "mirror" pair of options, namely Options 1 and 4 (Option 1 E_S =20000 kN/m^2, E_B =30000 kN/m^2; Option 4 E_S =30000 kN/m^2, E_B =20000 kN/m^2) is characterized by a variation of the elastic modulus 10000 kN/m^2. At this, maximum horizontal and vertical displacements are characteristic exactly of Option 1, in which the subgrade is weaker.

5. Conclusions

The research of the strained state in the "subgrade – base" system at the variation of deformation parameters of its elements is carried out. For this, finite-element models were developed, in which the track superstructure with assembled rails and sleepers, the subgrade and its base were reproduced. Numerical analysis was carried out in the static position on the trainload. The obtained results of the strained state of the models are components of horizontal and vertical displacements. The results of the research show that the base impact with lower deformation parameters is greater than in the subgrade with a reduced, unlike normative, elastic modulus.

The obtained parameters of the strained state (horizontal and vertical displacements) prove that the most suitable for operation is Option 2, that is, the reference one. The variation of the deformation parameters leads to the heterogeneity of the strained state, increases the horizontal and vertical displacements in case of a significant difference of the elastic modulus. The analysis of such cases should become the blueprint for the introduction of measures to strengthen these parts in the "subgrade – basis" system.

The solution to this problem becomes the blueprint for the scientifically sound application of some technologies in strengthening the subgrade and the base which increases their elastic modulus. Such a task is more complicated since strengthening leads the system under consideration to another level of heterogeneity, which is a positive one. Therefore, the results presented in this work are the conceptual basis for the development of new types of subgrade with strengthening.

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Importance of Fire Safety Equipment for Ensuring Safety in Road Tunnels

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Abstract

Road tunnels are an important part of the transport infrastructure in each country. The operation of road tunnel constructions is accompanied by the occurrence of emergencies. One of the most significant emergencies is fire. Even though the occurrence of fires is not very high, the consequences are often significant. For this reason, considerable long-term attention has been paid to ensuring the fire safety of road tunnels. Fire safety equipment plays an important role in ensuring tunnel safety in the event of fires. The range and type of safety equipment installed in road tunnels vary considerably from country to country. The article describes the most important fire safety equipment which is usually installed in road tunnel constructions. The differences in the range of installed fire safety equipment in selected countries are compared. Specific requirements for some fire safety equipment are evaluated in detail. Finally, the causes of differences in the range and types of installed fire safety equipment between countries are discussed. The article emphasizes the necessity of equipping tunnel constructions with safety devices.
KEY WORDS: *road tunnel, fire, safety, equipment, comparison*

1. Introduction

Today, road tunnels are built and operated in all countries of the world. They are being built for various reasons, including shortening the distances of the built roads, passing through mountain areas, limiting traffic noise or protecting the environment. The growing number and length of road tunnels are also associated with a growing number of extraordinary events that occur at these locations. One type of extraordinary event is represented by fires.

Some of the most significant fires in road tunnels include the fire in the Salang tunnel in Afghanistan in 1982, during which 176 people perished, the fire in the Mont Blanc tunnel between France and Italy in 1999, which claimed the lives of 39 people, the fire in the Gotthard tunnel in Switzerland in 2001, killing 11 people, and the fire caused by a bus hitting the portal of the Reigersdorf tunnel in 2001, during which 24 people suffered injuries. All of these fires were caused by traffic accidents or vehicle fires [1].

Between 2013 and 2019, there was a total of 2 to 5 fires per year in road tunnels in the Czech Republic [2]. When compared to the average number of fires in the Czech Republic, which amounts to approximately 20,000 a year, the aforementioned number of road tunnel fires does not seem significant [3]. Nevertheless, historical events suggest that the consequences of tunnel fires can be catastrophic.

Construction safety requirements in the European Union are particularly based on the Directive of the European Parliament and Council (EU) No. 305/2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC. Some of the characteristics that the road tunnel structures must comply with include fire safety requirements. These requirements include: preserving the loadbearing capacity of the given structures in a fire, preventing the spread of the fire inside and outside the given buildings, organizing evacuation proceedings, rescuing people and securing the safety of the given rescue units [4].

The requirements for the minimal degree of tunnel safety in the European Union are specified by Regulation of the European Parliament and Council No. 2004/54/EC on minimum safety requirements for tunnels in the Trans-European Road Network. Furthermore, construction/technical and operating conditions are specified for tunnels longer than 500 m [5].

Safety requirements for the construction of road tunnels are specified in more detail in the recommendations issued by the World Road Association PIARC [1] and in the national regulations of individual countries.

In order to be able to solve extraordinary events, the construction of tunnels must be prepared from the structural, technical as well as operational perspectives. Cooperation of the project engineers, construction contractor,

tunnel operator and rescue services is necessary to achieve compliance with the given requirements. Apart from other things, road tunnel safety is ensured by the proper use of safety devices. An important role among them is played by fire safety devices.

The objective of the article is to describe the most important fire safety devices, which are usually installed in the road tunnel structures, and to compare differences among selected countries. At the end of the article, the causes of the differences and their extent and the differences among the types of the installed fire safety devices among individual countries are discussed.

2. Basic Tunnel Characteristics in Relation to the Given Safety Devices

A road tunnel is a linear underground structure that houses roads (highways, motorways or local roads) that allow for the fluent and safe driving of vehicles under mountain massifs, water obstacles, inhabited areas, cultural and historical or economically valuable areas, etc. The tunnels must comply with the given fire safety and occupational health and safety requirements (applicable to the tunnel users and tunnel operation employees), fluent and safe driving requirements and the applicable economical requirements. Moreover, the tunnel operation maintenance demands should be kept at a minimum [6].

The required safety level is achieved in situations where the risk of an occurrence and consequences of an extraordinary event are so low that they can be considered acceptable. When assessing the risks, the standard [7, 8] or specific procedures [9] can be taken into account. Individual safety measures can be described by the so-called "safety chain", which is of a repetitive nature and which is shown in Fig. 1.

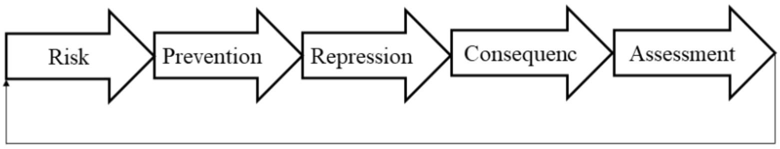

Fig. 1 Schematic diagram of a safety chain [10]

The safety measures in the road tunnels are based on the assessments of all aspects that have an impact on safety. These aspects include infrastructure, operation, tunnel users and vehicles. They consider the following parameters:

- tunnel length;
- number of the tunnel tubes;
- number of the driving lanes;
- cross-section geometry;
- vertical and horizontal lining;
- structure type;
- one-way or two-way traffic;
- traffic intensity;
- risk of traffic congestions;
- time needed for the commencement of rescue services;
- presence and ratio of trucks;
- presence, ratio and type of hazardous cargo transports;
- access road characteristics;
- width of the driving lanes;
- speed limit;
- geographic and meteorological conditions [4].

Equipping road tunnels with safety devices is based on their classification, i.e. their assignment into individual "safety categories". Despite the fact that the tunnel classification methods in individual countries differ, the following factors are normally considered:

- tunnel length;
- traffic intensity;
- traffic character.

From the perspective of length, the tunnels usually belong among tunnels that are shorter than 500 m (short tunnels), tunnels that are 500-1,000 m long (medium tunnels) or tunnels that are longer than 1,000 m (long tunnels). Traffic intensity is expressed as the number of vehicles that drive along a single driving lane at a given time. From the traffic character perspective, tunnels can be divided into one-way or two-way tunnels. The stated factors can be called "characteristic tunnel parameters", which have a fundamental impact on its structural design and the used safety equipment [10].

Apart from the aforementioned factors, other parameters, such as the merging of individual lanes, intersections or permitted or prohibited transport of hazardous substances, can be also considered. The classification methods for assigning tunnels to individual safety categories differ from one country to another.

Generally speaking, the longer the tunnel and the greater the traffic intensity, the stricter the requirements for the

given tunnel fire safety.

3. Installation Requirements for Safety Devices in Road Tunnels

For clarity purposes, the following paragraphs compare the installation requirements for some safety devices installed in road tunnels in the Czech Republic, Italy, France, Germany, Norway, Austria, Slovak Republic, Switzerland and Great Britain (see Table 1).

Table 1

Overview of requirements for the installation of safety devices in selected countries [10, 11]

Safety devices	Czech Republic	France	Netherlands	Italy	Germany	Norway	Austria	Slovakia	Switzerland	Great Britain
Longitudinal ventilation	•	•	•		•	•	•	•		•
Transverse ventilation	•	•	•		•	•	•	•	•	•
Ventilation of emergency and rescue routes	•	•	•		•			•	•	•
Emergency lighting in tunnel	•	•	•		•		•	•		•
Emergency lighting of escape routes	•	•	•	•	•	•	•	•	•	•
Points for emergency calls (emergency telephone)	•	•	•	•	•	•	•	•		•
Automatic detection of events	•		•			•		•	•	
Detection of fire and smoke	•	•	•		•		•	•		•
Loudspeakers	•	•	•		•		•	•	•	•
Backup sources of energy	•	•	•		•	•	•	•		•
Powder fire extinguishers, internal hydrants	•	•	•		•	•	•	•	•	•
Stable extinguisher devices			•					•	•	•

Table 1 shows if the selected countries have requirements related to the compared safety devices in road tunnels (existing requirements are marked with black points in the table). Table 1 demonstrates that the extent of the safety equipment installation requirements in road tunnels differ from one country to another.

4. Installation Requirements for Selected Fire Safety Devices in Road Tunnels

The important safety devices that are installed in road tunnels also include „fire safety devices".

Fire safety devices are systems, technical equipment and products that condition the fire safety of individual structures or other devices. A special category of the fire safety devices is formed by the "dedicated fire safety devices". These devices are devices with specific project engineering, and assembly, startup and operation requirements [12, 13].

Table 2

Overview of the detailed conditions for installing fire detection equipment and stable fire extinguishers in the selected countries (modified based on [6, 10, 11, 16])

Country	Fire and smoke detection/stable fire extinguishers	
	Fire and smoke detection	**Stable fire extinguishers**
Czech Republic	In tunnels longer than 300 m	
France	In tunnels without human supervision	
Netherlands	In tunnels with a control center; in tunnels without control centers only if the ventilation operation during fire differs from the given standard ventilation operation	Limited use for cooling the structures
Germany	In tunnels longer than 400 m with forced ventilation	
Austria	When a forced ventilation system is installed	
Slovakia	In all tunnel areas	Areas with a backup power supply, electric substations and collectors
Switzerland	Automatic detection that reacts to temperature, connected to a given control room and traffic signage	
Great Britain	In tunnels with a control center; in tunnels without control centers only if the ventilation operation during fire differs from the given standard ventilation operation	Automatic fire extinguishing systems are not suitable for traffic areas; gas and foam fire extinguishers are not suitable for areas where people are present; water fire extinguishing systems can cool down smoke

Some of the most important dedicated fire safety devices include electric fire signaling devices (parts of the fire signaling system equipment), stable fire extinguishing devices and smoke and heat exhaust devices (parts of the smoke and heat movement-directing equipment).

The following fire ventilation concepts (strategies) are used for fire ventilation proposals [14]:

- natural (longitudinal) ventilation;
- longitudinal ventilation with a fixed setup;
- longitudinal ventilation with a flowrate regulation to a defined value;
- transverse ventilation.

The most efficient, but also the most expensive ventilation alternative is transverse ventilation [15].

Table 2 represents an overview of the detailed conditions for installing fire detection equipment and stable fire extinguishers in the selected countries.

An overview of more detailed requirements for fire ventilation of tunnel tubes in selected countries is showed in Table 3.

Table 3

Overview of more detailed requirements for fire ventilation of tunnel tubes (modified based on [6, 10, 11, 16, 17])

Country	Tunnel ventilation from the safety perspective		
	Without a requirement for fire ventilation (natural ventilation)	**Longitudinal fire ventilation**	**Transverse** (semi-transverse) **fire ventilation**
Czech Republic	- Usually for tunnels up to 500 m long	- One-way tunnels with a lower number of congestion cases - One-way tunnels with a higher number of congestion cases - Two-direction tunnels *(flow speed 1.2 – 10 m.s^{-1}, usually not more than 3 m.s^{-1})*	- One-way tunnels with a higher number of congestion cases (T2) - Two-direction tunnels (T3)
France	- For municipal tunnels up to 300 m long - For tunnels outside of cities up to 500 m long	- One-way tunnels outside of cities - One-way municipal tunnels - Two-way tunnels *(flow speed 1.2 – 3 m.s^{-1})*	
Netherlands		- Without differentiating among the tunnel characters *(flow speed 2.5 m.s^{-1})*	- For longer tunnels and greater traffic intensity
Germany	- For tunnels up to 400 m, in some cases up to 600 m long	- One-way tunnels with a lower number of congestion cases - One-way tunnels with a higher number of congestion cases - Two-way tunnels *(flow speed 1.5 – 3.6 m.s^{-1})*	- For long tunnels
Norway	- For tunnels up to 250 m long	- Tunnels longer than 500 m and with a straight inline or an incline greater than 2° - Other tunnels with an incline of up to 2° *(flow speed 2 – 3.5 m.s^{-1})*	
Austria	- Provided a sufficient air exchange for standard operation is ensured and the length of emergency exit routes is satisfactory	- Without differentiating among the tunnel characters *(flow speed 2 m.s^{-1})*	
Slovakia	- Usually for tunnels up to 500 m long	- One-way operation with a small probability of congestion (standard highway tunnels) - One-way operation with a high probability of congestion (standard municipal tunnels) - Tunnels with two-way operation *(flow speed 1 m.s^{-1} to up to critical speed)*	- One-way operation with a high probability of congestion (standard municipal tunnels) - Two-way operation tunnels
Switzerland	- For two-way tunnels up to 200 m long - Several hundred meters for one-way tunnels	- One-way tunnels with a lower number of congestion cases (RV 1) - One-way tunnels with a greater number of congestion cases (RV 2) - Two-way tunnels (GV) *(flow speed 1.5 – 3 m.s^{-1})*	
Great Britain	- For one-way tunnels up to 300 m long	- Without differentiating among the tunnel characters (based on the fire capacity) *(flow speed 1.3 – 7 m.s^{-1})*	

It is clear from Table 2 and Table 3 that the requirements for the installation extent of the stated types of fire safety devices significantly differ from one country to another.

We can generally say that tunnels are built without any fire ventilation (natural ventilation) requirements if they are 200 to 500 m long when it comes to one-way as well as two-way traffic tunnels. Longitudinal ventilation can be installed in one-way tunnels with a lower number of congestion cases, one-way tunnels with a greater number of congestion cases as well as two-way tunnels. This is usually restricted by a certain length and traffic intensity. Transverse ventilation needs to be installed in all other cases.

5. Conclusions

Securing safety in road tunnels forms an integral part of their project engineering, construction, and operation. Safety devices installed in the tunnels play an important role in this process. Some specific safety devices include fire safety devices and particularly dedicated fire safety devices. These devices include electric fire signaling system devices, stable fire extinguishing devices and smoke and heat exhaust devices. Fire safety devices thus form a part of the safety concept of road tunnel structures.

Safety devices in tunnel structures can be described by a safety chain, which includes the given risk determination, preventive measures, repression measures (event solution [18]), event consequences and their assessments. The use of the safety chain is of a cyclic character. It is a suitable method for creating safety systems in road tunnels.

Equipping of road tunnels by safety devices is based on their classification into individual “safety categories”. When assigning a tunnel to a certain safety category, some of the important factors that are considered include tunnel length, traffic intensity and traffic character. Nevertheless, other factors can be considered as well.

The article compares the requirements for the extent of equipping road tunnel structures by safety devices in selected countries. The article focuses on the Czech Republic, France, Netherlands, Italy, Germany, Norway, Austria, Slovakia, Switzerland and Great Britain. The stated countries form a representative sample for comparing the extent of the individual safety requirements. It is clear from Table 1 that the extent of the requirements for equipping the structures by safety devices significantly differs from one country to another.

When comparing the extent of the requirements for equipping the structures by fire safety devices, special attention was paid to electric fire signaling system devices, stable fire extinguishing devices and smoke and heat exhaust devices. These devices are of fundamental importance from the safety perspective. Table 2 compares the installation requirements for fire signaling system devices and stable fire extinguishing devices. Table 3 compares the requirements from the perspective of fire ventilation for situations when natural ventilation is sufficient and situations when forced ventilation is required.

It is clear based on Table 2 and Table 3 that the installation requirements for the stated types of fire safety devices are also quite diverse.

The differences in the scopes and installations and their particular implementations are the result of many different factors. Some of the most important ones include historical reasons, specific local conditions, relations to the existing regulations of a given national character, equipment systems and the preparedness of rescue services. The differences of the requirements among individual countries do not have to be necessarily perceived as negative. When there is a sufficient continuity between the installation requirements for the compared fire safety devices and other requirements for the structural and technical implementation of the tunnel structures, an acceptable degree of safety can also be achieved even when the scopes of the requirements differ.

Proper functions of the fire safety devices are also closely linked to the tests of the described fire safety devices, which can be classified as tests conducted during the production, project engineering, startup and operation stages [19]. The tests are conducted by monitoring partial device parameters, software simulations or tests with a “real energy source”. The necessity to conduct appropriate tests has been demonstrated by many cases of correct and also incorrect functions of key fire safety devices.

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Impact of LPG and DME Blends Composition on Fuel Consumption and Overall Efficiency Over the Full Range of SI Engine Loads

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Abstract

The article presents the analysis of fuel consumption for a passenger car with a SI engine, powered by a blends of two LPG and DME gas fuels. The tests were carried out on a chassis dynamometer with a variable engine load, which was to reflect the movement of the vehicle in road conditions. Fuel with different mass shares of individual components was used. Measurement of the specific fuel consumption made it possible to calculate the overall efficiency of the engine. The article also presents the position at which the tests were carried out, as well as the motivations for further testing of alternative fuels.
KEY WORDS: *gaseous fuel, LPG+DME blend, fuel consumption, general efficiency*

1. Introduction

Internal combustion engines have been constantly developed for over a century. This development applies to the materials from which engines are constructed, production technology, as well as the method of supplying engines. All developed areas ultimately have an impact on increasing the efficiency of internal combustion engines. Higher efficiency means greater usable power on the one hand, and lower fuel consumption on the other. The amount of fuel burned by an internal combustion engine, its quality and the combustion process of a given engine have a direct impact on the emissions of harmful and toxic exhaust compounds. Regardless of the technical advancement of the engine, it will have the higher emissions, the higher its average fuel consumption in the cycle. The current, highly restrictive emission standards have determined vehicle manufacturers to develop beyond engine methods to reduce the amount of pollutants in the exhaust, including catalytic converters and filters. However, each filtration system has some limited efficiency. Regardless of the above, the internal combustion engine is a device inside which there is a chemical reaction - combustion. The compounds formed as a result of combustion contain min. simple compounds such as CO2. Regardless of the filtration system used, CO2 emissions can only be reduced by using less fuel, or by using a fuel with a lower carbon content [1].

2. Alternative Fuels

In addition to the evolution of the propulsion itself, work is also underway on the use of alternative fuels. The alternative name specifies the possibility of using these fuels in conventional vehicles. Alternative fuels are both renewable fuels obtained from biomass and fuels obtained on the basis of fossil energy carriers. There are several motivations for using alternative fuels. These include: the desire to reduce emissions of harmful compounds, including CO2, and less dependence on oil supplies.

In assessing whether a given fuel can act as an alternative fuel, criteria are used. One of them is ecological assessment, which verifies the origin of the fuel, the method of its production and the composition of the products of combustion of such fuel. This is the entire fuel life cycle as presented in the WTW (Well to Wheel) analyzes. The next assessment is the costs associated with the use of this fuel. The most important here are the costs of adapting the vehicle to burn alternative fuel, the price of fuel, as well as the form of possible financial compensation for the vehicle owner on the part of the legislator. For example, they can be tax breaks. An important assessment of alternative fuel is also its availability, method and time of refueling. The practical criterion for assessing the use of alternative fuels is also fuel consumption, directly dependent on the energy density of the fuel and the possibilities of its storage in the vehicle - the size of the tank [1].

3. Fuel Blends

Fuel mixtures are also applicable. One of them may be a mixture of propane - butane, known under the generally accepted name LPG with dimethyl ether - DME. Similar physico-chemical properties allow the formation of a mixture of these two fuels. LPG gas is produced in the refining process from crude oil. DME can be produced in a synthetic manner or arise from organic compounds - it is then referred to as BioDME and has the characteristics of biofuel [2, 3].

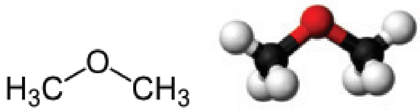

Fig. 1 Structural and summary formula of DME [4]

4. Methodology and Research Process

The tests were carried out for selected DME + LPG mixtures. LPG used in the research is technical gas with equal proportions of propane and butane. The stand for creating mixtures is presented in Fig. 2. The following formulas were used to calculate the mass shares of individual fuels:

Determination of the percentage of the mixture:

$$A = \frac{m_A}{m_F} \times 100\% ; \tag{1}$$

Determining the mass of an ingredient in a mixture of a certain concentration:

$$m_A = \frac{m_B \times A}{100\% - A} ; \tag{2}$$

The amount of ingredient in the mixture at the specified concentration:

$$m_B = \frac{m_f \times (100\% - A)}{100\%} , \tag{3}$$

where m_A – mass of the first component; m_B – mass of the second component; m_f – mass of the mixture; A – percentage share.

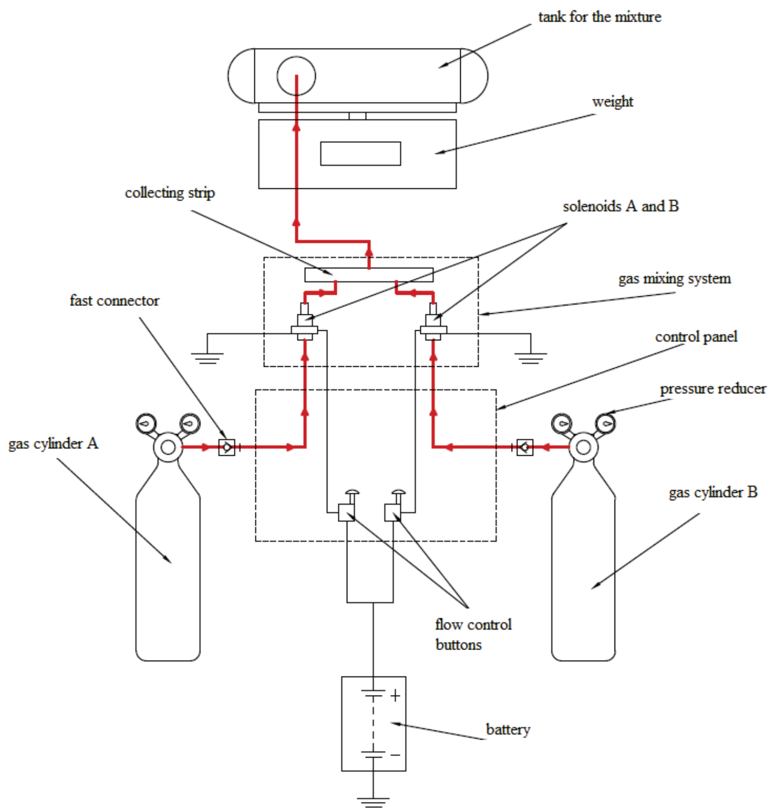

Fig. 2 Diagram of the station for the production of a gas mixture [8]

Mixtures are produced by refueling gaseous fuels in a common tank. First, gas fuel with a larger mass fraction should be refueled in order to calculate the mass fraction of the second fuel needed in the next step in order to obtain a mixture with specific proportions. Each time, to carry out a full cycle of measurements using a given mixture, 6

kilograms of fuel were prepared in a pressure tank placed on the balance (Fig. 4). The tests were carried out using the mixtures presented in the Table 1.

Table 1

Mass shares of individual mixtures

Blend	LPG mass share	DME mass share	LPG mass	DME mass	Blend mass
7 % DME	93%	7%	5,58 kg	0,42 kg	6 kg
11 % DME	89%	11%	5,34 kg	0,66 kg	6 kg
14 % DME	86%	14%	5,16 kg	0,84 kg	6 kg
17 % DME	83%	17%	4,98 kg	1,02 kg	6 kg
21 % DME	79%	21%	4,74 kg	1,26 kg	6 kg
26 % DME	74%	26%	4,44 kg	1,56 kg	6 kg
30 % DME	70%	30%	4,2 kg	1,8 kg	6 kg

Fig. 3 DME storage tank

Fig. 4 Tank for the production of gas mixtures

The test object was a 1.6 dm^3 engine in an Opel Astra F car, equipped with an injection power supply system (Fig. 5). Basic engine specifications are presented in Table 2. The fuel used during the tests is a mixture of LPG and DME gases of various proportions. The test was performed under determined engine operating conditions for the following engine loads: 21, 33, 48, 60, 75, 90 and 100%. The degree of the load was defined by the position of the accelerator pedal. The measurements were repeated for selected rotational speeds: 2000, 2500 and 3000 rpm. Two ignition advance corrections have been applied to improve the combustion process. The car's engine was powered directly from the tank for the production of gas mixtures (Fig. 4). Setting the tank on the scale enabled the measurement of specific fuel consumption.

Fig 5. Vehicle on the test stand

Table 2

Technical data of the tested engine [5]

Engine identification	X16SZR
The number / arrangement of cylinders	4 R
Displacement	1596 cm^3
The degree of compression	9,6
The diameter of the cylinder	79,0 mm
Piston stroke	81,5 mm
Power max.	55 kW
Engine rotation max.	5200 rpm
Moment of rotation max.	128 N·m
Torque rotation max.	2800/min

5. Analysis of Obtained Results

Due to the large amount of measurement data obtained during the tests, the analysis of results has been limited to one engine speed - 3000 [rpm]. The following charts present the results of measurements of fuel consumption depending on the tested mixture and engine load.

Due to the gas mixture used, the engine settings have been corrected. The ignition timing was increased by 3 and 6°, respectively [2].

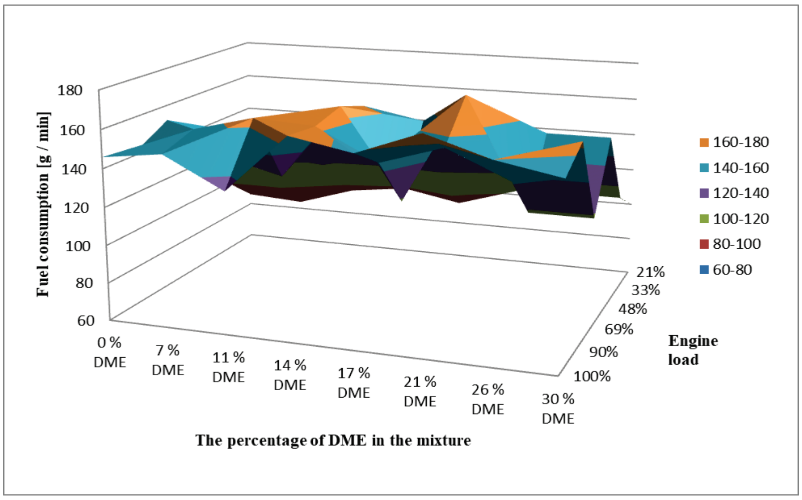

Fig. 6 Graph showing fuel consumption [g/min] depending on the percentage of DME and engine load, for KWZ correction 3°

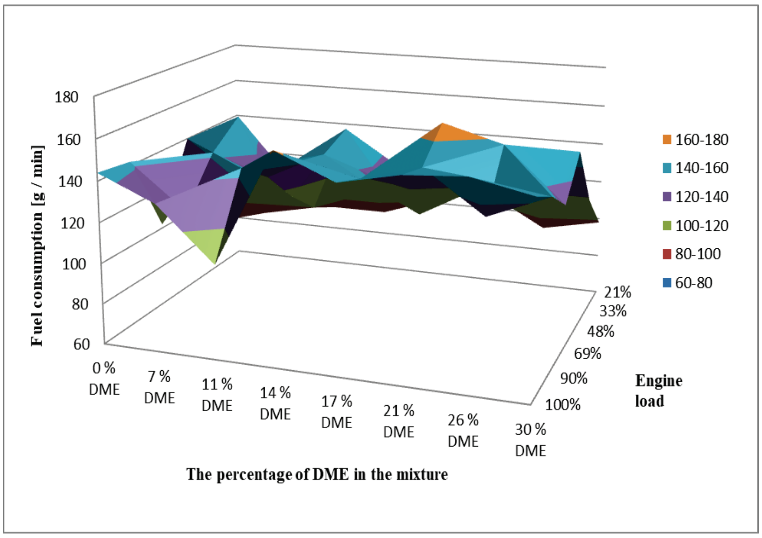

Fig. 7 Graph showing fuel consumption [g/min] depending on the percentage of DME and engine load, for KWZ correction 6°

5.1. Calculation of General Efficiency

General efficiency is a measure of the use of energy contained in the fuel. Thus, it determines the efficiency of converting thermal energy contained in the fuel into mechanical energy given by the engine to the power consumer [6].

Calculation of general efficiency:

$$\eta_e = \frac{N_e}{G_e \times W_u}, \tag{4}$$

where N_e – power on wheels in kW; G_e – fuel consumption in kg/s or m^3/s; W_u – a calorific value of the fuel kJ/kg or kJ/m^3.

These calculated results are presented in Table 3 and Fig. 8.

Table 3

Results of general efficiency calculations

	General efficiency	
	correction 3°	**correction 6°**
7 % DME	0.245481	0.309387
11 % DME	0.302363	0.323188
14 % DME	0.243231	0.246234
17 % DME	0.287166	0.291348
21 % DME	0.240396	0.263783
26 % DME	0.241703	0.241109
30 % DME	0.281967	0.279887

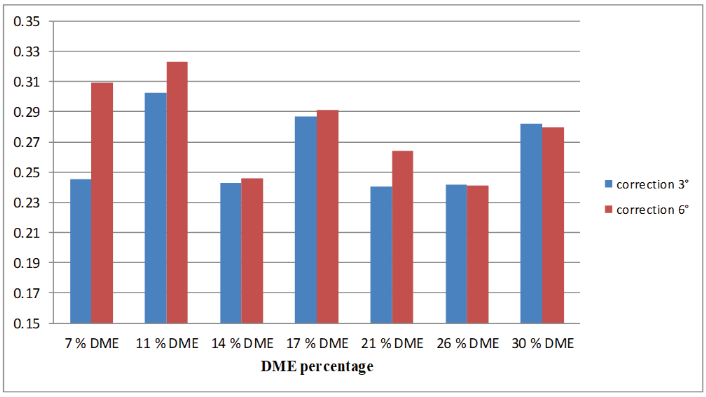

Fig. 8 Graph showing the overall efficiency of the engine, at a speed of $n = 3000$ rpm, for various mixtures and correction of ignition advance by 3 and 6°

6. Conclusions

Gaseous fuel mixtures are an alternative to conventional fuels used to power combustion engines. Due to its similar physico-chemical properties, dimethyl ether is a fuel easily miscible with LPG. With proper adjustment of engine settings, the percentage by mass in the entire mixture can be up to about 30%. Preparation of a mixture of LPG and DME is an uncomplicated process, however, requires high accuracy. Comparing Fig. 6 and Fig. 7, in which the ignition timing correction was 3 and 6 degrees, respectively, compared to the factory settings of the controller, you can notice a reduction in fuel consumption in the entire range of engine loads, for all mixtures used.

The lowest fuel consumption at maximum engine load was recorded for a mixture of 7 and 11% DME, but with a correction of ignition timing of 6°, fuel consumption decreased. The highest fuel consumption was recorded when the engine was running at medium load, for a 17% DME mixture, for each correction. Correction of ignition advance by 6 ° gave the greatest benefits for the 11% DME mixture.

The overall efficiency was calculated taking into account the different calorific values for each mixture. Calculations show that the overall efficiency is greater for an ignition advance correction by an additional 6°. At the same time, overall efficiency is highest for a mixture of 7 and 11% DME.

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Modelling of Technology of Disassembling and Assembling of Freight Trains at Marshalling Yard

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Abstract

This article considers the questions of mathematical modelling of the technology of disassembling and assembling of trains at marshalling yards in order to determine the optimal sequence for the disassembling of trains from the hump. At present, the question of increasing the calculations accuracy for shunting operation arrangement by mathematical modelling taking into account local conditions is particularly acute. Freight trains arrive at the marshalling yard for processing, and they are processed according to a specific technological schedule. There are more than 10 of such technological schedules, they are very diverse and, they also have different times and their processing order. They depend on the category of train: empty or loaded, arrived from abroad or sent abroad, is there a reforwarding of consignment or not. All these local conditions should be taken into account in the mathematical model. Integration of this model into the automated working station of the shunting station operator allows detecting bottlenecks in operation, planning and making the optimal technological decision – which freight train should be first broken down from the gravity hump. In the future, it is planned to use this mathematical model for simulation modelling of the marshalling yard operation. To solve this problem, a mathematical model of the technological process has been developed, which takes into account the features of disassembling and assembling, the amount of work, technical equipment and the uneven arrival of wagon traffic volume to the station. The proposed model is dynamic and is based on a discrete scheduling theory. Using a mathematical model, it is possible to calculate performance indications for the forecast period using real-time input data.
KEY WORDS: *mathematical modelling; discrete scheduling theory; rail traffic; technology of disassembling and assembling; optimal sequence; performance indicators; marshalling yard*

1. Introduction

Currently, some of the sources for increasing the efficiency of station processes are the optimization of technological processes and increasing the efficiency of technical equipment and shunting means application, as well as raising the effectivity and safety of the road traffic [1]. As a rule, any marshalling yard operation technology takes the time for processing the wagon traffic volume, and shunting means are used herewith. To a certain extent, these two elements are interconnected with each other, namely, saving time in some cases provides conservation in shunting means and vice versa.

In this regard, the optimization task for resource conservation is becoming relevant – reducing the time spent by wagons at marshalling yards and the intelligent use of shunting means. As a result of solving this problem, it will accelerate the wagon turn-round, i.e. will save wagons as a resource.

At present, the shunting station operator independently makes a decision on the procedure for trains disassembling and assembling at the marshalling yard, based on the broad picture of the station and its experience in this field. Thus, the optimal operation of the marshalling yard depends on the "experience" of the shunting station operator. The solution of this optimization problem is a reserve for increasing the efficiency of the marshalling yard and its economical effectiveness as well as improves the performance of operational work, ensuring rhythmic processing load, reducing standstill of wagons at harbor stations [2].

The solution to the problem of minimizing downtime at the marshalling yard can be solved using the theory of scheduling [3, 4].

2. The Current Situation and Identifying the Main Problems in the Operation of the Marshalling Yard

The scope of works performed by the marshalling yard is characterized by one of the important economic indicators of its work – the wagons turn-over, namely, the total number of transit wagons arrived and sent per day with processing, without processing, and local wagons.

Today, under the influence of global trends and the geopolitical situation in the Latvian railway market, the situation is significantly getting worse. The rail-freight traffic continues to reduce; its decline began already in the first half of 2019.

There are two marshalling yards on the Latvian railway – Daugavpils and Shkirotava, which are the main control

stations for the arrangement of wagon traffic volume. The wagon turn-over of the Daugavpils station decreased on average by 21% per day of 2020 compared to 2019, and by 37% compared to 2018. The same situation exists at Shkirotava station, this indicator fell by 32% compared to 2019, and by 43% compared to 2018 (Fig. 1).

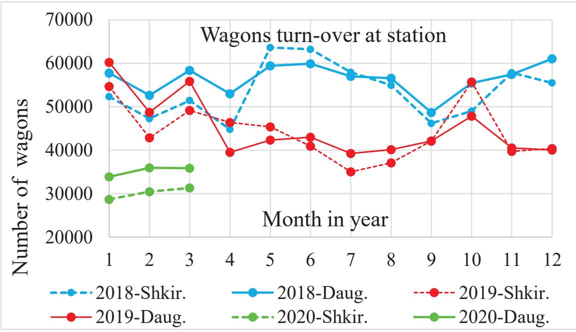

Fig. 1 Dynamic pattern of wagons turn-over on Daugavpils and Shkirotava stations for 2018-2020 years

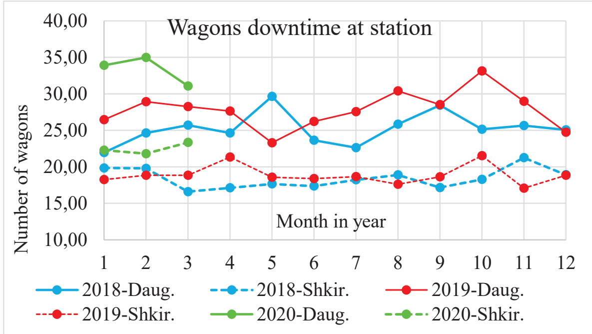

Fig. 2 Dynamic pattern of total wagons downtime on Daugavpils and Shkirotava stations for 2018-2020 years

A steady presence of seasonal fluctuations in wagons turn-over is observed against the background of a tendency towards a decrease in the scope of work (Fig. 1). Taking into account the dynamics of fluctuations in the scope of work at marshalling yards, this factor negatively affects the operational activities of marshalling yards. At the moment, it is important for any marshalling yard to evaluate its economic efficiency and increase energy efficiency. Such technology effectiveness is assessed by the downtime of wagons, the use of shunting means and infrastructure. It leads to an increase in the misallocation of shunting means, and therefore to an increase of operating expenses at the station (Fig. 2).

As a rule, at marshalling yards, the downtime of transit wagons without processing and with processing is separately taken into account. In its turn, the downtime of transit wagons with processing are divided into three elements: downtime in the disassembling system, accumulation time of wagons in the break-up yard, and downtime in the assembling system.

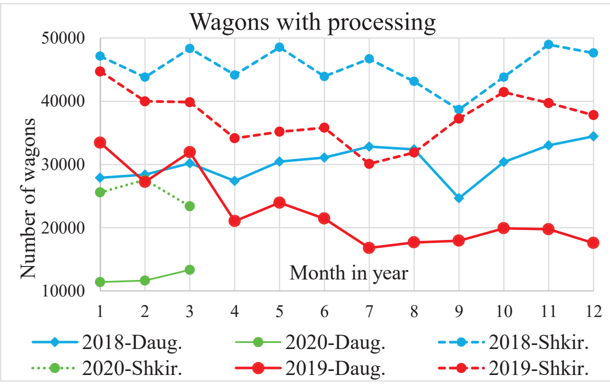

Fig. 3 Dynamic pattern of wagons with processing on Daugavpils and Shkirotava stations for 2018-2020 years

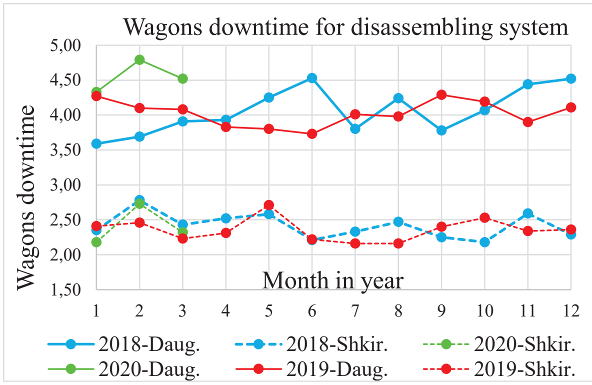

Fig. 4 Dynamic pattern of wagons downtime in the disassembling system on Daugavpils and Shkirotava stations for 2018-2020 years

When comparing the **downtime in the disassembling system** of the two stations, it can be seen that despite the decrease in the scope of work at the Shkirotava station, the downtime almost remained the same, but at the same time it is less by about 40% than at the Daugavpils station (Fig. 3). From the analysis of statistical data, the main problem of overstatement of wagon downtime is at the Daugavpils station (Fig. 4), because at present, the existing track system of the Daugavpils station is such that the marshalling yard and the arrival yard are parallel to each other. As a result of this, in order to break down the train from the hump, there is additional time for pulling the train from the arrival yard onto the turnout track. Also, the electric interlocking system outdated according to physical and technical parameters, and the gravity hump is equipped with manual control of mechanical means. It follows from this that at the Daugavpils station the track system and outdated equipment of the points and signals control system of the station negatively affect the wagon downtime in the disassembling system.

An analysis of the correlation between the volume of wagon traffic processing and the downtime in the disassembling system was also made. The result of this analysis allows us to conclude that both at Daugavpils station ($r_{xy} = 0.681$ for 2018; $r_{xy} = 0.213$ for 2019) and at Shkirotava station ($r_{xy} = 0.272$ for 2018; $r_{xy} = 0.422$ for 2019), the correlation ratio reflects mainly weak or very weak connection, which proves the inefficiency of the current disassembling technology [5].

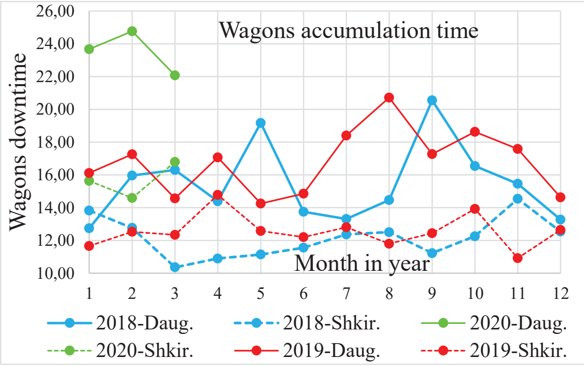

Fig. 5 Dynamic pattern of wagons downtime in the accumulation system on Daugavpils and Shkirotava stations for 2018-2020 years

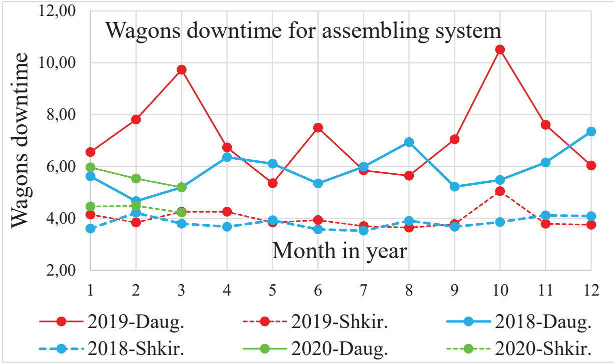

Fig. 6 Dynamic pattern of wagons downtime in the assembling system on Daugavpils and Shkirotava stations for 2018-2020 years

The solution to the problem is the modernization of the Daugavpils station interlocking system and the review of the station arrangement of tracks, namely development of the transport and logistics infrastructure as a catalyst for the economy [6], as well as the review of the work technology at both stations.

Comparing the downtime of transit wagons with processing, certain conformity is observed in the fact that the Daugavpils station processes the less number of these wagons than the Shkirotava station, and the **wagons accumulation downtime** at the Daugavpils station, on the contrary, is greater than at the Shkirotava station (Fig. 5). This is particularly confirmed when determining the correlation ratio between the downtime of these wagons accumulation at these two stations. The processing of statistic data on wagons downtime for 2018 established a negative weak correlation (r_{xy} = - 0.417), and for 2019 – a very weak correlation (r_{xy} = 0.034) [5]. This proves that at the Daugavpils station the technology for processing transit wagons with processing is inefficient in comparison with the Shkirotava station. This is especially evident when analyzing statistic data for 2018, when there is a simultaneous “failure” of scopes in September for both stations, as well as the situation in August 2019, the accumulation downtime at Daugavpils station increased sharply, but not for Shkirotava station.

Thus, we can conclude that with a decrease in the volume of wagons processing, the problem mainly arises in the break-up yard, namely, the accumulation time of wagons increases sharply, as a result of which the trains assembling process slows down. In this situation, in order to start assembling the trains according to the assembling plan, a non-productive downtime of shunting means arises. This fact raises the question – what is the optimal number of shunting railroad engines necessary to ensure the processing of freight trains at the lowest expenses?

The solution to this problem lies in the fact that with a decline in volumes, it is necessary to develop a more effective plan for the assembling of technical itineraries, namely, to change the normal value of the length and mass of a freight train, as well as to arrange two-group trains.

Comparing the **downtime in the assembling system** at two stations, it can be seen that there is a significant exceeding of downtime at the Daugavpils station than at the Shkirotava station (Fig. 6). This is because at the Daugavpils station the gravity hump is not equipped with an automated system for the breaking up of trains and targeted control for the rolling speed of the cuts during the breaking up of trains, therefore “windows” are created between groups of wagons on the marshaling track, as well as the most of the marshaling tracks are of insufficient useful length, which causes additional shunting movements during the train assembling.

Using the correlation analysis, it was concluded that a weak or very weak connection was found between the volume of processing the wagon traffic and the downtime in the assembling system both at the Daugavpils station (r_{xy} = 0.603 for 2018; r_{xy} = 0.298 for 2019) and at the Shkirotava station (r_{xy} = 0.236 for 2018; r_{xy} = 0.492 for 2019), which proves the inefficiency of the current braking down system technology [5].

The solution to this problem is the modernization of the gravity hump and the equipping of the even-numbered lead of break-up yard with the new electrical interlocking system for points and signals control, using programmable logic controller (PLC) to switch and control the points and to control signals and rail section [7], as well as the extension of the break-up yard railway tracks, the revision of the assembling system technology at two stations.

Analyzing the **downtime of wagons without processing**, it was found that at Shkirotava station it is significantly higher than at Daugavpils station (Fig. 7 and Fig. 8). This is a result of the fact that the port cannot accept freight because there is no corresponding arrangement of tracks at the port railway station or there are no loading and unloading facilities at this station, therefore freight trains are forced to “be down on certificates” in the transit park at Shkirotava station. In this case, the excessive responsible downtime of wagons is formed, which, in accordance with the regulatory framework of the Latvian Railways, requires additional operations for its paperwork. Ultimately, this leads to penalties for the guilty in downtime party. To solve this problem, it is necessary to develop a set of adjusting measures to reduce the number of train delays occurring due to unacceptance by port railway stations.

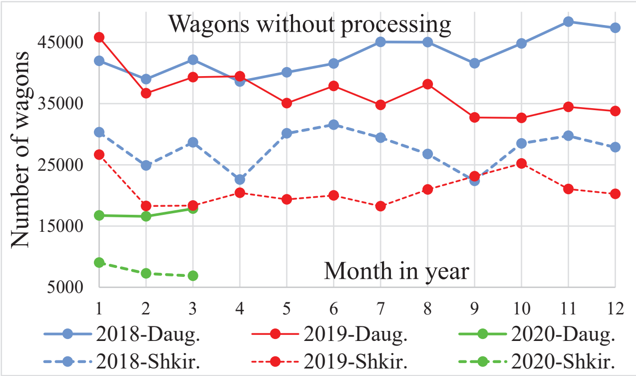

Fig. 7 Dynamic pattern of wagons without processing on Daugavpils and Shkirotava stations for 2018-2020 years

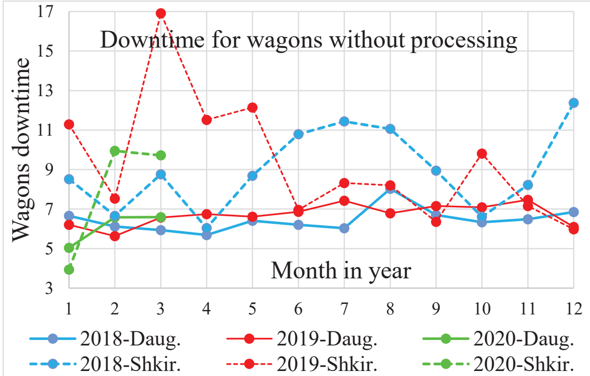

Fig. 8 Dynamic pattern of downtime for wagons without processing on Daugavpils and Shkirotava stations for 2018-2020 years

3. The Solution of Current Problems using Mathematical Model for Trains Disassembling and Assembling Technology at the Marshalling Yards

Due to the uneven arrival of trains at the marshalling yard, the amount of train and shunting operations in each day is different. For each specific case, it is necessary to find such control solutions which will ensure the fact the processed wagon traffic volume in the current circumstances quickly leaves the station, and freight trains do not delay on the rail approaches [8].

The search for optimal solutions is performed with the help of real-time management, the purpose of which is to ensure complete and high-quality performance of the station with minimal operating expenses under the specific conditions of the planning period. In this regard, it is necessary to create a decision support system for the operational personnel of the station, which will solve the main problem of choosing an energy-efficient technology from many possible options. The evaluation criterion for the selected operation technology of the station is:

- minimum daily maintenance expenses associated with the downtime of wagons at the station;
- minimum daily maintenance expenses associated with the implementation of shunting operation;
- exclusion of penalties associated with the excess downtime of wagons.

To solve this problem, it is necessary to develop a mathematical model of the marshalling yard operation technology, which will take into account the peculiarities of assembling and disassembling, the scope of work, technical equipment, arrangement of tracks at the station and the uneven wagon traffic volume arrival to the station.

The proposed model will be dynamic and based on the theory of schedules in the form of “Flow shop” (stream line) type problem solution. Using a mathematical model, it will be possible to determine operating expensed and calculate performance indicators for the forecast period using real-time input data [9].

In order to increase the accuracy of calculations by mathematical modelling of the operation technology taking into account local conditions, an algorithm for choosing the technology of the station operation will be compiled.

As a result, a mathematical model of the marshalling yard operation technology will be compiled, which will ensure the following functions:

- periodic assessment and forecast of the situation concerning difficulties in operation at the station, determining the necessary internal and external control actions to eliminate these difficulties;
- making a decision on the procedure and terms for performing technological operations at the end of the assembling and determination of the exact set of the train being made up;
- establishing the sequence of trains rearrangement to the departure yard;
- making a decision on the splitting up of train, in which the shunting station operator will determine in advance the particularities of each train splitting up and provide measures to eliminate delays;
- establishing the sequence of the train disassembling to fulfill the train departure plan and ensuring the continuous operation of the hump;
- determination of the desired sequence of train arrival, performed in some cases in order to accelerate the arrival of delayed trains, necessary for the implementation of the departure plan.

The implementation of the mathematical model with the help of software will allow simulating real processes performed at the station with a high degree of approximation as well as it will increase the competitiveness and the reserve of the financial and economic stability of business-entities’ cluster on the basis of synergetic effect [10].

4. A Mathematical Model of Assembling and Disassembling Technology for Trains at the Marshalling Yards

The task of trains disassembling and assembling procedures at the marshalling yard is characterized as follows: “The break-up yard has the required number of accumulated wagons to make up the train in a certain direction, provided that there is a free path of the train schedule and there is a foot-plate staff. Otherwise, if there is no certain number of these wagons, then in what order should trains be broken down in order ensure the optimal operation of the marshalling

yard?". The purpose of the decision is to minimize the total downtime of the wagons, both under accumulation, and in trains awaiting for disassembling.

The task is solved as a dynamic one, with a system of restrictions and with priorities when requirements are simultaneously received in the disassembling and assembling system.

Statement of the problem. Assume that it is given: $O = \{O_1, \ldots, O_j, \ldots, O_n\}$ – a set of technological operations for processing freight trains (requirement); $M = \{M_1, \ldots, M_i, \ldots, M_m\}$ – a set of executors who perform a technological operation (operation); r_i – the moment of demand receipt in the service system (this value represents the moment the beginning of the technological operation in the station yards); d_i– planned (scheduled) period (this value represents the moment by which the i operation should be completed, i.e., the end time of the technological operation set by some external reasons relative to the system under consideration) [3, 4].

The permissible duration of a technological operation for processing a freight train, which are the sum of the moment the requirement arrives and the planned period: $a_i = d_i + r_i$.

The technological operation for processing a freight train consists of g_i operations. For each operation, a set of the following values is specified: $m_{i1},\ t_{i1};\ m_{i2}, t_{i2};\ \ldots\ ;\ m_{ig_i}, t_{ig_i}$. Where m_{ij} is the number of the executor who performs the technological operation, $1 \le m_{ij} \le m$, t_{ij} is the duration of the technological operation execution, i.e. the length of the time interval required to perform the corresponding technological operation for the executor of this m_{ij} operation.

Then the total duration of all operations for processing a freight train (duration of operation) is determined by the formula:

$$t_{ij} = \sum_{j=1}^{g_i} t_{ij} \ . \tag{1}$$

It is required to determine the total train waiting time of the technological operation beginning, taking into account the optimal schedule for processing freight trains at the marshalling yard.

Let W_{ij} denotes the waiting time for the start of the technological operation ij, i.e. the time interval between the (j-1) end and the j beginning of technological operation for the i operation. Then the total waiting time for all station movements is determined by the formula:

$$W_i = \sum_{j=1}^{g_i} W_{ij} \ . \tag{2}$$

The result of scheduling will be the determination of the set of W_{ij} numbers. In most cases, the operations performed prevail over each other, and this fact should be reflected by the criteria for schedule assessment. When formalizing a dynamic model with a system of restrictions and with priorities, the weight coefficient u_i for the time interval W_{ij} can be introduced; the smaller the coefficient, the higher the priority of the operation. Thus, as a criterion for schedule assessment, we apply the criterion of timely work execution (marshalling in accordance with the planned period). For example, priority will determine: if the train includes a terminating group of wagons; receiving a freight train is more important than shunting movements; uncoupling and picking up a train locomotive is more important than moving a shunting engine; if, according to the forecast, two freight trains will be ready for departure at the same time, the first one, that is sent on the nearest train path, will be made up, and the second will be made up later. These conditions will determine the priority of one station movement over another for the timely execution of technological operations.

Suppose that for each operation, the values u_i characterizing its relative priority are given. We will use these values in the criteria for evaluating the schedule. Then the total waiting time for all technological operations can be set in one of the following formulas:

$$\bar{W}_u = \sum_{j=1}^{g_i} u_i W_{ij} \ . \tag{3}$$

If determining the weight of the operation (priority of the operation), then the total weighted duration of all technological operations using the objective function of the model can be determined:

$$F = \sum_{j=1}^{g_i} t_{ij} + \sum_{j=1}^{g_i} u_i W_{ij} \to \min \ . \tag{4}$$

Using this formula, it is possible to solve the dynamic problem with the simultaneous receipt of requirements in the disassembling and assembling system, so that the operation of the marshalling yard is optimal.

5. Conclusions

As a result of the mathematical model development for a new technology of wagons disassembling and assembling at marshalling yards, it will be possible to use it for Daugavpils station, because at this station, the wagons downtime is significantly excessive in comparison with the Shkirotava station. Using this model, it will be possible to identify problems in station operation and the fact why unproductive downtimes occur in the system of disassembling, making

and accumulation.

When choosing a new technology, the criteria for minimum total operating expenses associated with the following are used:

- with downtime of wagons in the system of disassembling, making and accumulation;
- with the downtime of wagons at stations associated with the implementation of shunting operation;
- with the construction of a new recentering yard, lengthening of the railway tracks in the marshalling yard, as well as the maintenance of railway tracks in it;
- with the modernization of the hump and the equipping with a new electrical interlocking system to control the points and signals of the even-numbered lead of the marshalling yard.

In general, the use of modeling the technology of the marshalling yard using the example of the Daugavpils station after changing the station arrangement of tracks by constructing a new receiving yard, which will be located sequentially for the marshalling yard, modernizing the gravity hump, equipping with a new electrical interlocking system to control the points and signals of the even-numbered lead of the marshalling yard and lengthening of the railway tracks may have significant effects:

- increase in the performance of the hump engine by 15-20%;
- increase in the performance of a shunting engine that operates on turnout tracks by 25-30%;
- reduction of wagon downtime in the disassembling system by 10-15%;
- reduction of wagon downtime in the assembling system by 15-20%;
- reduction of wagon downtime in the wagon accumulation system by 10-15%;
- increase the processing ability of the hump by 10-15%.

As a result of the technology modelling application, resource conservation indicators will be improved, namely, energy costs for shunting operation in the system of disassembling and assembling will decrease, which will increase the energy efficiency of the Daugavpils station technology.

In the long term, the effect of implementation a system for support the decisions made by the station's operational personnel will allow us to assess the dynamics of the situation and make the choice on the optimal sequence of technological operations for processing freight trains at the station.

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The Advisability of Using Dual Gauge for Expansion of the International Traffic

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Abstract

The possibilities of railway transport for the organization of transportation between the countries are not used to the full extent, since there are a number of technical reasons. The usage of dual gauge (1435/1520 mm) is one of the solutions. As an example of using dual gauge is the international project "Rail Baltica", Lviv railway and etc.
KEY WORDS: *Rail Baltica, transport corridors, dual gauge, railway*

1. Introduction

Track gauge on railway transport is one of the most important parameters of the track infrastructure. There are several standards of track gauge in the world, and when there are sections with a different track gauge, special measures must be taken – either to perform a bogie exchange or to reload cargo or transfer passengers to cars with the appropriate track gauge. This problem can be also solved by combining both tracks into a combined (dual) gauge. Dual gauge, unlike the standard one, consists of three (Fig. 1) or four rails (Fig. 2).

Three rails can be used in a situation when the width difference of two tracks is sufficient to install a rail of the smaller track into the larger track, using one of the rails as a common one [1]. For example, 1668 and 1435 mm in Spain [2], 1435 and 1067 mm in Australia and Japan, 1520 and 1067 mm on Sakhalin, 1676 and 1000 mm in Bangladesh.

To combine tracks that differ little from each other, only a design that uses four rails is possible. This is exactly the situation, in particular, on most of the western borders of Ukraine: the difference between 1435 and 1520 mm is only 85 mm.

On the Lviv Railway (Ukraine), the total length of dual gauge (1520 and 1435 mm) is about 150 km. The Main Department of Track Facilities together with the Scientific and Design Technology Bureau of Track Facilities of Ukrzaliznytsia, factories-manufacturers and specialists of Lviv Railway track services developed and introduced into production new dual rail gauge of 1520 and 1435 mm with reinforced concrete sleepers and intermediate elastic fastening. The experimental section of such a track is located from Chop and Diakovo stations to the state border of Ukraine (Fig. 2).

Fig. 1 Three-rail track near the station

Fig. 2 Section of dual rail gauge 1520 mm and 1435 mm

In contemporary conditions, a project to connect at least two sections of dual gauge with the subsequent establishment of an intermodal hub could be attractive. The combination of Mukachevo and Mostyska stations with a European track (distance almost 300 km) is an appealing option, to build a large transshipping hub in Lviv. Undoubtedly, such projects require foreign investments [3].

A vivid example of such a hub is the Slovak terminal “Dobra”, which plays a key role in the development of container traffic on the V European Corridor (Italy – Slovenia – Hungary – Slovakia – Ukraine – Russia) [4].

Back in 1998, the Karpaty terminal was constructed in Ukraine, the production facilities of which are located near the Batovo hub station (near the Chop city). However, it clearly loses to its Slovak competitor and requires further development.

In addition, Ukraine and Poland could join efforts in constructing a general intermodal cargo transshipment terminal and thus provide their dual rail lines by the reliable cargo traffic [5, 6].

One of Europe's priority rail projects with dual gauge is the “Rail Baltica” railway, which is a part of the North Sea-Baltic railway corridor connecting Finland, Estonia, Latvia, Lithuania, Poland, Germany, the Netherlands, Belgium, and Luxembourg. [7-10]. The length of the "North Sea–Baltic" corridor is 3200 kilometers.

2. Priority Projects of Dual Gauge in Ukraine

Currently, the deepening of the European gauge on the Ukrainian territory is in three border regions. The largest segment of dual gauge (1520 mm + 1435 mm) is located in Transcarpathia between the Chop – Batovo – Mukachevo stations (about 40 km, electrified) and Batovo – Korolevo – Diakovo (about 80 km) [11]. In the Volyn region, the European gauge is laid from the Polish border to Kovel (64 km), and in Lviv: Varlamova Volia – Mostyska – State Border (7 km of 1435 mm track and 11.8 km of dual gauge); Khyriv – Starzhava – State Border and Khyriv – Nyzhankovychi (12.9 km of 1435 mm track and 25.7 km of dual gauge); Rava Ruska – Hrebenne (7.1 km of 1435 mm track). The indicated sections are included in the international transport corridors (Crete No. 3, No. 5 and Hdank–Odesa).

Ukraine has offered Slovakia and Romania to transport goods from one country to another through the Transcarpathian region, simultaneously using the combined railway Khalmeu/Diakove – Batovo – Korolevo – Chop/Chyierna-nad-Tysou.

Ensuring the mobile movement of passenger trains, primarily from Poland to Ukraine is relevant for Ukraine. It is impossible to change the Ukrainian gauge to the European one because of the need for intensive investments. Therefore, options for the reconstruction of domestic destinations are offered [11, 12]. By implementing the uncongested railway traffic between Lviv and Warsaw, it is possible to transport goods and realize journeys of Ukrainian passengers to any of the EU countries, the Balkans, or the Baltics.

2.1. Infrastructure Project Eurogauge “Mostyska-Lviv”

One of the most important directions connecting Germany (and through it other countries of Western Europe) with Ukraine is the Crete transport corridor No. 3. One of the priorities may be the infrastructure project proposed by the Ministry of Infrastructure of Ukraine "Eurogauge "Dry Port". The project envisages the development of railway infrastructure for the construction of dual gauge1435/1520 mm on the Mostyska-1 – Rodatychi section, Lviv region. The estimated cost is 11 million euros, the estimated implementation period is until 2022. The Mostyska-1 – Lviv railway section is a part of the Crete International Transport Corridor No. 3 (Berlin – Wrocław – Lviv– Kyiv). This section is double-track, with a track gauge of 1520 mm, the double track is combined with a track of 1435 mm, until the ‘90s to the station Rodatychi (length 42 km), at this time – to the station. Mostyska-1 (Fig. 3).

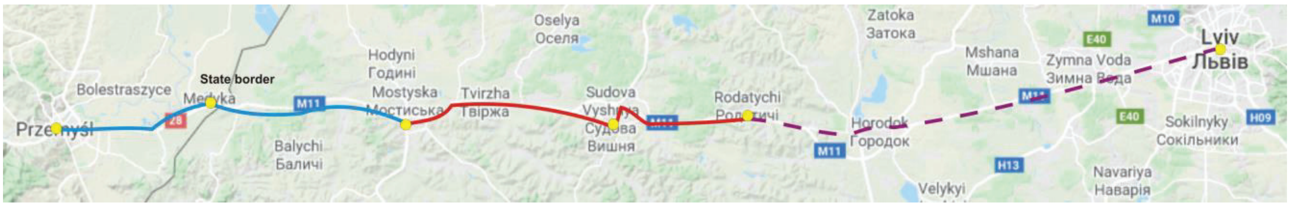

Fig. 3 The project of a section for the State border – Rodatichi dual gauge with a promising way to Lviv (via Google Maps)

The Lviv-Mostyska section is electrified with direct current. Electric locomotives CHS7 in passenger movement and VL10 in freight one are used in service for trains. There are eleven stations in this area. The maximum speed for passenger trains is 120 km/h, for freight trains is 80 km/h.

From the analysis of the profile and plan of the Lviv-Mostyska section, it was found that the largest number of curves has a radius from 700 to 1200 m, their specific gravity is 12.1%. The specific gravity of curved radii up to 700 m is 4.9%. A large number of restrictions on the parameters of curves are characteristic of plan of the line. The ruling gradient is 8‰.

Superstructure: rails type P65, a continuous welded rail. Fasteners and sleepers are new or used combined with new ones. Sleeper density: in straight lines and curves – 1840 pcs/km, except for wooden sleepers on a ribbon track in curves with a radius up to 1200 m – 2000 pcs/km. The ballast is crushed stone, 30 cm thick under sleepers.

The total number of artificial structures on the site is eighty-one pieces, of which sixteen are reinforced concrete bridges, eight are stone pipes, eight are reinforced concrete pipes, and four are metal bridges.

The time of freight train from Lviv to Mostyska (excluding standing at stations) is about 70 minutes, and passenger one is about an hour at an average speed of 70-75 km/h.

According to the forecasts, Ukrzaliznytsia plans to build 1520/1435 mm dual gauge from Mostyska to Lviv, which will open new opportunities for passengers, Ukrainians will have a direct high-speed service from Lviv to Krakow, Prague, Vienna.

Dual gauge will allow trains to depart from Europe, without wasting time for changing bogies, to travel to Sknyliv railway station, located 5.5 km from Lviv. This destination point was chosen to avoid overloading the Lviv station, through which actually all domestic trains run. And Sknyliv can become an international railway hub, switching part of the passenger traffic in Przemyśl. In addition, for the comfort of passengers, Ukrzaliznytsia plans to launch an express train between Sknyliv, the airport and the city's central railway station.

Transportation will be carried out by European operators, as there is no appropriate rolling stock in Ukraine. In the overall scope of works, it is necessary to lay 69.8 km of the 1435/1520 mm dual gauge, to build 3.1 km of the 1435 mm track, to perform 58.2 km of expansion for the main platform of a roadbed, to carry out comprehensive and recreational repair of 9.5 km of the existing dual gauge and reconstruction of eight stations, to perform reconstruction and modernization of the power supply infrastructure, to build the infrastructure for the railway station at the Sknyliv station for the 1435 mm gauge.

2.2. Infrastructure Project "Eurorail Lviv-Rava-Rusk-Warsaw"

The target of the ″Eurorail Warsaw–Lviv″ project is establishing an effective international railway service between Poland, other EU countries, and Ukraine under conditions of actively growing political, economic and social relationships. Laying dual gauge would allow trains to travel non-stop from Lviv to European cities.

For the construction of new dual gauge, in particular on the Rava–Ruska–Lviv section to the railway station Briukhovychi near Lviv (Fig. 4), it is necessary to perform a set of works: to lay 58 km of new dual railway gauge; to reconstruct five stations; to equip nine crossings with automation; reconstruct eighteen artificial structures and enlarge the major site of the roadbed with a length of 59.1 km.

The choice of Briukhovychi as the destination point of the European gauge is not accidental. Despite the developed broad-gauge infrastructure around the Lviv railway station, its rebuilding requires significant investments. Therefore, it is easier and cheaper to lay the European gauge to Briukhovychi station on the outskirts of Lviv, from which one can reach the city center by motor-vehicle transport in 10 minutes.

The total cost of the main works for the development of railway infrastructure and for the construction of dual gauge on the Rava–Ruska–Lviv section to the railway station Briukhovychi, according to preliminary estimates, is 50 million euros (excluding funds for the development of designing estimates and other works).

The Lviv-Rava-Ruska section, single-track, is served by diesel traction, belongs to the low railway category both in terms of traffic size and maximum speed.

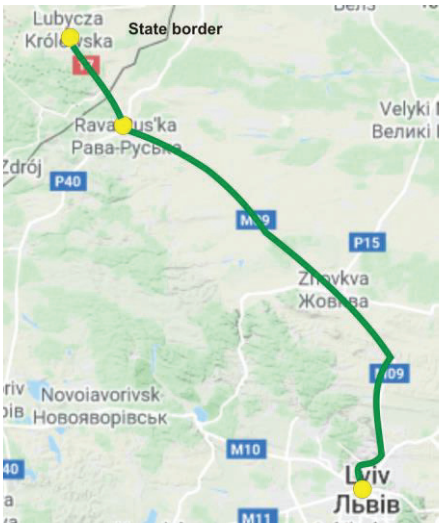

Fig. 4 Plan of the Lviv–Rava–Ruska–Warsaw railway route (via Google Maps)

The development of measures for the reconstruction of railway sections is preceded by an analysis of the technical condition of the line, parameters of the plan, and the longitudinal profile. According to the data of the rail-sleeper-ballast map as of 01.01.2019, the following characteristics of the existing gauge are given. The density of a line is 5 million tons gross/km per year. The passed tonnage of the line ranges from 13 to 24 million tons gross/km. The maximum speed of passenger trains passage along the section is 80 km/h, freight ones are 60 km/h.

In this section there is a ribbon track with rails P65 type, the length is 25 m. Sleeper density varies from 1449 pieces/km to 1904 pieces/km, as the section has curves of small radii from 203 to 300 and more meters.

Depending on the size of the radii, the track is laid on reinforced concrete and wooden sleepers. That is the reason why four types of intermediate fastenings are operated on the section. The total number of artificial structures on the section is eighty-two pieces, of which forty-two are reinforced concrete bridges, five are stone pipes, twenty-eight are reinforced concrete pipes, five are metal bridges, and two are metal pipes.

The longitudinal profile of the Lviv–Rava–Ruska section with a length of 68 km is mainly a descent with gradients from 9 to 16‰, steep gradient 10‰ - 15.2% (Fig. 5).

The plan of a line has a significant impact on the value of the permissible speed limit. The presented histograms show that the specific gravity of curves with a radius of up to 500 is 15.9% (Fig. 6). A large number of restrictions by the parameters of the curves component and adjacent ones are characteristic for the plan at the Lviv–Rava–Ruska section. Due to the complex plan of the line, it is often impossible to increase superelevation of the outer rail in curves, which requires lengthening the transition curve, it is often cannot perform with short straight between two curves. According to the results of traction calculations, it is found out that at the maximum permissible speed up to 80 km/h, the average running speed is about 50 km/h, and the travel time is 80-90 minutes.

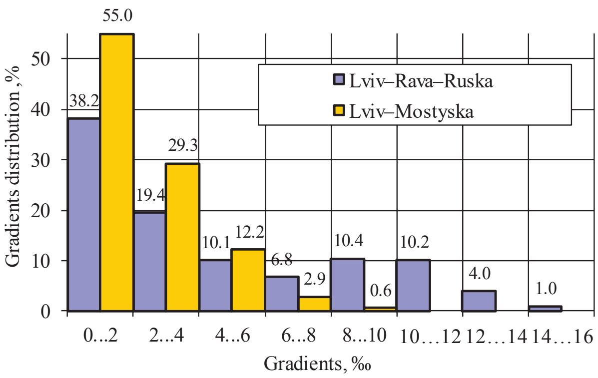

Fig. 5 Histogram of gradients distribution

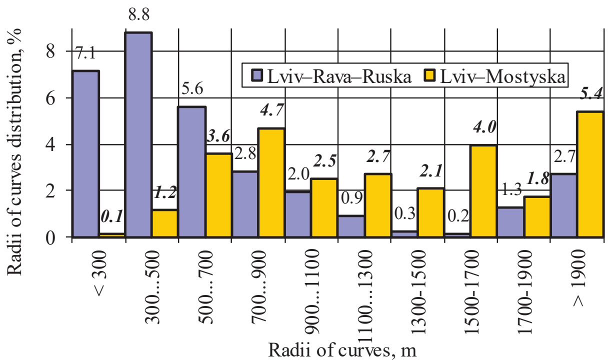

Fig. 6 Histogram for radii of curves distribution

Analysis of histograms (Figs. 5 and 6) shows that both in terms of profile and plan, the Lviv–Mostyska section has significantly better indexes in comparison with the Lviv–Rava–Ruska one. The aforesaid is confirmed by the level of average running speed, which is 1.5 times higher in the first section. In addition, the Lviv–Mostyska section is double-track, which allows at 4-5 times ensuring the higher train-handling capacity.

According to the Instruction on laying and maintenance of the dual railway gauge 1520 mm and 1435 mm [13] dual gauge is laid on wooden sleepers in straight and curved sections of a track with a radius not less than 300 m or reinforced concrete sleepers, special type in straight and curved sections with a radius of not less than 350 m. Fig. 6 shows that on the Lviv–Rava–Ruska section, curves less than 300 meters is 7.1%. Therefore, in this case, dual gauge is not laid, and its application requires a widening of the roadbed with the transition to a new track or the restructuring of curves, which will also lead to a shift in the axis of the track.

3. Advantages and Disadvantages of Dual Gauge

Laying dual gauge does not require the structure of a separate roadbed, which can be attributed to the advantages of this method in organizing train traffic. However, the use of dual gauge requires junctions and bypassing of end of block sections due to the need to lay turnouts of standard 1520 mm and European 1435 mm gauges, which leads to a decrease in the speed of trains when passing stations [14].

The solution of this problem, as well as the construction of the second gauge with a width of 1435 mm parallel to the existing line of 1520 mm, leads either to the need to reconstruct the end of block sections on this direction, or the use of curves to bypass them [11]. At this, such constructions as flat crossings, a gauntlet, and combining of 1520 mm gauge and the Western European 1435 mm gauge are used.

According to the definition of The Organization for Cooperation of Railways (OSJD) a gauntlet and combining of tracks (used in constraint environment) this is a part of tracks of the double-track section, where one rail track is mounted on another and laid on common sleepers with the help of two crosspieces without turnouts for gauntlets (Fig. 7) and one crosspiece and one turnout for combination (Fig. 8). In reality, in the areas of gauntlets there are options without changing the motion side and with the change of motion side.

Four hundred twenty-one sets of turnouts for 1435 mm gauge, thirty crosspieces lying separately, forty-two sets of flat crossings are operated within the “Lviv Zaliznytsia” regional branch for combination and crossing of 1435 mm gauge with each other and with standard 1520 mm gauge. Fig. 9 shows a fragment of the tracks gauntlet, where one rail track is move up to the other and laid on its sleepers using a crosspiece without turnouts.

In addition, to ensure the connection of dual gauge with separately located 1435 mm and 1520 mm tracks on the Lviv Railway, individual structures of connection are operated. For example, the combined turnout is operated along the Khust distance of the track at the Berehove and Vynohradove stations, type P50, mark 1/11, left-side, on the wooden bars (Fig. 10).

Fig. 7 Scheme of the tracks gauntlet

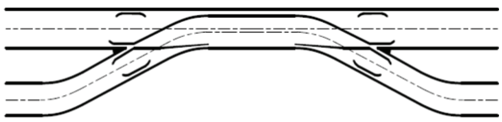

Fig. 8 Scheme of the tracks combination

Fig. 9 The tracks gauntlet

Fig. 10 The combined turnout

In Ukraine, a special turnout was developed for the movement of trains with different track gauge as one of the options for design solutions. The dual turnout according to the Dn410 project with rails of the European profile, type UIC60, mark 1/11, 1435 mm gauge on the wooden bars with a crosspiece and with welded rail ends was laid in May 2005 on the first major track of the intermediate railway station Kosyny, regional branch "Lviv Railway" [11]. In September 2017, the turnout according to the Dn410 project was inspected and it was established that the passed tonnage was 8.9 million gross tons, the speed was 60 km/h in the direct route, and 25 km/h in the sideways one. Due to the fact that dual gauge is laid on reinforced concrete sleepers to ensure the equal elasticity of the railway track, it is necessary to start laying such turnouts on reinforced concrete beams.

On dual gauge sections, the same train traffic along a track of each width will hardly be provided. Different cyclicity of loading will lead to asymmetric operation of an under sleeper base. In the presence of improper maintenance in the sleepers and ballast condition, this can provoke an increase in the intensity of the residual strain accumulation.

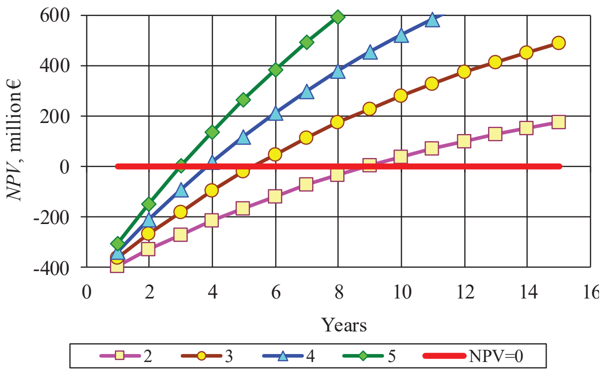

Fig. 11 The progressive total of the net present value depending on the size of passenger traffic (Lviv-Mostyska-Krakow-Warsaw section)

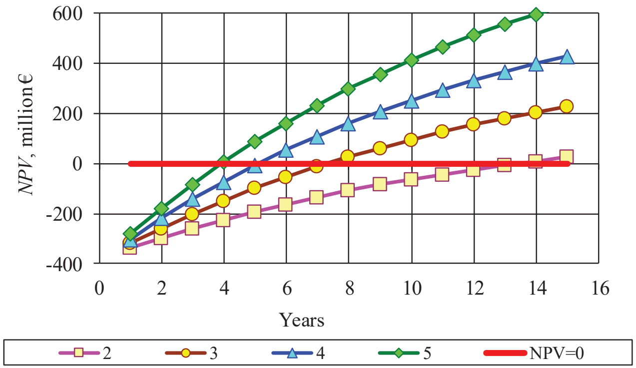

Fig. 12 The progressive total of the net present value depending on the size of passenger traffic (Lviv-Rava-Ruska-Warsaw section)

A further comparison was conducted on such an index as the net present value (*NPV*). The model developed by the authors for forecasting and evaluating the efficiency of railway transportation from the border of one state to the border of another was presented in [11, 15]. The main index (*NPV*) used in the model is the difference between total income and all types of costs, with consideration to the time factor. The list of recorded expenses includes investments, locomotive fleet, car fleet, current operating costs, costs that depend on the type of technological operations, and the stay period of freight cars at the break-of-gauge points.

The transportation fee was set in accordance with the order of the Ministry of Infrastructure of Ukraine "On Amendments to the Tariffs for the Carriage of Passengers, Luggage and Cargo-Luggage by Rail in International Transport", No. 208 March 25, 2019.

Options of passing passenger trains in the amount of two to five pairs per day were considered as forecast data. It is established that the net present value depending on the size of passenger traffic was previously observed in the Lviv-Mostyska-Krakow-Warsaw option (Fig. 11) in comparison with the Lviv-Rava-Ruska-Warsaw option (Fig. 12).

4. Conclusions

Analyzing the options considered, we can conclude that the construction of dual gauge would facilitate a non-stop quick and comfortable trip from Lviv to European cities. The driving time for the longer version is shorter and is 5.7 hours, compared to 6.2 hours in the second case. Operating costs for passenger train mileage is 6.0/6.5 euros/train-km against 8.0/8.5 euros/train-km in the second case.

According to the Lviv–Mostyska–Warsaw project, the length of the option is 1.6 times higher and its forecasted cost is 120 million euros against 50 million euros: the cost of the Lviv–Warsaw project via Rawa-Ruska, ie the difference is 58%. The authors do not share such a valuation, considering it to be understated, and therefore the study assumed a unit cost of 5 to 10 million euros per 1 km.

At the quantity of two pairs of passenger trains a day in the first case the positive effect comes at $t = 9$ years, in the second option at $t = 13$ years. With a doubled traffic volume, the income appears in the 4th and 5th years, respectively. It should also be noted that in the first version $NPV = 306$ million euros against 132 million euros in the second one at the cost of dual gauge construction 5 million euros/km (177 million euros total) against 7 million euros/km (25 million euros total) respectively.

The final decision on the advisability of using dual gauge for expansion of the international traffic should be made after clarifying the volume of round-trip traffic between Lviv and Warsaw, taking into account, as it was noted above, the complexity of the longitudinal profile and plan of options, technical equipment, and operating standards.

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Evaluation of the Main Roads Network Pavement Condition Index with a 3D Laser Scanner System

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Abstract

The length of the Lithuanian national road network is 21,237 thousand km, of which the highway roads are 1750,71 km. As primary roads highways have the highest requirements, the most important of which is fast and uninterrupted vehicle traffic. These key tasks, which are the responsibility of the road administration and maintenance authorities, require the maintenance of a sufficient level of service (pavement condition), which is determined by automated condition surveys with a 3D laser scanner. Evaluation of the condition of the highways with a 3D laser scanner consists of two steps: first – accurate pavement surface condition survey, second – analysis of the collected data. Afterward, the pavement condition index is determined for each homogenous sector, these indexes and sectors are parameters of the pavement management system. This article presents the new road test equipment RST63, which was launched in Lithuania and introduced innovative technologies in the Baltic States. It also presents an analysis of the pavement condition data collected by this equipment, provides up-to-date data on the highway road network, and evaluates the highway network by pavement condition index (PCI). PCI method is new methodology in Lithuania of evaluating pavement condition level through three perspectives (comfort, safety and structural indices) and combining them to one global PCI index.
KEY WORDS: *road surveys, RST63, pavement surface, pavement performance, pavement condition index, evaluation of pavement condition, pavement serviceability*

1. Introduction

Currently according to Lithuanian Road Information System LAKIS, LRA maintain more than 21 thousand kilometers of national roads, of which 1750,710 km are highway roads (also known as main roads), 4927,684 km are national roads and 14559,243 km are regional roads.

To successfully manage the entire road network condition, as a part of road asset management, road maintenance, and development plans are being prepared. For this purpose, the Pavement management systems (PMS) are used. PMS can be described as a set of tools to help a road network manager identify the best maintenance and repair strategies to maintain the condition of a good service road network [3].

PMSs are applications, depending on the installed functions, that allow evaluating the condition of roads, rationally allocate funds between the budgets and repair works, select the types of repairs, self-assess the economic benefits of the funds spent today, and spent in the future.

One of the key elements of PMS is the determination of the road surface condition index (PCI), which allows determining the order of priority for maintenance works (program) based on the condition of the structure and functional properties [2].

In the asset management area, there are many methods to evaluate road pavement condition. The most common name in this field is found to be the Pavement Condition Index (PCI). PCI has become a generic name in the field of pavement management area and is used as an international name for pavement condition assessment indicators. There are different standards for its calculation and interpretation which depends on the country and its regulations where it is applied for. Despite different calculation principles, the purpose of the PCI is the same - to evaluate pavement condition and to determine its serviceability.

The PCI is a numerical and dimensionless index used to describe the overall level of road surface condition and is widely used in transport engineering and asset management [5, 6]. In Lithuania, the PCI calculation is prepared according to the COST 354 Action calculation methods when the road surface is evaluated by different aspects like safety, structure, and riding comfort (also known as General Condition index).

To effectively manage the condition of the road network and calculate PCI, it is necessary to carry out a survey on the technical parameters characterizing the condition of the road surface.

Road surface condition surveys are performed to assess and describe the condition of the road network by measuring technical parameters (TPs).

The values of the technical parameters of the road surface determined during the surveys can be expressed in various performance indicators (PI) (longitudinal or transverse evenness, Skid resistance, etc.) which are a dimensionless number that evaluates the TP on a set scale thus enabling engineers to compare different PIs (longitudinal with transverse evenness) and also to combine them which let to describe the pavement condition thru different

aspects [5].

Survey of road pavement condition parameters is a process of measurements to determine overall ride quality (indicators of comfort or safety), damage, road pavement strength, or skid resistance. This data collection on pavement condition is the most expensive step in the pavement management process, which can be performed in several ways: Automated continuous measurement or visual inspection (manually).

Now new laser technologies allow road authorities to collect a lot of data about pavement condition during surveys with the latest laser technologies. Also new pavement evaluation method of calculating PCI allows to set optimal priority for maintenance works.

2. Main Roads Network

National importance highway roads are the main Lithuanian roads intended for convenient and fast communication between the main cities of Lithuania and with neighbor countries. There is huge heavy vehicle traffic on these roads. According to the decision of the United Nations Economic Commission for Europe, the highway roads of Lithuania are included in the international road network (6 European motorways), called “E roads” and numbered with index E and the corresponding number (ex. E85). Most of the highways also belong to Corridors I (and its siding I A) and IX B of the Trans-European Network (TEN-T).

There are three types of pavement in the highway road network - Asphalt (1690.5 km), Cement concrete (59,930 km) and cobblestones (0,251 km) (source: Lithuanian road information system LAKIS). There are roads in the main road network that have the status of a freeway or highway – sections of high-speed roads. The length of such sections is 429,867 km, which is 24.55% of total main road network.

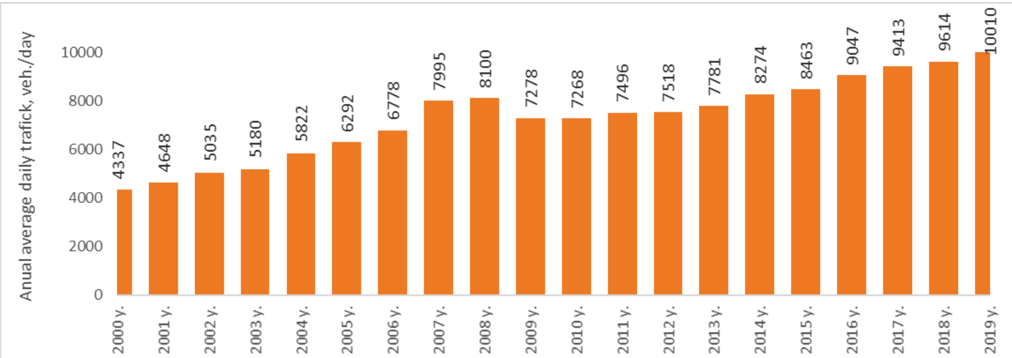


Fig. 1 Annual average daily traffic change since the year 2000

There are main roads or main road sections that have two carriageways, which are analyzed separately like different road. The length of such sections is 623,651 km, which increases the length of the analyzed main road network to 2373,227 km.

The overall traffic volume of the highway road network is 4.12 times higher than that of national roads network and 23.7 times higher than a regional roads network [7].

Annual average daily traffic (AADT) for highway road network is 10010 cars/day (see Fig. 1). The composition of the highway road network traffic is: 8395 cars/day for light vehicles and 1615 cars/day for heavy vehicles. Comparing the traffic composition change in 2018 - 2019, it was found that the AADT for light vehicles increased by 4.43%, and for heavy vehicles increased by 2.5% [7].

The growth of AADT in the main roads (highway roads) network has been observed since the year 2000, and it was only during the economic recession in years 2009-2010 that it declined. 2019 traffic increased by 131% compared to the year 2000 [7].

3. Road Surveys with RST63

The RST63 equipment is unique, consisting of three separate components - a point laser, a second-generation Laser Crack Measurement System (LCMS-2) and a 360 angle LadyBug camera (see Fig. 2). All of this equipment enables collecting as much information as possible during one measurement. That allows a complete analysis of the pavement condition, also allows visual analysis of road surroundings. Pointcloud data and 360 images could be used in the road design process, object analysis, inventory works or similar tasks.

Point lasers are dedicated to measure the longitudinal profile of a road, subsequently calculated to longitudinal road roughness and MPD.

The LCMS-2 component is two 3D-type lasers that produce a highly accurate digital image of the road surface (point cloud) by scanning the pavement surface. Later it can be assessed with mathematical models to calculate a variety of geometrical parameters, such as longitudinal and transverse roughness, longitudinal and transverse slopes which are relevant for removing water from a pavement surface; identify and categorize road pavement damages such as cracks, patches, bleeding, potholes; identify man-made objects such as manhole covers or grids; Identify the

horizontal structural marking of the pavement (raised or milled); generate a 3D model of the pavement that will speed up road repair planning, reduce repair design costs and improve the quality of the final design.

Fig. 2 Road survey vehicle RST63. In picture: *a* – 360 degrees camera; *b* – LCMS-2 lasers; *c* – right-of-way camera; *d* – point lasers; *e* – distance measurement unit

This data is perfectly complemented by a high-resolution images captured with a 360-degree camera mounted on a survey vehicle. The images captured with this type of camera allows you to view the surrounding environment on a computer screen (a feature/service similar to the popular Google StreetView service). This allows road maintenance or road design companies to view road objects and the situation from the workplace without having to go to a road section. Proper calibration of the system and the use of specialized software allow tasks like perform a measure of object geometry.

Characteristics of the road surface collected by RST63 surveys:

- Road roughness, which is defined as the number of pavement irregularities per unit length. It is one of the indicators of the road surface, which describes the influence of the road surface on the driving stability, comfort and fuel consumption of vehicles. Road roughness is one of the key indicators used to select, repair and economically justify road sections to be repaired.
- The texture of the road surface is an important indicator of the condition of the road surface and influences the ride conditions of the vehicle. The dynamic behavior of the vehicle depends on the texture. Pavement roughness is defined as the average depth of the pavement microprofile.
- Rut depths on the pavement are one of the pavement indicators that influence the safe traffic of the vehicle. This is the longitudinal imprinting or wear of the asphalt pavement on the wheel tracks. Water may accumulate in the ruts, which can lead to aquaplaning. The rut depths are defined by the depth of the rut in mm.
- The main damage to the road surface is: longitudinal, transverse or alligator cracks, bitumen flushes, potholes, patches, delamination and other damages.

Between May and December 2019, the Transport Competence Agency investigated about 15,300 km of asphalt paved roads of national importance. Measurements were made in all lanes in all directions, operating at speeds from 20 to 90 km/h.

4. Evaluation of the Condition of the Main Road Network

In Lithuania pavement condition assessment is carried out in accordance with the Description of the National Road Pavement Condition Assessment Procedure (hereinafter - Methodology) approved in 2018 [4]. This methodology has been developed in accordance with the principles of COST Action 354 [5], taking into account the available research equipment and requirements in Lithuania. This document provides guidelines for calculating PCI.

Based on the PCI methodology, the PCI calculation algorithm can be divided into three steps:

1. Transponation of individual Technical Parameters (TPs) into Performance Indices (PIs);
2. Aggregation of individual PIs into Combined Performance Indices (CPIs);
3. Aggregation of individual CPIs into the Pavement Performance Index (PCI).

The condition indices, combined condition indices, and pavement condition index are rated on a five-point scale from 0 to 5, where 0 is Very Good and 5 is Very Poor.

4.1. Performance Indices

The performance index is an index that assesses a specific technical condition of a road surface condition (eg: longitudinal unevenness of the road surface, rutting, bearing capacity, etc.). Each individual performance index can be derived from a technical parameter determined during the measurement.

Performance indices are defined as non-dimensional technical parameters in a five-point system (0-5), where 0 defines a very good value for the pavement parameter and 5 defines a very poor value.

4.2. Combined Performance Indices

The evaluation of combined pavement condition indices is important for analyzing the influence of qualitative

pavement indicators on road safety, driving quality and strength characteristics. There are three combined condition indices (CPIs) - comfort, safety and structural - that measure individual condition indices based on their characteristics and influence.

Weighting factors are used in the calculation of combined condition indices to increase or decrease the influence of individual condition indices [4].

The Comfort condition index measures the influence of individual condition indices, expressed through weighting factors, on ride quality - comfort. When calculating the comfort condition index, the following indices of the pavement condition are evaluated: unevenness; rutting; mean profile depth; cracks and surface defects. We can understand which indicators are considered more important in the combined comfort index by looking into listed weighting factors in a Table 3 of Methodology [4]. Road roughness is a significant indicator that influences the comfort index, followed by rut depth and surface defects. Less significant indicators are cracks and mean profile depth.

The safety condition index measures the influence of individual condition indices (and through them also the condition parameters) expressed with weighting factors on the ride safety. The safety condition index evaluates the following road condition indices: rutting; mean profile depth and surface defects (calculated separately by assessing only bitumen bleeding defect). Evaluating the weighting factors in a Table 4 of Methodology [4] allows us to understand which indicators are considered more important in the safety condition index. The rut depth is a significant indicator that influences the safety index, while less significant is the mean profile depth and the bitumen bleeding defect.

The structural condition index evaluates the structural properties of the pavement through individual condition indices expressed with weighting factors. The structural condition index evaluates the following pavement condition indices: roughness; rutting and cracks. We can understand which indicators are considered more important in the structural condition index by looking to the weighting coefficients listed in a table 10 of Methodology. The amount of cracks is a significant indicator influencing the structural index, while less significant is the roughness of the road surface and the depth of the ruts.

4.3. Pavement Condition Index

The total pavement condition index evaluates the pavement condition through the combined pavement condition indices: comfort; safety and structured indices.

The weighting factors used in the calculation of the total pavement condition index are given in Methodology Fig. 1 [4]. The weighting factors depend on the type of road - main, national or regional road.

Referring to the Fig. 1 of Methodology [4], we can see that the combined safety condition index is the most important indicator for calculating the PCI, followed by the comfort condition index and the least important factor in the calculation of the PCI is the structural condition index.

The PCI priority ranking of the road sections is based on four levels of sorting:

- Level I - Sorted by PCI in descending order;
- Level II - Sorted by combined comfort index in descending order;
- Level III - sorted by combined structural index in descending order;
- Level IV - Sorted by combined safety index in descending order.

4.4. Evaluation of Highway Road Network Pavement Condition

Roundabouts and their accesses were not considered in the analysis, so the length of the analyzed main road network is 2359,616 km. After analyzing the data collected during the measurements, the road network was divided into 2375 homogeneous road sections with an average size of 0.994 km.

The results of the PCI calculations are presented by grouping them by traffic intensity groups and distinguishing high-speed roads (Expressways and motorways status sections) due to different operating conditions.

Based on survey results, it was found that the pavement condition of a main road network is rated as Good, and the PCI value is equal to 1.83. Comfort, safety, and structural indices were also found to be rated as good (respectively 1.999, 1.24, and 1.69).

The distribution of the condition according to the comfort index among the five groups (Very Good, Good, Fair, Poor, and Very poor) is shown in Fig. 3, part a.

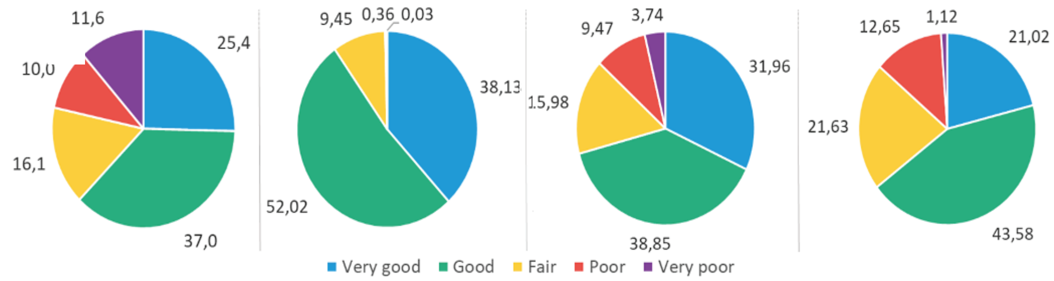
It was determined that the pavement to be rated Very Good by the Comfort index is 25,4% (599,099 km), Good – 37,0% (872,203 km), Fair – 16,1% (379,225 km), Poor – 10,0% (236,133 km) and Very poor – 11,6% (272,956 km).

The distribution of the condition according to the safety index among the five groups (Very Good, Good, Fair, Poor, and Very poor) is shown in Fig. 3, part b.

It was determined that the pavement to be rated Very Good by the Safety index is 38,13% (899,818 km), Good – 52,02% (1227,508 km), Fair – 9,45% (223,045 km), Poor – 0,36% (8,585 km) and Very poor – 0,03% (0,66 km).

The distribution of the condition according to the structural index among the five groups (Very Good, Good, Fair, Poor and Very poor) is shown in Fig. 3, part c.

It was determined that the pavement to be rated Very Good by the Structural index is 31,96% (754,238 km), Good – 38,85% (916,754 km), Fair – 15,96% (376,952 km), Poor – 9,47% (223,434 km) and Very poor – 3,74% (88,238 km).



a b c d

Fig. 3 a – Comfort index distribution for highway road network, %; b – Safety index distribution for highway road network, %; c – Structural index distribution for highway road network, %; d – PCI distribution for highway road network, %

The distribution of the condition according to the pavement condition index among the five groups (Very Good, Good, Satisfactory, Poor and Very poor) is shown in Fig. 3, part d.

It was determined that the pavement to be rated Very Good by the Pavement condition index is 21,02% (495,958 km), Good – 43,58% (1028,404 km), Fair – 21,63% (510,342 km), Poor – 12,65% (298,598 km) and Very poor – 1,12% (26,314 km).

The weighted average of PCI for the analysis of high-speed roads belonging to the national road network is 1.48 (Good) for AADT grouping and 1,48 (Fair) for HV AADT grouping. All homogeneous sections of high-speed roads were grouped (see Table 1) by general traffic intensity groups.

Table 1

PCI values for high-speed roads in general traffic (AADT) and heavy vehicles (HV AADT) intensity groups

Range (veh./day)	Length of homogeneous sections, km	PCI value	HV AADT Range (veh./day)	Length of homogeneous sections, km	PCI value
more than 27500	169,224	1,72	more than 4200	109,015	1,06
from 16000 to 27500	158,4	1,5	from 2650 to 4200	296,649	1,65
from 13000 to 16000	204,423	1,15	from 2400 to 2650	160,99	1,5
from 11500 to 13000	194,613	1,68	from 1350 to 2400	263,522	1,49
less than 11500	128,196	1,37	less than 1350	24,68	1,12

Based on the results of the analysis in Table 1, we can see the results are distributed evenly between the groups. The smallest PCI value was found in the third group and equal to 1,15. The group with the highest AADT has the highest PCI value equal to 1.72.

Based on the results of the analysis in Table 1, we can see the results are distributed evenly between the groups. The smallest PCI value was found in the last HV AADT group and is equal to 1,12. The second group by HV AADT has the highest PCI value, which is equal to 1,65.

The weighted average of PCI for the analysis of remaining main roads is equal to 2.02 (Fair) for AADT grouping and 2.86 (Fair) for HV AADT grouping. All homogeneous sections of the remaining main roads were grouped (see Table 1) by traffic intensity groups.

Based on the results of the analysis in Table 2, we can see the results are distributed almost evenly between the groups. The smallest PCI value was found in the first group and is equal to 1,71. The third group of AADT has the highest PCI value, equal to 2.34.

Table 2

PCI values for remaining main roads in general traffic (AADT) and heavy vehicles (HV AADT) intensity groups

Range (veh./day)	Length of homogeneous sections, km	PCI value	HV AADT Range (veh./day)	Length of homogeneous sections, km	PCI value
General annual average daily traffic			heavy vehicles daily traffic		
more than 8100	518,941	1,71	more than 1300	418,122	4,63
from 6000 to 8100	285,576	2,1	from 800 to 1300	294,746	1,93
from 4700 to 6000	186,209	2,34	from 550 to 800	276,303	2,17
from 3500 to 4700	302,26	2,14	from 400 to 550	249,64	2,16
less than 3500	211,774	2,23	less than 400	265,949	2,51

Based on the results of the analysis in Table 2, we can see the results are distributed not evenly between the

groups. The smallest PCI value was found in the second HV AADT group and is equal to 1,12. The first group by HV AADT has the highest PCI value, which is equal to 4,63.

5. Conclusions

Overall highway (main) road network pavements condition by PCI is evaluated 1.83 (Good) while the range is from 0 to 5, where 0 is Very Good and 5 is Very Poor.

The distribution of the main road network pavements condition according to the pavement condition index is: 21,02% of very good, 43,58% of good 21,63% of fair, 12,65% of poor, and 1,12% of very poor condition.

The technical parameters of the road surface condition of motorways and expressways roads from the remaining main road network roads are: the road surface roughness is smaller 0.42 m/km and is equal to 1.27 m/km; the rut depth of the road is 1.06 mm smaller and is equal to 5.44 mm; mean profile depth is greater by 0.12 mm and is equal to 1.50 mm and cracking rate average is smaller by 0.71% and is equal to 0.68%.

It was estimated that highways of the national road network have better condition than remaining main road network roads with respectively PCI values are equal to 1,48 and 2,02 with AADT grouping. Also high-speed roads of the state road network have better condition than remaining other (national and regional) roads network roads with respectively PCI values are equal to 1,48 and 2,86 with HV AADT grouping.

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Problems of the Central Joint in an Articulated Frame

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Abstract

The paper deals with the design of the central joints and the causes of their disproportionate stress-strain states in forestry forwarding machines with an articulated frame. An analysis of the causes is performed with the recommended possibility of adjustments to eliminate possible defect situations.
KEY WORDS: *Articulated machine, central joint, structural modification, dynamic simulation, strength analysis*

1. Introduction

Forest forwarders are presented on the current market primarily as two-frame articulated machines with the steering of a folding the frames in the central joint using hydraulic cylinders. These machines are used for their capability of the terrain crossing, excellent traction of all wheel units and the possibility of adapting the torque flow to the required wheel units. The forest forwarder integrates two machines, that's a timber handling crane and a transport machine (Fig. 1).

Fig. 1 Forest forwarder LVS 700 - overcoming terrain obstacles

Fig. 2 Detail of the central joint of the forest forwarder LVS 700

The chassis structure consists of a front frame and a rear frame connected by a central (pivot) joint. The front frame of the machine is loaded with a constant load from the motor unit, piston pumps, cab, axle with hydraulic motor and tanks. This load is distributed on the ground through bogie axles and wheels. The rear frame is loaded with a constant load from the side stake and a variable load from the weight of the load and from the action of the hydraulic steering.

A very important part of the machine is the central (pivot) joint, which provides the function of connecting the two frames. The joint function allows two rotational degrees of freedom with the possibility of steering or blocking movement (Fig. 2).

Better operational reliability can be achieved not only by suitable dimensioning of the central joint, but also by the machine frames around the central joint. Primarily, it is necessary to define the possible causes of a limit or even extreme load case, it's the technological action or the position. Serious conditions can occur during machine operation, side loading, driving the machine on site, driving speed with an active crane, or driving on a slope.

2. The Developmental Phase of a Central Joint Design

The design of the central joint was structurally modified from the original prototype design (Fig. 3, left) to a serial version of the LVS 700 machine (Fig. 3, right). Important modifications were made during the development and testing of the prototype:

1. Modification of the length of the central joint (pos. *1*, Fig. 3). When changing the design, the mounting of the axial bearing of the machine changed. This also changed the length of the casing of the central joint. The length of the machine and the distance of the axles from the center joint have been maintained.

2. Modification of the steering hydraulics piston holder (pos. *2*, Fig. 3). The modification of the structure of the steering hydraulics piston holder consisted mainly in the side stiffeners. The pitch of the pins and their distance from the

axis of rotation was maintained.

3. Modification of the frame brake mounting (pos. *3*, Fig. 3). The modification consisted in the implementation of a frame brake console.

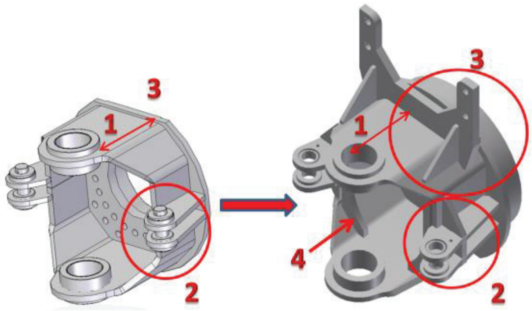

Fig. 3 Prototype center joint model (left), serial center joint model (right); Differences in the structural nodes; *1* – length of the central casing, *2* – modification of the steering hydraulics holder, *3* – frame brake console, *4* – stiffeners of the central joint casing

These design modifications of the central joint for the serial version were also intended for the innovation of the LVS 720 in order to be able to improve technological operations. New technological operations are related to the improvement of the user comfort of the machine operator during loading. It is new technological operations that are a problem for the operational reliability of the central joint. In order to increase the operational reliability of the machine frame, it is necessary to define the cause, it's the technological action or the position. First, a dynamic simulation of the model was performed to determine the causes and then a strength analysis of the central joint.

3. Numerical Model and Load Cases

The supplied design model of the LVS 700 machine is modified to a numerical model for dynamic analysis in the MSC ADAMS (Fig. 4). The numerical model for dynamic analysis consists of:

22 moving parts, 16 point mass, 3 cylindrical joints, 17 revolute joints, 2 spherical joints, 2 fixed joints, 16 atpoint primitive joints, 10 motions, resulting in 11 degrees of freedom.

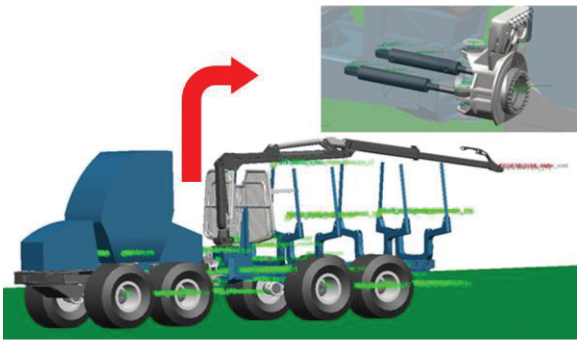

Fig. 4 Numerical model for dynamic simulation in MSC ADAMS

The load cases can be divided into several modes according to an operation:

A. The driving mode consist the machine ride through the terrain between the mining and the log pile.

B. The working mode consists in loading or unloading the load at the place of the mining or of the log pile.

C. The combined mode assumes that the machine is driven at the mining place with a maximum speed up to 5 km/h with the possibility of the handling the crane.

Similar modes and similar approach was used in the papers [1]. The forwarder is capable of carrying up to 7.5 t. Four categories were created for the load and further in the simulations they were combined with the load cases similarly as used in the paper [6, 8].

4. Dynamics Simulation of the Machine

Three defined types of modes for a forwarder machine were used for the simulation. This analysis was performed on a similar principle and a similar approach as used in the papers [2, 4]. The loading methodology and the type of terrain were designed for each individual load case. The type of terrain was created with respect to availability, workability and usability in practice, as used and published [3]. Selected parameters that affect the deformations of the central joint were monitored in all simulations. The maximum value, but also the limit value of use (for example stability) was monitored for these parameters [1]. Fig. 5 is a graph of the force loading of the main vertical pivot joints

of the center joint during the dynamic simulation. In this dynamic simulation, the machine is loaded to a maximum capacity of 7.5 t, ride up a slope of 12° at a speed of 5 km.h-1 and turns by 180°. In this combined mode, the machine ride and handles a 200 kg load with a crane to improve stability.

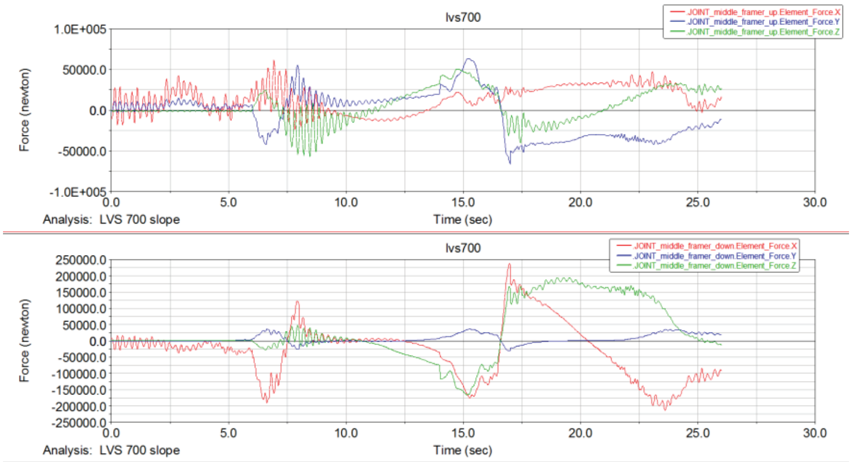

Fig. 5 Graph of the time course of the force in the pivot connections between the central joint and the rear frame (upper pivot – upper graph, lower pivot – lower graph) for the combined mode (MBS-analysis id: lvs700_wheel_slope_8_7t_manip)

5. Strength Analysis of the Central Joint

The computational model of the strength analysis was created for the numerical solver MSC MARC. A model of the central joint LVS 700, a replacement for the front and rear frame and for the steering pistons was created. The reason was to create such boundary conditions similar to the real environment and to use a minimum number of computational elements. The number of elements of the meshed model is 26 277 and the number of nodes is 26 978 (Fig. 6). Similar principles of the meshed model approach were used and presented in the papers [5, 6]. The complexity of the calculation solution is given by the number of combinations of operating cases, operating inclinations and axle connections. The resulting stresses were determined for reduced stress according to the HMH theory (von Mises) and adequate deformation.

Fig. 7 shows the distribution of the reduced stress in the combined mode (FEM-analysis id: orig-03-105). In this case, the stress limit is significantly exceeded during the technological action of slewing the crane to an angle of 105° and loading the crane with the maximum lifting torque. The limit stress of over 250 MPa is exceeded on the inner stiffeners, on the outer stiffeners at the steering piston holder, around the thrust bearing bolts and on the joint casing.

Deformations of the central joint can be verified from FEM analysis (Fig. 7). The value of deformation is assuming linear elasticity. Using strain gauges, it is possible to determine the magnitude of surface strain. It is safer to use high-speed motion analysis, as described in [7].

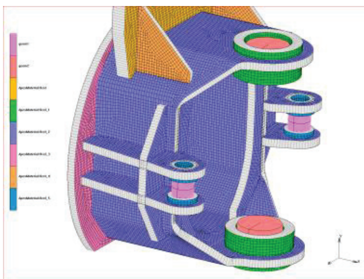

Fig. 6 Central joint – serial product, meshed computational model for a FEM analysis

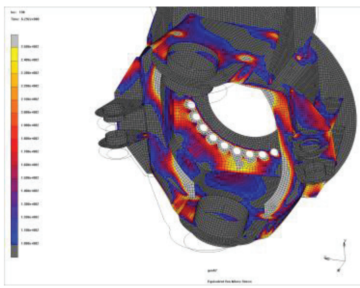

Fig. 7 Central joint – serial product (FEM-analysis id: orig-03-105) - combined mode, load case - 7.5 t full load, crane slewing angle 105°, reduced stress von Mises, stress range 100-250 MPa, deformation scale 10: 1

6. Development Versions of the Optimized Shape of the Central Joint

Development versions of the optimized shape of the central joint were modified in two conceptual ways:

A. Modification of the current structure by adding suitably shaped stiffeners in critical nodes, which will not affect other structural and functional parts of the machine (Fig. 8).

B. Modification of the structure with a change in the shape of the current structure, which will not affect other

structural and functional parts of the machine (Fig. 9).

The manufacturer required the addition of the suitably shaped stiffeners to critical nodes for previously produce center joints. The design of the central joint of the LVS 700 forwarder was most often optimized by structural modifications of the central joint (Fig. 8) at critical node 2 (Fig. 3) and at critical node 4 (Fig. 3).

In addition, the manufacturer required a new design version for further production with operational reliability requirements with respect to the fatigue properties of the center joint (Fig. 9).

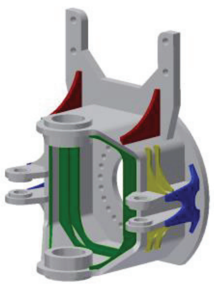

Fig. 8 Development version with the addition of the shaped stiffeners

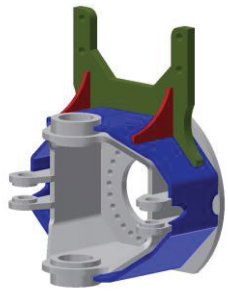

Fig. 9 Development version of the structure shape modification

7. Conclusion

The development of the design modifications during optimization was gradual and led to various concepts of modification of the previous structure. Important for the development was the manufacturer's requirement that the center joint increase the reliability of the forwarder structure to improve durability and safe use. The optimization of the central joint can be divided into two conceptual ways of design for the development version by modification and addition of the shaped stiffeners, or the development version of the modification of the structure by modifying the shape of the current structure.

The construction of the central joint is created by welding technology. This is the most affordable method of creating parts of complicated shapes. In terms of strength, the standard quality material can be supplemented with components from high-strength material. As for the continuous shapes of the structure and the more robust and a strong resistant structure, then casting is more acceptable.

Acknowledgement

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Assessment of Vibration of Transport Belts of a Strand-Type Transmission

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Abstract

The paper indicates significant development of strand-type transmissions on the example of thermoweldable belts, which are briefly characterized by their advantages and limitations. As a practical example, the problems of vibration of a belt transmission with a PU75A thermoweldable belt are presented. The dependence of the effective value of the vibration acceleration signals on the belt transmission load at a selected rotational speed is presented and interpreted. The nature of the spectra of transmission vibration signals without and with braking torque load is illustrated. The importance of this issue for engineering practice is indicated.
KEY WORDS: *thermoweldable belts, experimental research, transmission vibration*

1. Introduction

The history of the use of V-belts in strand-type transmissions goes back to the beginning of the 20th century. In the last dozen or so years, due to the intensive development of manufacturing techniques, the development of new materials and the planning of innovative belt designs, a number of new applications of these belts in drive and transport technology have appeared. The use of V-belts in motor drives [1-3] of agricultural and food industry machines [4] is widely known, but still being expanded.

The development of strand-type transmissions applies to both modified geometrical forms of belts and pulleys [5]. At the same time, designers are focused on limiting the sources of incorrect function of such transmissions, which may be inaccuracies in the manufacture and assembly of machinery and equipment [6-9], unbalance of rotating components [10], wear of components [11], and change of transmission temperature. The V-belts used in the strand-type transmissions are most often made of composite materials based on plastics [12-14]. Until now, the production of transmission belts has traditionally used steel or polyamide cords as a supporting layer, rubber or caoutchouc to make a flexible layer, and a fabric-rubber composite (vulcanized canvas or cord tape) for the protective layer. Nowadays, composites and materials of various structures are used in the production of transmission belts. A separate new group of transmission belts are thermoweldable belts constructed of one or more permanently connected layers of materials. Research in this area is conducted for various types of transmission belts. Modelling of features of materials used for flat transmission belts is presented in the paper [15], and processes of their perforation in the papers [16, 17], while assessment of thermomechanical features of round transmission belts is included in [18]. For each type of thermoweldable belts, the process of joining them is very important [19, 20].

The advantages of thermoweldable V-belts include: the possibility of welding their ends, which ensures obtaining a V-belt of any length and its quick replacement in the event of damage, excellent abrasion resistance, resistance to oil, grease, dirt and some chemicals, resistance to influence of temperatures from –30°C up to + 80°C, considerable elasticity at a relatively low stretch level, high friction coefficient, and thus very good anti-slip properties even at load changes, quiet function, significant flexibility, safety of use in contact with food (confirmed by certificates of the food law).

The thermoweldable V-belts are usually made in six variants with different hardness. For their unambiguous and correct identification, the colour of the belt was adopted as an indicator of hardness. The precursor in the production of this type of V-belts was the Beha Company, which also proposed their systematics in connection with colours.

For the purpose of this paper, following six popular types of thermoweldable belts, made of materials of different hardness determined according to the Shore scale, will be characterized: PU 75 A, PU 80 A, PU 85 A, PU 90 A, 40 D polyester, 55 D polyester.

Belts made of PU 75 A type polyurethane (80 Shore A, red) are characterized by high quality and considerable flexibility and are particularly useful in transport devices as well as in transmissions with small belt pulleys. They are used to transport frozen goods. Their main advantage is the possibility of using them both as driving and transporting belts.

Belts made of PU 80 A type polyurethane (84 Shore A, transparent) are mainly used in the food industry, for processes where it is necessary for them to come into direct contact with meat, fish, fruit, vegetables, bread, etc.

Belts made of PU 85 A type polyurethane (88 Shore A, green / yellow), which is a medium-hard material, are an ideal solution for power transmission in machines and devices, including conveyors of various types.

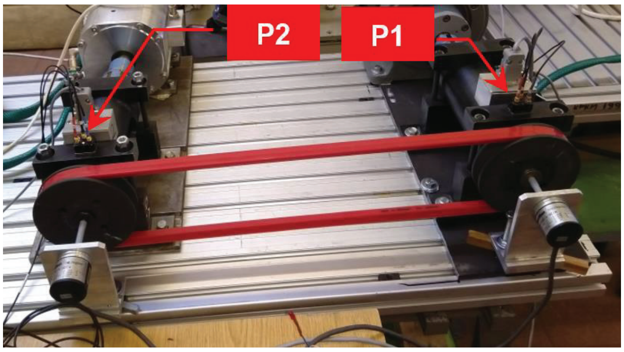
Belts made of PU 90 A type polyurethane (92 Shore A, white) due to the excellent elasticity and damping prop-

erties of this material are designed for applications requiring heavy loads. They often replace ordinary V-belts in conveyor devices.

On the other hand, belts made of 40 D type polyester (92 Shore A, beige) and 55 D type polyester (98 Shore A, blue / beige), i.e. of materials of high hardness, are designed to work under heavy loads and at temperatures from –28°C up to +100°C. They are used in roller conveyors in glass and tile manufacturing plants as well as in grinders and crushers.

One of the factors affecting the use of a particular type of drive or transport belt are mechanical vibrations and their impact on associated devices. The sources of vibration in machines [21] can be drive units [22-24], working mechanisms or transmission gears. Vibration may change their characteristics depending on the operating conditions [25]. This may contribute to increased noise and vibration of machinery and equipment [26-32]. Many studies are currently conducted to investigate the causes and then reduce the environmental impact of noise [33-35]. The authors hereof plan to conduct experimental tests in the field of acoustic emission of selected types of belts.

This paper will present the results of the author's own research on the vibration of a transmission with a PU 75 A type belt. Fig. 1, a presents a universal test stand for measuring vibration, load capacity, efficiency and thermal condition of a transmission with a polyurethane belt, and Fig. 1, b shows the directions of vibration measurements adopted.



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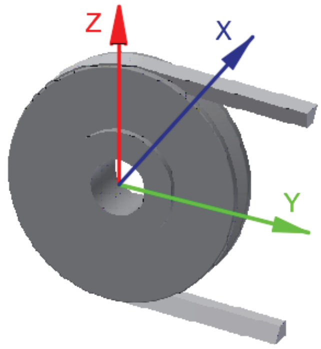

b

Fig. 1 Tests of transmission gears with a PU 75 A type belt; a – view of the test stand with marked mounting points of vibration transducers; b – directions of vibration measurements adopted

A hydraulic motor driving the active shaft is built on the basis of the stand; the passive shaft is connected by means of elastic couplings to a brake. The shafts with mounted torque meters are mounted in supports on radial ball bearings. A dynamometer - magnetorheological brake is used to apply load in the transmission gear unit under test. Signals from torque meters and rotary-code sensors are transmitted to an amplifier and then to a computer. A regulator enables setting a load on the dynamometer. The design of the magnetorheological brake used requires continuous water cooling.

2. Methodology and Course of Tests

The assessment of vibration of a transmission gear with thermoweldable belt was carried out in accordance with the assumptions of active experiment. It was assumed that the input parameters would be belt tension force, transmission load torque and driving shaft rotational speed, and the output parameters - values of vibration acceleration of selected elements of the test stand (transducers were mounted on driving and driven shaft bearing housings). The measuring system shown in Fig. 1, a allows simultaneous recording of fast changing time histories on 12 measuring channels with a dynamics of up to 160 dB. Brüel & Kjær 4504 type vibration transducers were used. The linear frequency response of the selected transducers was from 0.1 Hz up to 18 kHz. During the tests, signals in a band from 0.1 Hz up to 25 kHz were recorded. Sampling frequency was adopted at a level of 65 536 Hz and two triaxial vibration transducers (P1, P2) connected to a measuring cassette were used to record vibration signals.

During the tests, the transmission load was changed and its influence on the value of measures of punctual vibration signals was observed. The following punctual measures were analysed: effective value, peak value and kurtosis. No filtration was used during the analyses; an active shaft rotation speed of 500 rpm was adopted. It was agreed that the results of measurements obtained on the active shaft would be referred to as the word 'motor' and the results obtained on the passive shaft as the word 'brake'.

Fig. 2 presents changes in the effective value of vibration acceleration signals depending on the load on the belt transmission. In the case of signals registered at the driving pulley, these relationships are non-monotonic along all three directions, and in the case of signals recorded at the driven pulley along the X and Z directions, an exponential curve can be approximated. At the same time, it should be noted that the dynamics of changes of the effective value of signals is higher in the case of the X direction and is about 10 dB.

Another task carried out was the identification of the frequency of vibrations generated by the belt transmission drive unit (hydraulic motor). In order to determine the frequency of vibrations generated by the belt transmission drive unit, measurements of vibration signals were taken during the start-up of the belt transmission (with the pulleys braked

while loading the motor). The results of the frequency analysis of these vibrations are shown in Fig. 3. Based on the figure, the following frequencies of vibrations generated by the motor, interfering with signals during the tests: 175 Hz, 350 Hz, 525 Hz and 700 Hz are indicated. The vibration measurement directions are as follows: X is red, Y is blue and Z is green.

An equally important issue in vibration analysis is the assessment of the impact of input parameter changes (rotational speed of shafts, transmission gear load, and belt pre-tension force) on the spectrum of vibration acceleration signals.

Fig. 4, a presents the influence of belt pre-tension force on the vibration spectra measured on the drive shaft bearing housing at a shaft rotational speed of 500 rpm and a loading torque of 0 Nm, and Fig. 4, b presents the changes in the vibration spectrum at a shaft rotational speed of 500 rpm/min and a loading torque of 12.8 Nm. Based on the analysis of Fig. 4, it can be concluded that increasing the belt pre-tension force reduces the frequency level of the vibration signal in the range of 2.8 ÷ 10 kHz regardless of the belt transmission load. The red colour means a belt pre-tension of 80 N, while the blue one - a belt pre-tension of 120 N.

Fig. 5, a presents the impact of transmission gear load changes on the vibration spectra measured on the drive shaft bearing housing at a shaft speed of 500 rpm and a belt pre-tension force of 80 N. On the other hand, Fig. 5, b presents the changes in the vibration spectrum at a shaft speed of 500 rpm and a belt pre-tension of 120 N.

Figure 6 shows the phenomena of airbag creating and belt sucking on the example of a transmission gear with a PU 75 A type belt.

When the rotational speed of the active pulley reaches a great value, there are phenomena of belt sucking when it is leaving the active pulley and of airbag creating when it is climbing on the passive pulley of the transmission gear.

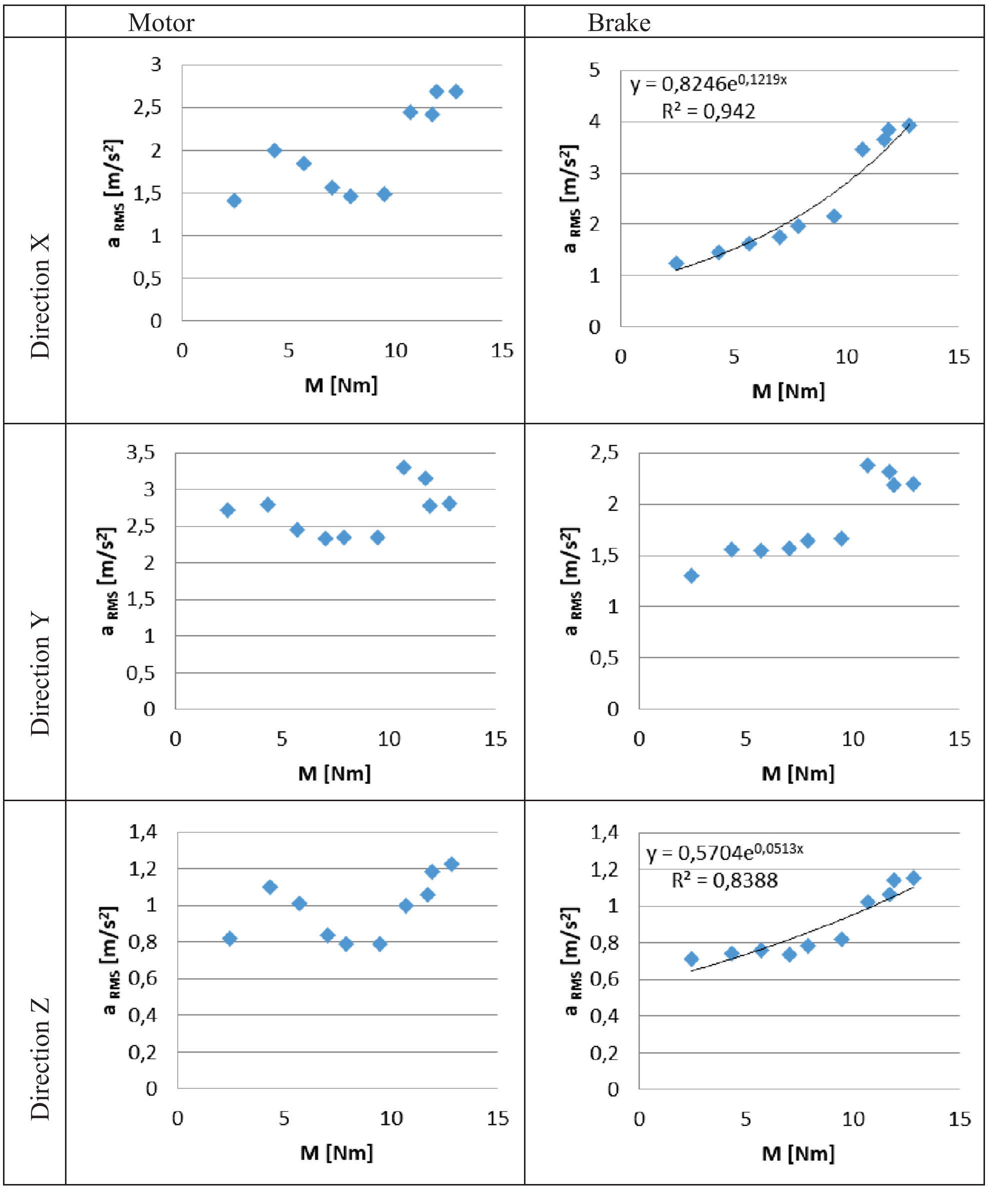

Fig. 2 Dependence of the effective value of vibration acceleration signals on the load of a belt transmission at 500 rpm

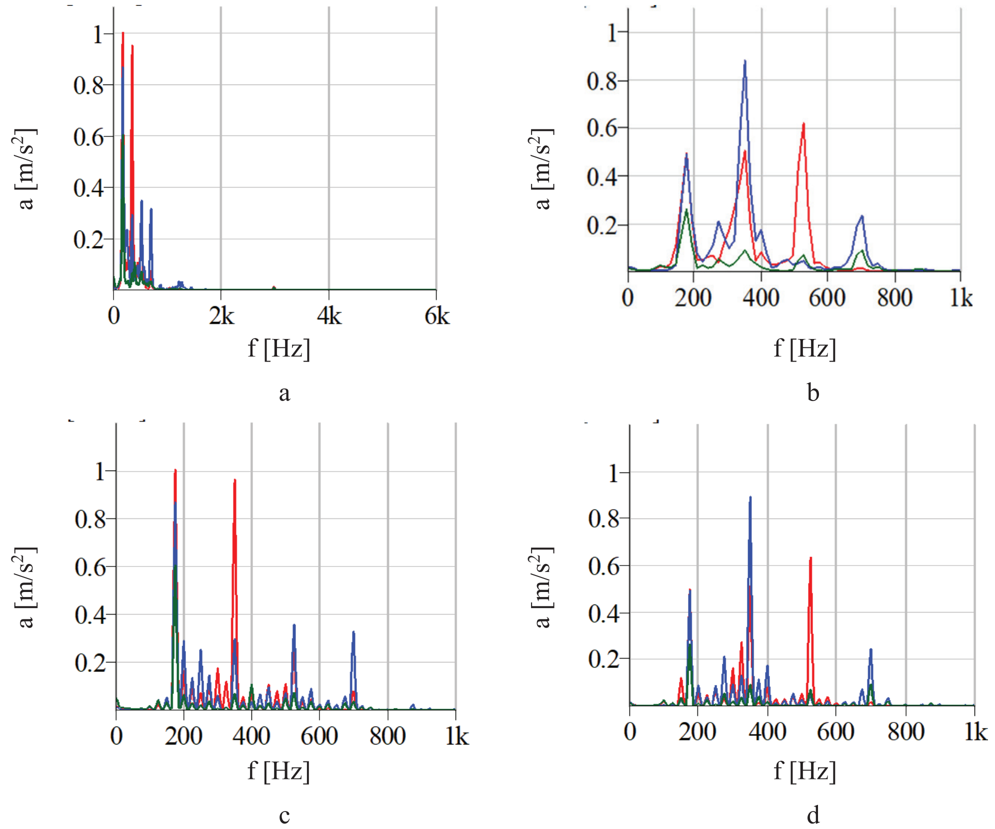

Fig. 3 Spectra of transmission vibration signals at rotational speed n = 0 and loading torque M = 0; a, b – full frequency band analysed; c, d – magnification - frequency band 0 ÷ 1 kHz

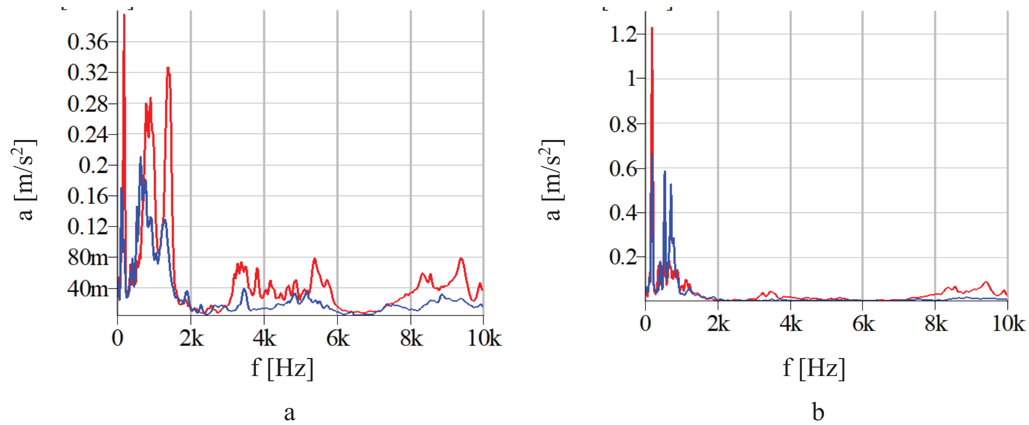

Fig. 4 Spectra of transmission vibration signals; a – n = 500 rpm, M = 0 Nm; b – n = 500 rpm, M = 12.8 Nm

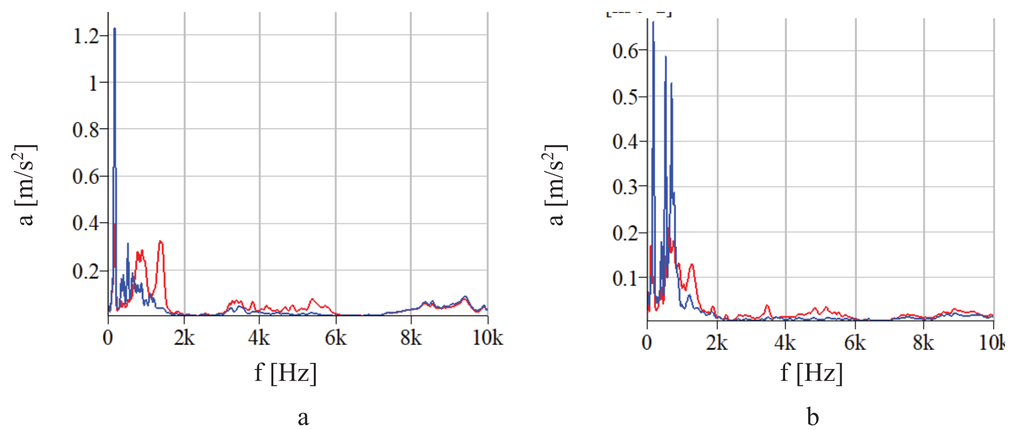

Fig. 5 Spectra of transmission vibration signals; a – n = 500 rpm, T = 80 N; b – n = 500 rpm, T = 120 N

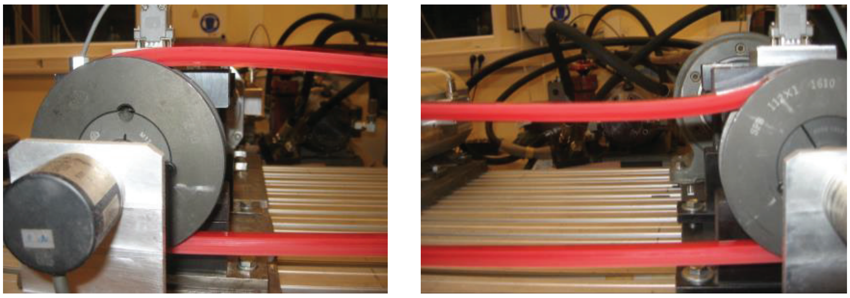

Fig. 6 The phenomena of airbag creating and belt sucking on the example of a transmission gear with a PU 75 A type belt

3. Conclusions

The paper presents a vibration analysis of a belt transmission with a PU75A type thermoweldable belt. One of the many advantages of these belts is the possibility of welding their ends, which makes possible to get a belt of any length and to quickly replace it in the event of damage. Based on the research conducted and analysis of the results made by the authors, it was found that the increase of rotational speed of the transmission gear shafts causes an increase in the effective value of vibration signals recorded along all directions, both at the driving and driven pulleys. With the increase in belt transmission load, the characteristic frequencies decrease regardless of the belt pre-tension. The test results will certainly be useful for designers and people involved in the operation of strand-type transmissions, in which modern transport belts have been used.

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ACAS Hybrid Surveillance as a Compensation Means to 1090 MHz Band Load in View of New European ADS-B Requirements

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Abstract

The aircraft surveillance systems ensure every adequately equipped aircraft will be tracked by other aircraft or on-ground sensors and presented on screens to the air traffic controllers or pilots. There are various applications in aviation used for these purposes. Since the main purpose of the usage of such systems is safety, which is necessary to be addressed more than ever before because of the constantly rising air traffic volume, new legislative measures are being introduced on national and international levels to help maintain the system safe and with a certain level of redundancy. Because of those actions and high air traffic volume, the used frequency band becomes saturated which can cause the aircraft transponders stop working and thus not providing aircraft position data. This paper analyzes the effect of the new 2020 European Commission requirement, which is mandating all aircraft of a certain category to be equipped with ADS-B version 2 capable transponders, to the 1090 MHz band load. Since the ADS-B version 2 capable transponders transmit more messages on the shared frequency band than the previous ADS-B version 0 capable transponders, the attention is paid on ACAS hybrid surveillance implementation, which could partially compensate the increase of messages caused by the new ADS-B equipage mandate and thus slow down the band saturation.
KEY WORDS: surveillance systems, aircraft, automatic dependent surveillance – broadcast, airborne collision avoidance system, hybrid surveillance, 1090 MHz band load

1. Introduction

To achieve a high level of safety despite the rising air traffic volume in Europe, the European Commission published new aircraft equipage requirements, Commission Implementing Regulation (EU) No 1207/2011, Commission Implementing Regulation (EU) No 1028/2014 and Commission Implementing Regulation (EU) No 2017/386. These regulations mandate, among others, aircraft with civilian registration and with a maximum certified take-off mass exceeding 5700 kg or aircraft having a maximum cruising true air speed capability greater than 250 knots, to be equipped with the ADS-B OUT ICAO version 2 transponders. This mandate will be applicable from 7th June 2020 [9].

ADS-B is a system, which, in case an aircraft transponder is equipped with the ADS-B OUT function, periodically broadcasts messages on 1090 MHz, containing position, velocity, identification and other information. Those messages are received at 1090 MHz on-ground receivers or by aircraft in vicinity equipped with the ADS-B IN function, and enable to track the target. There are three versions of ADS-B currently being used. ADS-B ICAO version 0, ADS-B ICAO version 1 and ADS-B ICAO version 2 [5].

Airborne Collision Avoidance System (ACAS) is a system used to mitigate the risk of mid-air collision. The system tracks aircraft in vicinity and in case a possible collision is identified, it provides pilots with necessary avoidance maneuvers to avoid the collision. The system acquires the position information about aircraft in vicinity from air-to-air messages which are transmitted among the aircraft on 1030/1090 MHz radio frequency [7].

The surveillance function of ACAS can be enhanced with the hybrid surveillance (HS) functionality. In such a case, the system uses received ADS-B messages to track the target. Since the ADS-B messages are transmitted periodically without any need of interrogation, the system is rather passive and does not saturate the frequency band as much as it would do without hybrid surveillance. The position data contained in the ADS-B messages are validated with active interrogations either once every 10 or 60 seconds, depending on the aircraft mutual position. As the nominal surveillance rate for aircraft not equipped with hybrid surveillance functionality is 1-5 seconds, the fewer frequency band saturation is evident [1, 7]

This paper brings an analysis of the current aircraft's ADS-B and ACAS hybrid functionality equipage. A sample of 85 aircraft had been chosen and the messages transmitted by those aircraft which were consequently received at the Czech Technical University's 1090 MHz receivers were analyzed. The purpose of the analysis was to determine the portion of aircraft concurrently equipped with ADS-B and ACAS hybrid surveillance functionality. Since the ADS-B version 2 capable transponders will be required in the European airspace, it should be demanded to have as many aircraft as possible equipped with the ACAS hybrid surveillance to decrease the risk of 1030/1090 MHz band load.

2. Materials and Methods

To perform this type of analysis, it was necessary to use receivers which would enable them to receive ADS-B as well as other Mode S downlink format (DF) messages. For this purpose, four 1090 MHz receivers owned by the Czech Technical University in Prague were used. Using those receivers, it was possible to receive ADS-B messages in downlink format 17 (DF17) as well as Mode S messages in downlink format 0 (DF0) and 16 (DF16) used by ACAS. A dedicated software developed in MATLAB was used to decode the messages and to make a fusion of equal messages received at more than one receiver (MATLAB R2017a, MathWorks, Inc., Natick, MA, USA).

Assessing the ADS-B Version

In order to analyze the proportion of aircraft concurrently equipped with ADS-B OUT capable transponders and ACAS with hybrid surveillance functionality, it was necessary to analyze the DF17 extended squitter messages received at the CTU's receivers. Each aircraft with a Mode S transponder is assigned a unique 24-bit address which is used to identify the aircraft transmitting the messages [2]. As it was already mentioned, there are three versions of ADS-B used. In the case of the ADS-B ICAO version 0, three messages are periodically transmitted as a standard. If the aircraft is equipped with the newer ADS-B ICAO version 1 or 2, six messages are usually transmitted (see Table) [2]. Therefore, it is obvious that in the case of version 1 and 2, the system contributes to the frequency saturation more than in the case of version 0, because more information is transmitted. Each type of ADS-B message can be determined by its Type Code field (5 bits) [2]. The three additional messages which are transmitted by ADS-B ICAO version 1 and 2 transponders are "Target State and Status Message", "Aircraft Operational Status Message" and "Aircraft Status Message" [2]. Therefore, if type codes related to above mentioned messages were received, the aircraft was recognized as the one equipped with the ADS-B ICAO version 1 or 2. The version which is going to be mandated from June 7th, 2020 is the ADS-B ICAO version 2 and thus it was necessary to distinguish between version 1 and version 2. This was done by decoding a 3-bit "Version Number" subfield which contains information about the version of ADS-B being transmitted and that is present in every Aircraft Operational Status Message (message bits 73 through 75) [2]. If this "Version Number" subfield contains all zeros in binary coding, i.e. "000", the airborne transponder is compliant with RTCA DO-260, which describes ADS-B ICAO version 0 transponders. Binary coding "001" determines the transponder to be RTCA DO-260A conformant, i.e. ADS-B ICAO version 1 transponder. Finally, if the subfield contains "010", it means the transponder is conformant to RTCA DO-260B, thus ADS-B ICAO version 2 compliant [2].

Table

ADS-B messages – broadcast rates during the aircraft in-flight status

		ADS-B Message	Broadcast Rate
Version 1/2	Version 0	Airborne Position Message	0.4 - 0.6 s
		Airborne Velocity Message	0.4 – 0.6 s
		Aircraft Identification Message	4.8 – 5.2 s
		Target State and Status Message	1.2 – 1.3 s
		Aircraft Operational Status Message	2.4 – 2.6 s
		Aircraft Status Message	1 s

Assessing the ACAS Hybrid Surveillance Capability

ACAS units without hybrid surveillance capability normally interrogate all aircraft in the vicinity using addressed messages in uplink format 0 (UF0) at least once every five seconds, depending on the particular system implementation and aircraft mutual position, and receive reply messages in downlink format 0 (DF0) containing the aircraft altitude. Using those messages, the aircraft can determine the intruder's position and use it as an input for the conflict prediction calculations [3].

In case the ACAS units are hybrid surveillance capable, the active interrogations with UF0 messages are used with lesser interrogation frequency. The intruder's position is determined from the received extended squitter messages (DF17) [1]. Since the position data encoded in the ADS-B messages are derived from Global Navigation Satellite System (GNSS), whose accuracy oscillates based on many factors, they are being validated using uplink format 16 (UF16) or 0 (UF0) messages at a rate dependent on the aircraft's mutual position (see Fig. 1) [1]. The aircraft which is being interrogated replies using downlink format 16 (DF16) messages [1]. The ACAS hybrid surveillance capable aircraft can use this functionality only if two conditions on the intruder aircraft's side are met. The intruder aircraft must be equipped with an ADS-B OUT capable transponder and it must have the capability to use long DF16 messages as replies to validation interrogations. This capability is indicated in the CA field (message bit number 7) in DF0 messages [1].

$$|a| \le 10000\,ft \text{ AND } \left\{ \left(|a| \le 3000\,ft \text{ OR } \frac{|a-3000\,ft|}{|\dot{a}|} \le 60s \right) \text{OR} \left(r \le 3NM \text{ OR } \frac{r-3NM}{|\dot{r}|} \right) \le 60s \right\}; \tag{1}$$

$$|a| \le 10000\,ft \text{ AND } \left\{ \left(|a| \le 3000\,ft \text{ OR } \frac{|a-3000\,ft|}{|\dot{a}|} \le 60s \right) \text{AND} \left(r \le 3NM \text{ OR } \frac{r-3NM}{|\dot{r}|} \right) \le 60s \right\}, \tag{2}$$

where a – vertical aircraft separation [ft]; $\dot{a}$ - vertical aircraft separation rate of change [ft/s]; r – aircraft range [NM]; $\dot{r}$ - aircraft range rate of change [NM/s].

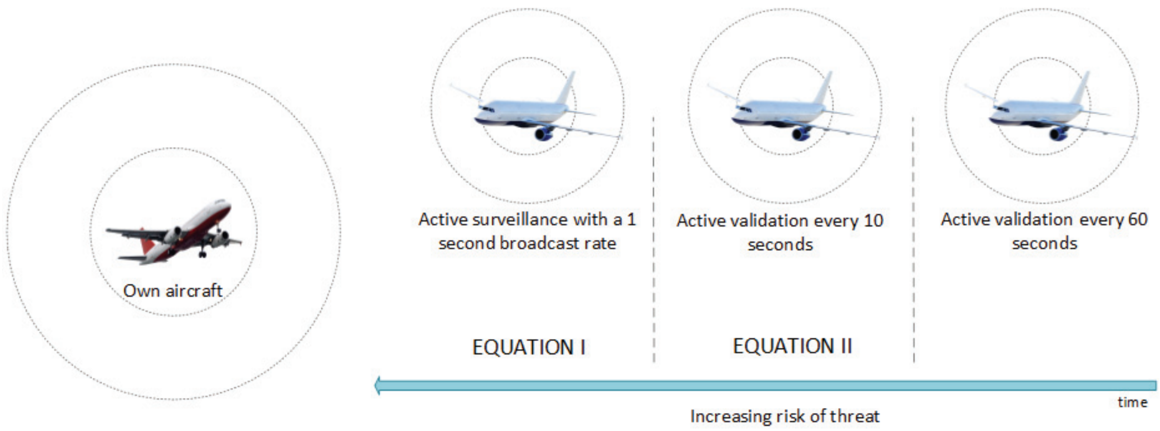

Fig. 1 ACAS Hybrid Surveillance validation messages broadcast rates

Since the CTU's 1090 MHz receivers can only receive downlink format messages which do not contain any identification information of the aircraft which is going to receive the message, it was necessary to find air traffic situations with two isolated aircraft in order to unambiguously determine the aircraft receiving the message.

If DF16 messages were found among the messages received from the two aircraft involved in the air traffic situation, the time spacing between them followed the rates in Fig. 1, and the aircraft being interrogated indicated CA = 1 in any of the DF0 messages, the aircraft which must have interrogated the aircraft which sent the DF16 messages, was considered to be ACAS hybrid surveillance capable.

3. Results and Discussion

The data was collected from 85 aircraft during the first half of 2019 in the Flight Information Region of the Czech Republic (LKAA FIR).

As shown in Fig. 2, the vast majority of aircraft flying in the LKAA FIR airspace were equipped with ADS-B. Only one aircraft was not equipped with the ADS-B OUT capable transponder.

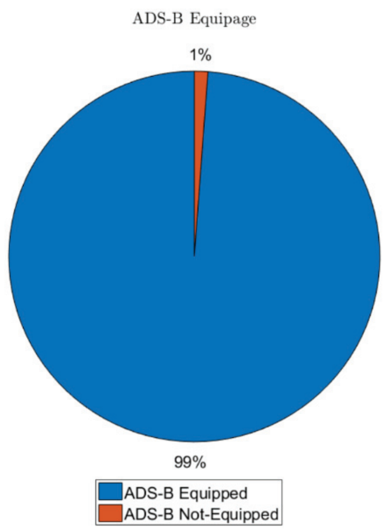

Fig. 2 ADS-B Equipage

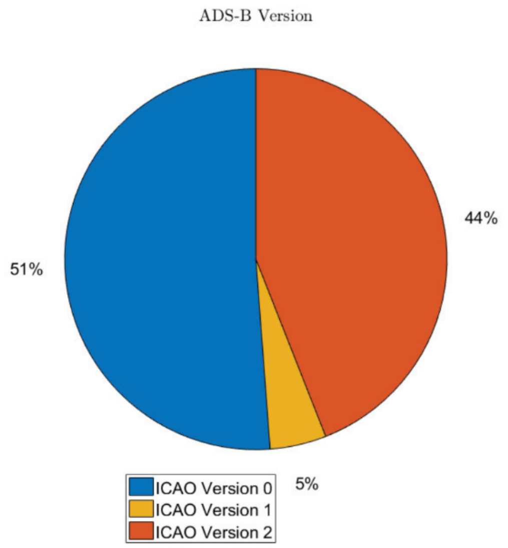

Fig. 3 ADS-B Version Equipage

Out of the 99% of aircraft equipped with the ADS-B OUT capable transponders, only 44% were equipped with ADS-B ICAO version 2 (see Fig. 3) at the time of measurement. This was quite surprising as more than half of the analyzed aircraft were still to be re-equipped with a newer version in a relatively short time period because of the new regulation being effective on 7th June 2020. However, the results clearly show there has been a certain progress in this matter as according to the previous analysis which had been done at the CTU, only 27% of analyzed aircraft were equipped with ADS-B ICAO version 1 or 2 transponders in the third quadrant of 2018 [4].

Moreover, 41% of all analyzed aircraft were identified as ACAS hybrid surveillance capable (see Fig. 4). This means that 41% of all analyzed aircraft were capable to use passive surveillance for ACAS purposes in case an intruder aircraft was equipped with ADS-B OUT transponder and hence not saturating the frequency band by limiting the number of active interrogations.

The next graph (Fig. 5) shows the proportion of aircraft concurrently equipped with ADS-B ICAO version 2 transponders and ACAS hybrid surveillance capability. The fact is, that only 54% of all analyzed aircraft were equipped with the ACAS hybrid surveillance while having the newest ADS-B version 2 transponders onboard.

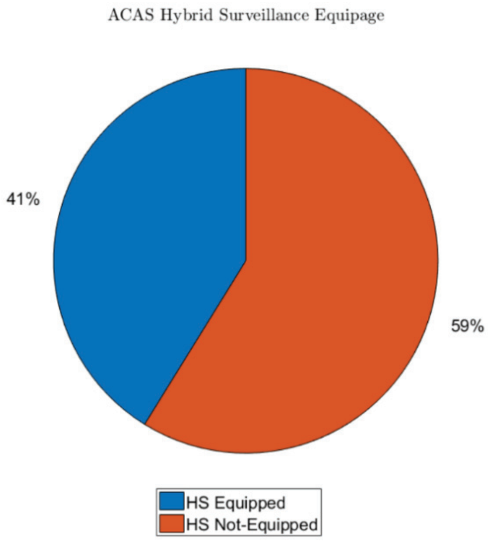

Fig. 4 ACAS Hybrid Surveillance Equipage

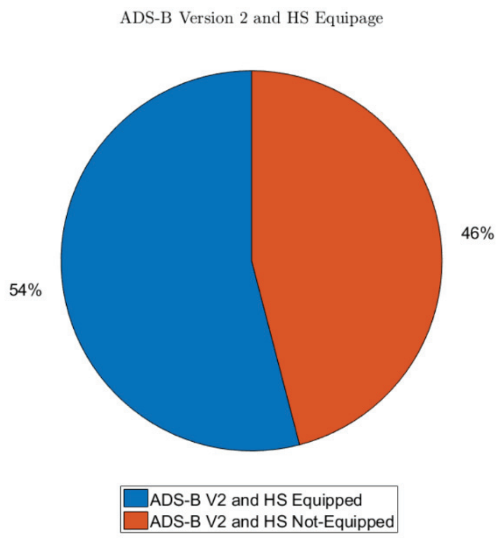

Fig. 5 ACAS HS and ADS-B v. 2 Equipage

If an aircraft is equipped with ADS-B version 0 transponder, then it transmits 4.2 DF17 messages on average every second. On the other hand, an aircraft equipped with ADS-B version 1 or 2 transponder transmits 6.4 DF17 messages on average every second (see Table). Hence, approximately 2.2 more long 112-bit downlink format messages (corresponding to 4.4 short 56-bit messages as far as transponder occupation time is concerned) are transmitted each second by every ADS-B version 1 or 2 capable aircraft, which is a 52% increase compared to ADS-B version 0.

The increase in 1090 MHz band load could be partially compensated by ACAS hybrid surveillance implementation. As ACAS equipped aircraft interrogate each other with 0.2 - 1 short 56-bit messages each second, depending on the ACAS implementation and the aircraft mutual positions, using hybrid surveillance, this number could be reduced to 0.017 - 0.1 long 112-bit messages per second, which corresponds to 0.034 – 0.2 short 56-bit messages. Hence, almost one short 56-bit message transmitted by an aircraft could be dropped each second if ACAS hybrid surveillance was used instead of the ACAS active interrogations. This would therefore partially compensate the increase of ADS-B version 2 messages by reducing its number to 1.7 long 112-bit messages transmitted per second by an aircraft. As each transponder shall be capable to handle at least 50 Mode S downlink format messages in any 1-second interval, the one saved message, if ACAS hybrid surveillance was used, would account for 2% of this limit number [8]. This may not seem as a huge saving to the overall band load, however, in a heavily congested airspace, even such a low value could likely, in some cases, well contribute to maintain the saturation at an acceptable level.

4. Conclusion

The European Commission published new aircraft equipage requirements that mandate all aircraft of a certain category to be equipped with ADS-B ICAO version 2 capable transponders from 7th June 2020 [9]. As those transponders will transmit 6.4 extended squitter messages on average each second, compared to currently broadly used ADS-B ICAO version 0 or 1 transponders, that transmit 4.2 extended squitter messages on average each second, it will contribute to the overall 1090 MHz band load. Since this band load is constantly becoming saturated because of increased air traffic and new surveillance technologies which are being deployed, it is necessary to propose new solutions and technologies which would enable to slow down this saturation and thus prevent aircraft transponders from being interrogated over their capacity limits [6].

This article provided an analysis of the proportion of aircraft currently equipped with the ADS-B version 2 transponders and ACAS hybrid surveillance. The analysis was performed as it was believed the ACAS hybrid surveillance could partially compensate for the increase of ADS-B extended squitter messages by reducing the number of ACAS active interrogations. The results showed that only 54 % of all analyzed ADS-B version 2 capable aircraft were equipped with ACAS hybrid surveillance, which is not a lot, considering that 2% reduction of the transponder capacity would have been achieved, had the aircraft been equipped with ACAS hybrid surveillance capability. This value may be considered neglectable at first sight, however, in a heavily congested airspace, it could, in some cases, well contribute to maintaining the band load at an acceptable level.

The analysis was performed on real data collected at 1090 MHz receivers. Because it was necessary to conduct the analysis on an isolated 2-aircraft encounter in order to evaluate the ACAS hybrid surveillance capability, most of the selected flights were conducted at night time. This is a limitation of the study, since there is a higher volume of freighter aircraft at this time, which are very often older than passenger aircraft and hence may be equipped with obsolete avionics.

In any case, it has been shown that if ACAS hybrid surveillance was mandated along with the ADS-B version 2 European Commission requirements, it would most likely decrease the contribution of this broadcast technology to the overall 1090 MHz band load.

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Enhancement of Operational Reliability of Elements in the Diesel Engine Cooling System of Locomotives

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Abstract

Operating experience of diesel locomotives on railways shows that the use of insufficiently purified water results in the destruction of water cooling systems. This problem is especially acute for areas with increased hardness and mineralization of natural waters.
The impact of the water demineralization degree on the corrosion rate of elements in diesel engine cooling systems of locomotives has been researched.
The dependence of the corrosion rate for various metals on the degree and depth of desalination and the cooling liquid temperature is proved.
Recommendations on optimizing the technology of cation treatment for cooling liquids ensuring the efficiency and durability in the operation of diesel engines of locomotives were developed.
KEY WORDS: *diesel, corrosion, cooling system, demineralization, ion exchange*

1. Introduction

One of the most important contemporary tasks of railway transport is to ensure safety against a backdrop of increasing the efficiency of the transportation process, which can be achieved by improving the organization of operational work, including a rational use and repair of the locomotive fleet [1-4]. That is, the improvement of maintenance and repair services for diesel locomotives should be carried out given the increasing reliability of their main assembly units and systems [5-10]. A reliable cooling system to a large extent determines the operational efficiency and maintenance of diesel locomotives. Statistics on the technical state of the diesel fleet confirm that the cooling system accounts for about 35% of all diesel malfunctions, and half of them are associated with nonconstruction elements.

The cooling systems applied to transport engines are very diverse. However, their “structure” is based on the traditional scheme of heat transfer from the engine to a cooling device. A wide range of accessible scientific research and innovative solutions indicates that with the improvement of cooling systems one can significantly increase the technical and economic performance of a diesel engine, reduce the stiffness of its operation, and increase the service life of units and aggregates in general. In the matter of improving the reliability of diesel engines, most of the largest modern enterprises (manufacturers of transport equipment) focus on upgrading cooling systems from viewpoint of possibility in regulating heat transfer; the arrangement of units and mechanisms; refinement of algorithms for the functioning of the elements that are components of the system itself.

Conforming to the existing patent classification, each of the elements in the system is divided on the principle and method of using the coolant, according to the method of contact with the atmosphere (that is, while rationalizing the cooling system, any of the elements may be involved, which may subsequently lead to changes in its technological parameters).

The major part of the proposed innovative solutions is associated with the use of various additional devices and elements that are included in existing cooling system circuits. These elements are given adaptation properties to existing modes and loads of the prime engine. This is particularly true for the options in placing the pumps, the nature of the arrangement, forms of cooling devices, and fans. The introduction of additional elements, as a rule, is associated with the need to adjust the functioning of the entire cooling system in certain modes or increase the coefficient of efficiency (CE) with the existing algorithm.

A significant amount of work on diesel traction, diesel locomotives design, operation, maintenance, repair, theoretical and experimental research on improving diesel cooling systems are widely represented in literary sources. However, works with consideration of conditions of large wear and overhaul with the life extension, issues of reliable and rational operation of cooling systems for diesel engines have not received sufficient development and remain relevant.

2. Particularities of Requirements for the Cooling Water Quality in Locomotives

A characteristic feature in the operation of diesel locomotives is the formation of various deposits in the diesel cooling system, which reduces thermal conductivity and obstructs the normal circulation of cooling water [11-13], resulting in:

– overheating of the most important parts and components of diesel engines can occur, which leads to an increase in thermal stresses and the appearance of cracks, deformations and warping of the exhaust manifolds with loss of leak tightness in the interface nodes;

– diesel locomotives cannot ensure the realization of full power due to insufficient cooling;

– the service life of seals is reduced and water leaks appear in various nodes of the diesel engine with the ingress of water into its crankcase, which leads to failure of the diesel.

A great impact on the efficiency and durability of cooling systems is provided by the quality of feed water. To ensure the reliable operation of these heat economy systems and reduce corrosion, it is necessary to keep the specified quality of the water used. Namely, the content of water-soluble oxygen and carbon dioxide, hydrogen ions, chloride ions, and sulfates. Table 1 shows the quality requirements of cooling water for locomotives. In the case of using, in addition to the specified composition, passivators such as phosphoric or chromic anhydride or sodium nitrite, they are added in amounts recommended by a special formulation [12, 14-19]. It should be noted that, unfortunately, in real practice, these passivators are currently very rarely added into water.

Table 1

Requirements for cooling liquid for locomotives

Indices	Sodium Phosphate Water				Water with sodium nitrate, sodium silicate
	Sodium nitrite			Caustic soda, chrompica	
	Caustic soda	Caustic soda bichromate	Bichromate		
Total water hardness, mgE/l, no more	0.2	0.2	0.3	0.2	0.2
Chlorine ion content, mg/l, no more	30	50	30	50	30
Phenolphthalein alkalinity, mgE/l, no more	0,3	–	–	–	1-3
Hydrogen index pH	7-9	8-8.5	6.5-7.5	7-8	8-9

The order of the operational process, namely, the diesel operating modes (Fig. 1), also affects the operability of cooling systems.

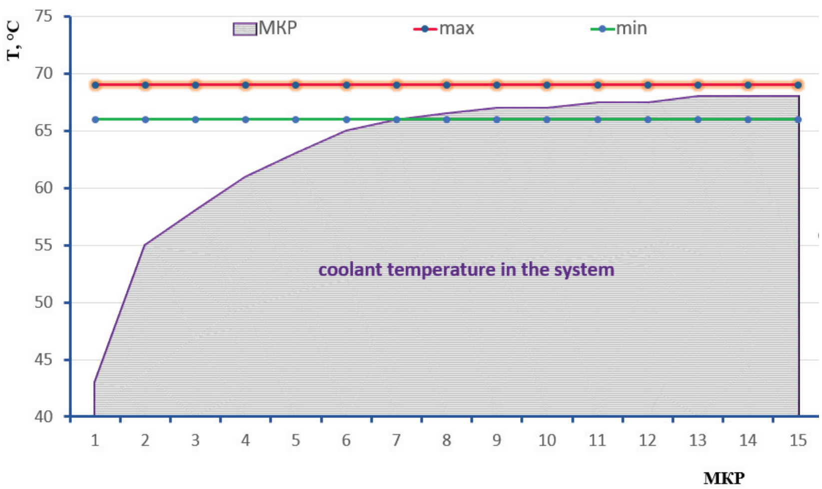


Fig. 1 Analysis of the dependence of the water temperature regime in a cold circuit on the machinist controller's position

"MKP" is the machinist controller's position; "max", "min" is the marks of the maximum and minimum values of the normatively recommended temperature range, respectively. As can be seen from the graph, the operation of the locomotive at low load and in idle mode leads to losses and wear associated with excessive cooling of the diesel engine and increased power take-off for the cooling system.

To keep the temperature of the coolant not higher than the specified limits, a change of the duty of fans in the refrigerating chamber is used. Also, in some modes, the coolant flows from one circuit to another. For example, at low

ambient temperatures, the cold circuit is heated with water from the hot circuit to prevent ice formation in the charge air cooler.

It is forbidden to shut down an engine at water temperature above 60°C in hot circuit in agreement with instruction manual, this leads to the cessation of water pumping through the cooling system. After the circulation is stopped, heat from the diesel elements is transferred to the coolant in the cooling jacket. Upon reaching a temperature above 105°C, the coolant boils. This leads to damage of rubber seals in the engine, thermal deformation of the valve covers, the mating face of the block, cavitation in the cooling jacket and pipelines. It may be one of the many reasons for the failure of both the cooling system and the diesel engine as a whole.

As the result of conducted analysis for the source water used in the locomotive depot at the Sunelnukovo station (in the area with high salinity), the authors determined the main water indices, which are presented in Table 2. As we can see from the analysis data, the cooling water contains significant amounts of active impurities that provoke corrosion as well as scaling. Since hardness salts are thermally unstable and have a negative solubility coefficient (i.e., their solubility decreases with increasing temperature), then when cooling systems operate at higher temperatures, one can observe the solution oversaturation and scale formation.

Table 2

Water chemistry used to cool diesels of locomotive at a locomotive depot

Concentration of cations			Concentration of anions			Dry residue, mg/dm^3	Hardness, mgE/dm^3		Alkalinity mgE/dm^3
Cation	mg/dm^3	mgE/dm^3	Anion	mg/dm^3	mgE/dm^3		total	constant	total
Ca^{2+}	82	4.1 ± 0.1	HCO_3^-	3050 ± 30	50 ± 0.5	2045±20	19.4 ± 0.11	7.03 ± 0.05	51±0.5
Mg^{2+}	183.6 ± 0.5	15.3 ± 0.2	Cl^-	381.4 ± 3.5	10.76 ± 0.1				
Fe^{3+}	0.19 ± 0.01	0.01 ± 0.002	SO_4^{2-}	1032.4 ± 9.6	21.5±0.2				
Alkaline metal (Na^+, K^+)	1446	62.9*	NO_3^-	0.81 ± 0.12	0.01 ± 0.002				

*determined by calculation

The most common deposits in cooling systems are the calcium carbonate $CaCO_3$ and magnesium hydroxide $Mg(OH)_2$ evolutions, resulting from the decomposition of hydrocarbons of these metals. These precipitates deposited on the surface of the cooling systems lead to a decrease in the efficiency of diesel, to metal overheating, which is accompanied by a decrease in strength and deformation of the devices. Judging by the data of Table 1 and Table 2, the content of Ca^{2+} and Mg^{2+} ions exceeds normalized by 90-100 times. A particularly negative point is the high total salt content, which is the main reason for the development of pitting corrosion in cooling systems.

Among the ions that provoke corrosion, the most dangerous is chloride ion, its presence in significant amounts destroys passive films and causes a high corrosion rate of iron and its alloys. At the same time, the chloride content in the water used for cooling exceeds the recommended one by thirteen times. In addition, the content of bicarbonate ions exceeds the total content of Ca^{2+} and Mg^{2+} ions. In other words, the alkalinity of water is increased, as evidenced by a measurement of pH and an index of total alkalinity (see Table 2). The most likely salt composition of the studied water is represented by compounds: $NaHCO_3$, Na_2SO_4, NaCl, $Ca(HCO_3)_2$, $Mg(HCO_3)$. All water-borne carbon dioxide is represented by HCO_3^- hydrocarbonate ions.

3. Research of the Corrosion Rate for Materials in the Diesel Cooling System of Locomotives

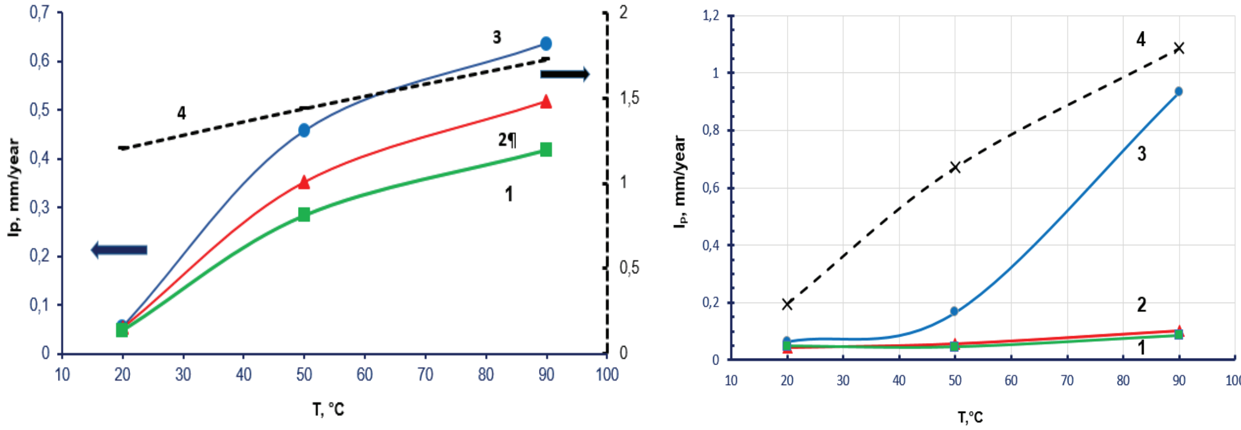
The operation of a diesel fleet of railways requires significant amounts of water for cooling systems. The low quality of the water used for these aims (in particular, its increased mineralization) is often the reason for unscheduled repairs of diesel locomotives due to pronounced pitting corrosion of the metal. Only on the example of a relatively small locomotive depot, the annual costs of unscheduled repairs for cooling systems can reach significant amounts. This is due both to the high salinity of a significant part in the water sources, and to the constantly changing physicochemical parameters of water as a result of anthropogenic activity. In some cases, there are attempts to solve this problem by using condensate from nearby boiler houses, however, the high costs of energy carriers and means for producing condensate increase operating costs and, for this reason, even untreated water is sometimes used in diesel cooling systems. For example, in one of the transfer depots, attempts to use such or imported water lead to the presence of pronounced pitting corrosion in the cooling systems, passing to a depth of several millimeters, which causes a violation of the leak tightness of the systems. Beyond that, locomotive depots consume additional significant amounts of high-purity water for topping up and repairing storage batteries. They receive it by distillation, which naturally requires significant electric energy consumption.

The authors have studied the effect of the water demineralization degree on the corrosion rate of materials in the diesel cooling system of locomotives. For this, corrosion rates for gray cast iron SCH 21-40 and steel St 20 (they are

commonly used in diesel cooling system of locomotives) were measured in waters with different salt contents, temperature and pH factor.

Figure 2 shows the dependences of the corrosion rate of cast iron (a) and steel grade St 20 (b) on the composition of the water used in cooling systems. In order to make comparisons for different indices of water quality, we chose different abscissa axes, which in some cases also use different scales. In all investigated cases, a decrease in salt content significantly reduces the corrosion rate, which qualitatively coincides with the known data [1, 11-12, 14].

It is revealing that in most cases, a decrease in the corrosion rate is especially significant with deep demineralization of water.



a b

Fig. 2 An example of the water temperature and degree of desalination impact on the corrosion rate of cast iron and steel: a - for cast iron; b - for steel grade St 20: *1* – water completely desalinated with a corrosion inhibitor; *2* - water completely desalinated by ion exchange; *3* – distilled water; *4* – half-desalinated water

An analysis of the results confirms that the corrosion rate increases significantly with increasing degree of mineralization of the aqueous medium: for steel St 20 by 3 times, but, for example, for steel St 5 by 5 times. This is attributable to an increase in the concentration of chlorine ions in water from 1.8 to 381.4 mg/l, which stimulate the corrosion process.

It is worth noting that for waters subjected to deep demineralization, an increase in temperature up to 90°C slightly increases the corrosion rate (while for waters with high salt content, an increase in the corrosion rate with rising temperature is more significant). With rising temperature to 60°C, the corrosion rate of steel and cast iron in the source (non-demineralized water) increases by 20 times. Obviously, the requirements for the basic composition of the water used in steel cooling systems for diesel engines of locomotives to prevent corrosion changes should be as follows: total hardness is 0.2 ± 0,1 mgE/l; pH factor is 9.3; dry residue – 95 ± 4.

Simultaneously, for systems made of cast iron, quite satisfactory results are observed for water that is close to the composition: total hardness is 4.2 ± 0.1 mgE/l; pH is 9.0; dry residue is 439±4.

4. Optimization of Cooling Water Treatment Technology for Locomotives

Although the solution to the problem of cleaning and preparing cooling water can be carried out in several ways (chemical, thermal, distillation, etc.), the ion exchange method is the most convenient and economical for usage.

The authors have studied and proposed the method for purification of the specified water by hydrogen cycle and subsequent OH-anion exchange. An important aspect is a focus on inexpensive, but highly effective ion-exchange resins, which are modern analogs of the technologically tested KU-2-8 and AV-17-8 (manufactured by Cherkasskiy PC “Azot”).

Until recently, sulfonated coals were widely used as ion-exchangers. However, they have slow kinetics of sorption from solutions (which requires large filtration areas), poor recoverability (the residual capacity after the first regeneration is much lower than half of the initial one), and insufficient mechanical strength. The selected ionites for the proposed method (Lewatit S 100 and Lewatit MonoPlus M 500) are free from many of the above disadvantages. For example, some ion exchangers are very sensitive to concomitant organic impurities, often found in water [12-13, 15, 20-22].

The essence of chemical desalination is the removal (as a result of ion exchange) of all cations and anions compounds contained in it. First, water is passed through the hydrogen-cation exchanger; all cations in water (Ca^{2+}, Mg^{2+}, Na^{+}) are exchanged for a hydrogen cation; then through an anion exchange filter, where all anions (contained in water Cl^{-}, SO_4^{2-} in the form of acids) are exchanged for the exchange anion: hydroxide (OH^{-}). Authors use the ion-exchange materials, they are solid grains of light and dark brown color, with a grain size of 0.315–1.25 mm (96% of a fraction). Ion exchange materials swell in water, increasing in volume by 2–3 times, therefore, before being loaded into the filters, the resins are pre-soaked for a day. After that, they are transferred to the filter and make sure that the resin is always covered with water. Drying-out of ion exchangers leads to a decrease in their exchange capacity. These ion

exchangers are chemically resistant, good adsorbents, and have high strength. Operation of the proposed system of ion-exchange filters (Fig. 3) is carried out in two stages and represents the following operating cycles: loosening, regeneration, washing off and desalination, which are controlled and regulated by instrumentation equipment and shut-off valves (Fig. 3, items 1 – 28).

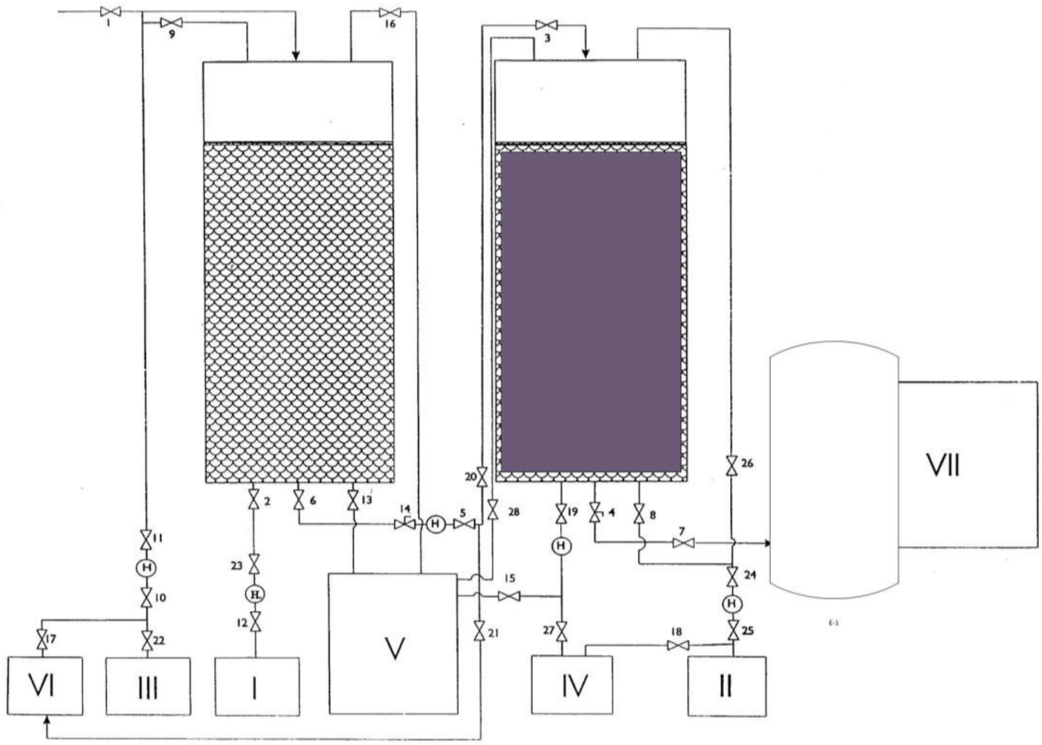


Fig. 3 Scheme of the proposed ion-exchange installation with additional loading on two stages: I –tank with water for loosening; II – alkaline regeneration tank; III – tank with a sulfuric acid regeneration solution; IV – tank with water for loosening the ion exchanger; V – tank for neutralizing acid-base wastewater; VI – tank with water for washing cation exchanger; VII – purified water collection tank; 1-28 shut-off valves and instrumentation sensors

A wide range of dynamic tests was carried out to approbate samples in all types of technological cycles of ion-exchange water purification. The essence of the dynamic method is that a solution of a saturating ion is continuously passed through a packed layer of a sorbent in a column until sorption equilibrium is established between the initial solution and the sorbent. As the solution is passed through the column, a sorption front forms in it (i.e., the sorbent is completely saturated in its upper part), then the adsorption front moves down the column. Since the formation of the saturated layer, the dynamics of sorption occurs in the mode of parallel transfer of the sorption front. When the front reaches the end of the column, there is a "slip" of the saturating ion into the filtrate. The further transmission of the initial solution leads to the fact that complete saturation is achieved over the entire thickness of the sorbent, i.e. equilibrium comes. From this time, the concentration of the filtrate becomes equal to the concentration of the initial solution.

The data obtained make it possible to formulate clear recommendations regarding the physicochemical parameters of all processes of the water treatment technological cycle, which allows ensuring the high cleaning efficiency and minimization of system failures.

5. Conclusions

Operating experience of diesel locomotives on railways shows that the use of insufficiently purified water results in the destruction of water cooling systems. This problem is especially acute for areas with increased hardness and mineralization of natural waters.

Thus, the obtained experimental data on the research of a wide range of factors causing corrosive changes in the design of diesel cooling systems and process conditions confirm the need to develop and implement contemporary innovative methods of demineralization and water treatment for servicing the railway fleet.

To solve this problem, a number of modern technological approaches have been studied to ensure a sufficient degree of demineralization for cooling liquids.

The method of water purification proposed by the authors and recommendations for optimizing the technology of ion exchange treatment of cooling liquids will ensure the durability of diesel locomotive engines and economic efficiency.

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Small and Medium Sized Ports Digitalization Level Evaluation and Benchmarking

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Abstract

Nowadays, small and medium sized ports are actively searching for ways to improve their operational activity. One of the observed directions of ports' development is digitalization of processes and operations. It should be noticed that small and medium sized ports very often face difficulties to implement and keep a similar digitalization level as it is in big ports, that may be influenced by limited financial and human resources. Implementing benchmarking of port's digitalization level may be useful for small and medium sized ports and allow them to choose best improvement solutions. The article aims to present the methodology of ports' digitalization level evaluation that may be used for benchmarking analysis by small and medium sized ports. The case study of ports located in the South Baltic Sea Region had been considered.
KEY WORDS: *small and medium sized ports; digitalization level; benchmarking*

1. Introduction

Nowadays, digitalization is widely implemented in the maritime sector, including ports [12]. Digital transformation covers different areas of ports' functioning, such as management and planning, port operations, commercial and support services and other. Implementation of digital solutions allows ports i.e. to increase their efficiency, decrease time and costs of selected processes performance, improve information flow and decision-making, increase safety and decrease the negative impact of transport on the environment in ports and port areas, enhance innovation etc. [15].

Different kinds of digital solutions are observed in ports, including simple, intermediate and high precision digital systems. A lot of small and medium sized ports use simple digital systems, e.g. IT systems devoted to specific cargoes, that are not integrated with systems used by port's customers and other participants of supply chains [1, 2, 6]. Such digital solutions can be created using common programmes (e.g. Excel or other) and can facilitate evidence and evaluation of cargos handling volumes or passenger flows, accounting requirements etc. Intermediate digital systems are based on blocks schemes and may be connected with information systems of other entities, e.g. customs, border control and others. Such types of digital systems may be created by port's IT specialists or special IT companies and are not too expensive [8, 11, 19]. High precision (modern) digital systems may integrate port terminals with port's Administration, customers, control bodies and other entities involved in supply chain operations. Such modern IT systems are usually developed for the needs of the specific port or port and other groups of users [3, 17, 20, 22].

Particular ports implement different types IT systems and have different levels of digitalisation. Planning further development ports often are searching for good practices verified by other ports that they could implement to improve ports' functioning. Such improvements often deal with ports aspiration to attract cargo flows and customers, promote port services, as well as introduce other important amenities for the existing and potential cargo owners and shipping companies [16, 21, 23]. Nowadays, one of the essential directions of ports development is digitalisation and IT systems implementation [3, 14].

Evaluation of the port's digitalization level may be helpful for ports to find rational solutions for digital systems development. It also gives the opportunity to compare ports operation and use benchmarking analysis to select the ports with best practices which it is possible to implement in other ports [7, 10, 18]. Such an approach may be helpful for small and medium sized ports that plan digital systems development.

The purpose of the article is to develop the methodology to evaluate the level of port's digitalization that may be used for benchmarking analysis used by small and medium sized ports. It was assumed that small or medium sized ports: are not core ports in the Baltic Sea region; their cargo handling is less than 10 million tons per year; there are specialized or universal ports; mainly municipality ports that have limited activity and possibilities, etc. [15]. The developed methodology considers using a marketing research tool to collect the data. The mathematical model allowing

conducting simulations have been proposed and the case study of 12 ports located in the South Baltic Sea Region (SBSR) was analysed. On the basis of research results, the appropriate conclusions have been drawn.

2. Analysis of Factors used to Assess Ports' Digitalization Level

Different factors influencing ports' digitalization levels in different ports are described in the available literature [9, 12-13]. These factors are connected with ports' facilities and implemented technological solutions, using software and hardware, management, communication with other entities, human resources, information flow solutions, and others [12, 19]. The digitalization level of ports largely depends on managerial decisions, ports' needs and customers' requirements, as well as available funds that could be invested in ports development.

The analysis of factors influencing ports digitalisation revealed that decisions related to IT systems development and port's digitalisation level assessment could be taken on the basis of analysis of information related i.e. to: navigation; port land surface; type of ships serviced in ports and systems used by shipping companies (e.g. "Laivas" digital system in Klaipeda port); cargo types serviced in port (e.g. KIPIS in Klaipeda port); people entrance into the port (e.g. the need to observe ISPS code requirements); emergency situations management in port; expected time of arrival (ETA) and actual time of arrival (ATA) of the ships; real (actual) depths in the port; legal documents valid in the port (e.g. port rules, navigational regulations and other); public procurement; port annual reports; port turnover; port development programs; port development projects; port Newsletters; companies operating in port and their activities; port control institutions; port promotion materials (video, audio etc.); port organization; port Administration working time; additional services available in port; port dues and tariffs; other additional information, conditions and requirements, specific for particular small and medium sized ports [8, 16].

Analysis of operation of small and medium sized ports showed that their digitalization levels compared to big ports are much lower and state between 40 – 60% of big ports' levels [2, 11, 14].

To sum up, the factors influencing port's the digitalisation level may be divided into the following groups:

- Digital performance management – these factors are dealing with ports strategy and openness to implement new digital solutions;
- IT elements – these factors involve used software and other systems for data analysis;
- Management and functionality – factors forming this group include undertaken initiatives and people attitude to modern systems;
- Smart systems – these factors deal with different smart solutions available on the market that may improve port functioning;
- Communication and human resources – factors describe the ways of employees' communicating and information sharing.

In order to evaluate the digitalization level of ports, the methodology used for the benchmarking analysis should take into account different factors relevant for the area of ports operation and specific economic environment.

3. Methodology

In order to evaluate the level of ports' digitalisation for benchmarking analysis the appropriate methodology had been proposed. Necessary data was collected using marketing research tools. The questionnaire was developed and interviews with ports representatives were conducted to collect data necessary for further analysis.

On the basis of literature analysis and observations of ports functioning about 43 factors reflecting the issue of ports digitalisation were selected. These factors were divided into 5 scoring groups (SG). Particular scoring groups covered the following factors:

- Scoring group 1 (SG1) "Digital performance management" included 4 factors: digitalization strategy (v1), digital business strategy (v2), digital innovation (v3), digital innovation implementation (v4). It was established that weight coefficient for this scoring group is 0,2, taking into account its influence on small and medium sized ports digitalization policy.
- Scoring group 2 (SG2) "IT elements" included 9 factors: IT infrastructure (v5), automation technology (v6), data analytics (v7), data security/communication security (v8), development/application of assistance systems (v9), collaboration software (v10), non-technical skills (v11), hardware infrastructure (v12), other equipment (v13). The weight coefficient of SG2 was taken 0,35.
- Scoring group 3 (SG3) "Management and functionality" covered 6 factors: functionality of measurement (v14), digitalization usage (v15), digitalization initiatives in company (v16), digitization trust in company (v17), client's trust to digitization (v18) and digitalization options in Company (v19). The weight coefficient for SG3 was assumed as 0,2, this group of factors is much dependent on groups SG1 and SG2.
- Scoring group 4 (SG4) "Smart systems" included 17 factors, such as: smart Enterprise Resource Planning system (v20), smart Warehouse Management System (v21), smart Port Community System (v22), web-based communication platforms (v23), mobile data access for employees (v24), mobile data access for customers (v25), Internet of Things (v26), cloud computing (v27), location technologies (v27), sensors (v28), big data and predictive analysis (v29), blockchain (v30), artificial intelligence (v31), robotics (v32), drones (v33), autonomous solutions (v34), digital twinning augmented and virtual reality (v35). The weight coefficient for this group was set 0,2.

- Scoring group 5 (SG5) “Communication and human resources” covered 8 factors: human resources network (v36), printed media (v37), Internet (v38), social media (v39), fairs (v40), conferences (v41), associations and consultancies (v42), scientific institutions (v43). The weight coefficient for this group was assumed as 0,05.

One more group of data (SG6) aimed to collect general information about analysed ports in order to facilitate benchmarking analysis and compare ports and selected terminals.

During interviews conducted in ports, particular factors were assessed by ports’ representatives using Likert scale (e.g. from 1 to 6, where 1 means that factor is not appropriate for the port/is not utilized by port, 6 – the factor is appropriate for port/ is widely implemented). Respondents had an opportunity to express their opinion and indicate the level of occurrence/utilization of a particular factor in port. The interviews were conducted several times in order to receive reliable information for further benchmarking analysis.

The mathematical basis for benchmarking was based on random factors analysis. In case the big number of random factors is analysed, it is possible to use Lepunov Central Theorem and Normal (Gaussian) distribution [5, 16]. Gaussian distribution (Fig. 1) is a bell-shaped curve. It is assumed that during any measurement values will follow a normal distribution with an equal number of measurements above and below the mean value. The characteristics of Gaussian distributions depend on the Standard Deviation (SD) and could be determined as follows: mean ±1 SD contains 68,2% of all values, mean ±2 SD includes 95,5% of all values, mean ±3 SD contains 99,7% of all values [5].

This approach was chosen for the analysis of collected data, mean values and standard deviations were determined for data received from particular ports. It was assumed that for analysis of small and medium sized ports digitalization level the standard deviation is equal +/- 1 with probability 68,2%, because data collected during interviews may contain differences.

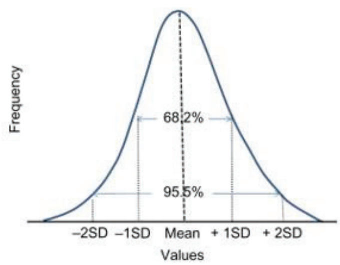

Fig. 1 A Gaussian distribution showing percentage of values within a certain standard deviation from the mean [5]

Evaluation of ports’ digitalization level was based on typical methods of data comparison, which mathematically can be described as follows:

$$E_{P_i} = \frac{1}{\eta_k} F_i , \tag{1}$$

where: E_{Pi} – i port’s digitalisation level; η_k – correlation coefficient, in analysed case it could be between 0,96 – 0,98; F_i – assessment of all scoring groups for i port that can be calculated as follows:

$$F_i = \sum_{n=1}^{5} \left(\frac{\sum_{j=1}^{m_n} S_{nj}}{m_n} k_{S_{nj}} \right), \tag{2}$$

where n – number of the scoring group, $n = 1,\ldots,5$ (it depends on the selected groups of factors); S_{nj} – assessment of scoring factor j in group n, given by respondent; m_n – number of the factors in group n; $k_{S_{nj}}$ – weight coefficient of the scoring group n.

Comparing the results of interviews conducted with the same expert but at different time period, the fluctuation and differences in expert opinions may be observed (it may be caused by differences in respondent’s perception of a problem area when the same questions are asked). Therefore, data filtration is needed. Filtration of data collected during the interviews can be done using Kalman filter and can be performed as follows [4]:

$$x_k = Ax_{k-1} + Bu_k + \omega_k , \tag{3}$$

with observations z_k:

$$z_k = Hx_k + \upsilon_k , \tag{4}$$

where A, B, H – coefficients; ω_k, υ_k – a sequence of noisy observations; x_k, u_k– control vectors.

The presented approach was implemented to analyze the results of the interviews. The appropriate computational model to conduct simulations was developed.

4. Case study of Small and Medium Sized Ports Digitalization Level Evaluation

In order to assess the digitalisation level of small and medium sized ports for future benchmarking analysis a case study of ports located in SBSR (South Baltic Sea Region) was analysed. The initial data was collected from 12 small, medium and big sized ports (P1-P12). Big ports were also analysed in the case study in order to collect relevant data for benchmarking analysis. The developed questionnaires were used to conduct interviews with responsible persons working on managerial positions in analysed ports. The interviews with the same experts in particular ports were conducted twice starting from September 2019 until May 2020. The respondents were asked to evaluate 43 factors divided into 5 groups using Likert scale from 1 to 6, as it was described in the research methodology.

The collected data was analysed and differences in expert's responses were found. Therefore, filtration of achieved data was done using the Kalman filter [4]. The example of differences in answers indicated by the same expert during two interviews in two different time periods is presented in Table 1.

Table 1

The example of assessments of factors v1-v10 given by the same expert during interviews

Interviews	v1	v2	v3	v4	v5	v6	v7	v8	v9	v10
1st interview	5	4	4	5	5	4	5	4	4	5
2nd interview	6	6	3	2	1	4	3	4	4	4

On the basis of received assessments of particular factors during the interviews, using the developed methodology and created a computational model, the digitalization level of all analysed ports was calculated. The results of the ports' digitalization level evaluation for the selected port are presented in Fig. 2.

The analysis of simulation results of data obtained during two interviews and filtrated using Kalman filter [4] showed that differences in received responses are between 8 – 12%.

The results of calculated digitalization level of analysed big, medium and small sized ports are presented in Fig. 3. The analysis of results shows that digitalization level of big ports is scored over 4 (ports P2, P3, P5, P7, P8). This information is essential for small and medium sized ports which level of digitalization was assumed between 2,6 and 3,8. Conducted calculations allowed to determine ports that may set the basis for benchmarking for particulary small and medium sized ports.

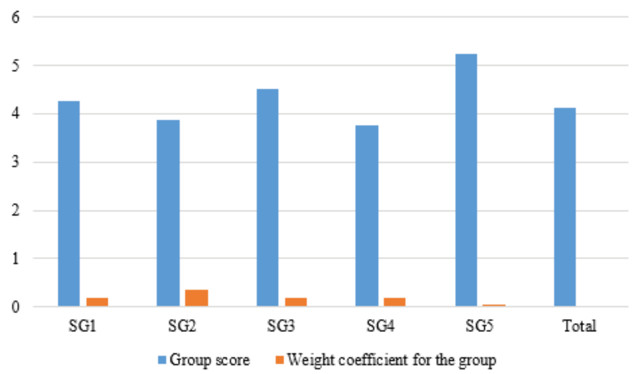

Fig. 2 Results of ports' digitalization level evaluation for the selected port

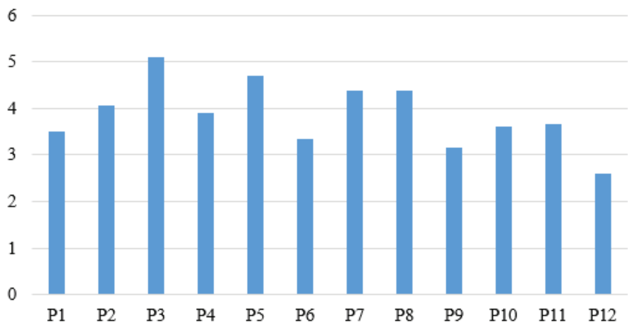

Fig. 3 Results of 12 ports digitalization level evaluation for benchmarking analysis

It should be noted that the maximum level of digitalization for benchmarking analysis, calculated using the presented methodology, could be scored 6. Such a result may be received by the autonomous container terminals. Autonomous container terminals' results may be taken as etalon for the benchmarking of the digitalization level for different ports and terminals, including small, medium and big sized ports.

The achieved results of digitalization level evaluation could be considered as indicative directions of ports' possible activities, because in some cases, especially in case of small ports, it is necessary to take into account port's capability, economic environment and operating conditions, traditions, customers' requirements and other factors.

5. Conclusions

Implementation of digital solutions to improve the small and medium sized ports operation and management is essential for their sustainable development and achieving a high level of competitiveness. That is due to the fact that nowadays the digitalisation level of small and medium sized ports is much lower compared to this level observed in big ports.

The presented methodology of assessing the digitalization level of ports could be used for benchmarking analysis by small and medium sized ports, as well as the big one in order to choose the best solutions for ports operation

improvement. On the basis of case study analysis, it was possible to determine the level of digitalisation of 12 ports located in SBSR and select the ports for benchmarking that may be implemented by small and medium sized harbors.

Our further research will be focused on the improvement of the developed methodology used to evaluate the port's digitalisation level, as well as on the analysis of a greater number of ports located in the Baltic Sea Region and abroad. Other factors influencing the selection of ports for benchmarking analysis will be considered.

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Safety Culture and Quality Culture as a Tool for Transport Infrastructure Protection

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Abstract
The current world pandemic brought a completely different perspective on security issues. Technical and organizational security are the two bases on which security research has been focused so far. Currently, health and social security issues have been added. Security research is a multi-level, multi-disciplinary and complex issue. In the research conducted at the three cooperating universities, clear constraints have been defined for specific reference objects. The general system of traffic safety management must comprehensively address all pillars - physical safety, fire safety, environmental safety, operational safety, occupational health and safety, information security. The article aims to show the possibilities of a new approach to a set of measures for a comprehensive increase in the safety of traffic objects
KEY WORDS: *safety, security, transport, infrastructure, quality, culture*

1. Introduction

Processes, technologies, behaviours, practices, and practices throughout human society. The evolution of the global society from 2012 to 2019 was characterized by continuous economic growth, which was reaching the limits of what is possible. The arrival of the global crisis was expected from 2018. No one could imagine what could trigger this crisis. Every major change at the global level also brings changes at regional, national and local levels. What seemed impossible in 2019, we are now experiencing. For years, academics and scientists have been working on building a SMART and SAFE company. Thus, in technologically advanced countries, the current restrictions on the movement of people did not significantly affect the lives of the majority of the population. In countries where modern information and communication technologies are only gradually gaining their place in society, online life is progressing [20].

In 2018, we spoke at the Conference on Safety and Health at Work about the need to link a culture of quality and a culture of safety. The social changes initiated by the COVID-19 pandemic will unequivocally lead to pushing the frontiers known in all areas. Cultural, ethical and social changes must be followed first. With the development of the COVID-19 pandemic, the first but fundamental changes in the legal environment are taking place at the national and European level. Changes in legal standards push the boundaries of human behaviour. This will, in turn, change the overall culture of European society. One of the basic principles of its functioning - the free movement of persons - has been completely changed to stop the spread of the COVID-19 virus. With some exceptions, in April 2020 (at the time of writing) the national borders of individual EU Member States were completely closed. All citizens who are currently coming from abroad are obliged to compulsory 14 days of national quarantine. By contrast, the free movement of goods provided by road, rail, water, and air transport currently operates without significant restrictions. The only limitation is the speed of delivery of the goods, as checks are carried out at national borders.

The article aims to present the results of long-term international research conducted in three Central and Eastern European countries. When we began exploring the links between a quality culture and a nascent security culture, we considered other threats than COVID-19. However, the methodology of the solution and the gradually obtained results led us to the recommendations that will be presented in the article.

2. Literature Review and Definitions

For a long time, research teams around the world have been researching security culture [23]. The authors focused their attention on the author's publications focused on transport and transport infrastructure . Ambros et.al. dealt with the safety assessment of Czech highways and first-class roads [1]. Chen et. Al. focused on research into road network vulnerabilities [3]. Dvořák and Leitner studied safety culture and quality culture, as well as the Assessment of Critical Infrastructure Elements in Transport [4-6, 12-13, 22]. Batarlienė was involved in research into building green transport corridors, a topic closely related to safety and quality [7]. Hofreiter was dedicated to the protection of buildings focusing on critical infrastructure elements in transport [8]. A group of researchers at T. Bata University in Zlín and VŠB Technical University in Ostrava focused on research on the resilience and vulnerability of critical

infrastructure elements [10, 16-17]. Researchers at the University of Pardubice under the leadership of Sousek have long been involved in crisis management of transport [18]. Military Academy researchers in Liptovsky Mikulas focused on the military aspects of crisis management [14]. Current researchers at the Technical University of Kosice are devoting comprehensive attention to security issues, both technical and organizational [11, 15, 19]. Basgen currently recommends applying the PDCA Deming Cycle (plan - do - check - act) to all security applications [2]. Howard recommends - take security to the next level. The Safety Management System (SMS) is a process of continuous improvement that reduces hazards and prevents incidents [21]. It protects the health and safety of your employees and should be integrated into everyday processes throughout the organization. Investing in SMS has a measurable impact on your bottom line and can be considered a competitive advantage. Adopting the SMS framework and thoughtfully implementing various aspects can have a significant impact on protecting your employees and improving your organization's performance and profitability. While security requirements may vary from industry to industry, all exemplary organizations focus on continuous improvement aimed at continually reducing risk to zero incidents [9].

3. Materials and Methods

Security is one of the basic needs of every citizen, every business, every city, region, and state. In the framework of many years of research into the issues related to security in all its parts, the pillars of security management in the organization have been defined. Fig.1. In addition to the defined objective, each research has defined solution limitations. The scope of this article is limited, so only basic ideas will be presented. The aim is to move the safety of the transport company to a higher level. For transport development, technical standards have been developed since the beginning of the construction of the transport infrastructure and transport system, which determined the rules for processes. Today at the beginning of the 21st century, we have made further progress. It is necessary to interconnect solutions, create a comprehensive approach to the topics addressed. Therefore, the concept of safety management of the transport company was created. As an example, the authors elected the Railway Infrastructure Manager (RIM) of the Slovak Republic. For this state-owned company, in-depth analyses were prepared based on the pillars of the organization's safety management pillars and new solutions were proposed based on them.

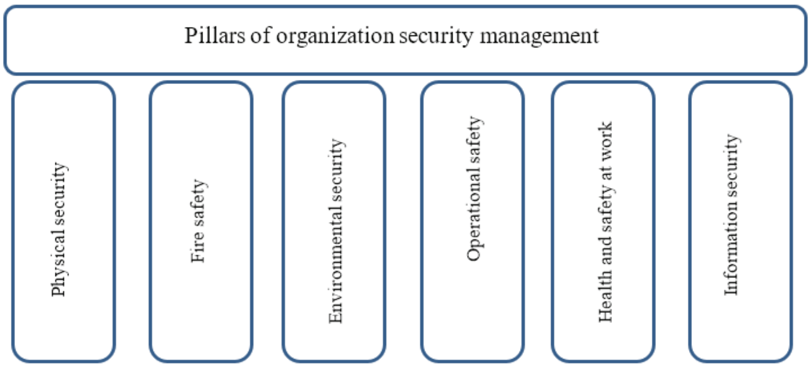

Fig. 1 Pillars of Organization Security Management

In addition to the pillars of the organization's safety management, based on recommendations of foreign authors (Basgen, Howard and others), they focused on key aspects of safety - people, safety planning, detailed measurable programs to meet partial safety goals, continuous improvement principle, measuring appropriate safety indicators the principle that security is above all else.

The basic limitations of our solutions included - working only with publicly available information, ensuring compliance with GDPR, the principles of information security and correct work with sensitive information. In our research, we used a very diverse method of scientific work. The group of general methods included - analysis of information sources, analysis of the legal environment, analysis of scientific and professional publications, synthesis, comparison, observation, controlled interview, questionnaire investigation, induction, deduction, and abstraction. In the field of security sciences, specific methods are also used - risk analysis, checklist, security audit, CCA, HAZOP, FMECA, what-if, FTA, HTA, qualitative, semi-quantitative and quantitative evaluation, and specific simulation methods. In addition to methods, we also focused on appropriate techniques - risk list, brainstorming, questionnaire investigation, assumption analysis, decision analysis, risk prioritization, risk response - acceptance, reduction, and risk avoidance.

4. Results

Key results of research in the field of quality culture and safety culture for rail transport include:

1. Establishment of a RIM security apparatus for the level of the Directorate General of Regional RIM Directorates.
2. Establish a security control room at the level of the RIM Directorate-General.
3. For RIM security management needs, prepare a set of operations and information security measures.

4. Using the PDCA method, continuously improve the entire established RIM safety culture system.

Testing and verification of research results - during the creation of the entire security management system, we regularly discussed the solved issues at international conferences in Bulgaria, Serbia, and Slovakia. All railway companies currently live very similarly during the transformation period. The division of competences for infrastructure management, passenger transport, and freight transport has fundamentally changed the priorities of the railway companies. The researchers agreed, there is no quality transport policy in these states. The priorities of the individual government programs do not create comprehensive pressure to modernize the railway infrastructure. There is a spontaneous development of other modes of transport, especially a large increase in road transport.

5. Discussion

New security enhancement systems are being developed in all areas of society. Researchers' focus on security and transport is broadly multidisciplinary. According to the recommendations of some authors (Basgen, Hofreiter, Howard, Nečas, Řehák), transport companies should aim at:

1. Examples of good practice - shaping a safety culture in business - success in business depends on success in safety, rightly arguing that any change brings opportunities to communicate safety improvement in all areas.
2. Have a safety guide - each company must respect the legal environment, technical standards and safety recommendations (physical, environmental, information, fire, occupational health, and safety), and management should publish a safety commitment.
3. Create a Safety Management System (SMS) - the company should set the framework and measurable indicators for safety.
4. Monitor Permanent risk reduction - continuous monitoring of threats and risk analysis, if mitigated, adopt mitigation measures.
5. Set achievable safety targets and monitor safety indicators.
6. Work with the scientific community to use risk maps and interactive graphs presenting safety indicators.

There are dozens of good examples of systematic safety and resilience enhancement in society and the corporate environment. The key is to define the position of the safety manager, who has full responsibility for safety in the company. Depending on the size of the company, an appropriate safety department must also be created. Each institution and firm must plan financial resources to increase security / reduce risks. One good recommendation is to organize regular workshops/seminars to identify current threats and opportunities.

6. Conclusions

According to world statistics, the highest proportion of accidents at work is caused by traffic accidents. Top automotive companies and transport companies promote their quality culture and safety culture. Based on years of research, after testing in practice and verification at international scientific conferences, we recommend the following model:

1. Security policy and objectives
   - management's commitment and responsibility for safety;
   - appointment of a key safety manager,
   - implementation of the safety management framework;
   - coordination of all parts of emergency planning and risk reduction,
   - keeping appropriate documentation.
2. Security risk management
   - hazard identification,
   - risk analysis, resilience analysis, vulnerability analysis,
   - mitigation measure.
3. Security insurance
   - monitoring and measuring safety indicators,
   - security workshops and seminars
   - the principle of continuous improvement of safety.
4. Supporting activities
   - security training and education;
   - safety training,
   - security communication.

The decision on changes to the approach to security is up to the company management. If the management of a company/institution understands the importance of security and decides on a comprehensive solution, then the know-how referred to in the article will greatly help it. The authors believe that the experience and knowledge that has been created in the international context will enrich society. The current COVID-19 global pandemic is clear evidence that failing to address security problems in the immediate post-emergence period can lead to global problems.

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Identification of Axle Counting System Failures Based on Diagnostic Matrices

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Abstract

Railway traffic control systems have an important role in ensuring the safe movement of people and the transport of goods. That is why they belong to the group of safety-related systems, often referred to as safety-critical systems. Therefore, these systems are expected to perform their functions not only with operational reliability but also with safety, i.e. no unacceptable risk. Technical diagnostics is one of the methods to achieve these goals. The authors of the article presented research results concerning the use of a model based on binary and probabilistic diagnostic matrices. As an example, the axle counting system was used, which is critical for maintaining railway traffic safety.
KEY WORDS: *safety, axle counting system, fault detection, diagnostic matrices*

1. Introduction

Concern for safety becomes an important aspect of human activity. Along with an increase in awareness and high expectations regarding safety, knowledge in this field is also being developed. Deliberations concerning system safety began safety science, which area is safety engineering [4, 6-7, 22]. Safety engineering consists of designing, constructing, modifying and maintaining technical solutions taking into account safety analysis that aim is, among others, assessing the level of safety of the solutions. Railway traffic control systems belong to safety-related systems group, often called safety-critical systems [13, 17, 19, 21]. One of the methods allowing gaining a necessary safety level of these systems is technical diagnosis [11-12]. The article proposes using a diagnostic method of railway traffic control systems basing on binary and probabilistic diagnostic matrices. The research has been conducted for axle counting systems that need to achieve the highest, fourth safety integrity level.

2. Binary and Probabilistic Diagnostic Matrices

Modelling is the first stage of a formal approach to issues related to the analysis of the functioning of technical objects. Diagnostic object models are created to conduct diagnostic inference, which allows describing the object and its behaviour in different conditions with the help of diagnostic relation on the feature state set and set of symptoms. When diagnosing technical objects one can use a model based on binary and probabilistic diagnostic matrices.

In the object diagnostic process a diagnostic test set is used. Each of the diagnostic tests generates an output diagnostic signal y_j, thus, as a result of accomplishing all possible tests one gets a diagnostic signal set Y (Fig. 1) [10]:

$$Y = \{y_j : j = 1,2,...,J\}. \tag{1}$$

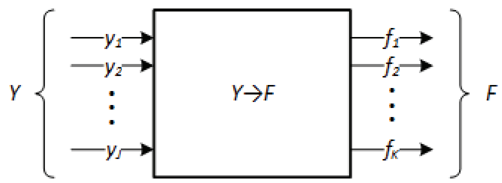

Fig. 1 Object diagnostic process on the basis of diagnostic signal assessment [10]

When diagnosing a technical object one can assess a failure set F, which causes that the object falls into an inoperative status.

$$F = \{f_k : k = 1,2,...,K\}. \tag{2}$$

Diagnosing a technical object requires a clear-cut association with failures of diagnostic signal values called

symptoms. Thus diagnosing combines the features of object status and symptoms. In the analysed case the diagnostic process is mapping the space of diagnostic signal values Y (symptoms) into the space of object status values W. If one assumes occurring only failures leading to the inoperative statuses of W_0 and operational statuses of object W_1 then the diagnostic process is described by the relation [9]:

$$Y \in R^J \Rightarrow W = \{W_0 \cup W_1\} \in \{0,1\}^K . \tag{3}$$

A relation notation <*f*, *s*> "failure – symptom" can be then presented as a binary diagnostic matrix (Fig. 2).

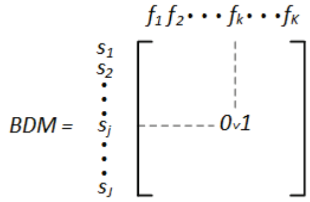

Fig. 2 Binary diagnostic matrix being the notation of the relation "failure – symptom"

Diagnostic inference taking into account the binary diagnostic matrix requires assigning to particular statuses of object diagnostic signals matching a particular failure $v_j(f_k)$, where k_{th} failure, j_{th} diagnostic signal:

$$V(f_k) = \begin{bmatrix} v_1(f_k) \\ v_2(f_{k+1}) \\ \vdots \\ v_J(f_K) \end{bmatrix} . \tag{4}$$

Assuming the occurrence of single failures, failure signatures $v_j(f_k)$ create its other columns. For example, if for failure f_1 four symptoms are observed and the occurrence of this failure requires the appearance of all symptoms, then the signature is:

$$v_1(f_1) = (s_1, s_2, s_3, s_4) . \tag{5}$$

However, if the symptoms s_1, s_2 and s_3 need to take place and s_4 should not occur, then:

$$v_1(f_1) = (s_1, s_2, s_3, \overline{s}_4) . \tag{6}$$

The diagnostic processes may be burdened with uncertainty resulting from e.g. diagnostic signal interference, errors in assessing value threshold in decision algorithms or lack of precision of models of the diagnosed objects. It then becomes intentional to use the probability diagnostic matrix (PDM). On the basis of a binary diagnostic matrix (BDM) one can create a probability diagnostic matrix, which elements are conditional probabilities $P(f_k|s_j)$ of failure occurrence f_k with the observed symptom s_j (Fig. 3).

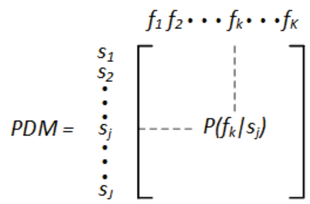

Fig. 3 Probability diagnostic matrix

Then, for assessing probabilities values Bayes' theorem can be used [2, 8, 16]:

$$P(f_k \mid s_j) = \frac{P(f_k) P(s_j \mid f_k)}{\sum_{i=1}^{K} P(f_i) P(s_i \mid f)_i} , \tag{7}$$

where K – number of failures.

3. Axle Counting Systems

Railway traffic needs to be managed in such a way as to ensure a safe distance between trains. Thus, it is necessary to get information about the trains' location. For this purpose, track occupancy control systems are used, which transmit train position information to the railway traffic control systems [1, 3, 14, 18]. They are based on a variety of control methods, the most modern of which use wheel detection points and are called axle counters [5, 15, 20, 23-25]. The task of axle counters is to state that a chosen track fragment (section) is unoccupied, basing on the axle balance of the railway rolling stock that is on the track. If the axle balance, meaning the result of deducting axles entering and leaving a given section, equals zero, the counter passes on information about an unoccupied section. If there is at least one axle of a railway vehicle or a failure has occurred, the system states a given section is occupied. Wheel sensors detect the direction of the rolling stock, which is important to count properly axles crossing the sensor in two directions (Fig. 4).

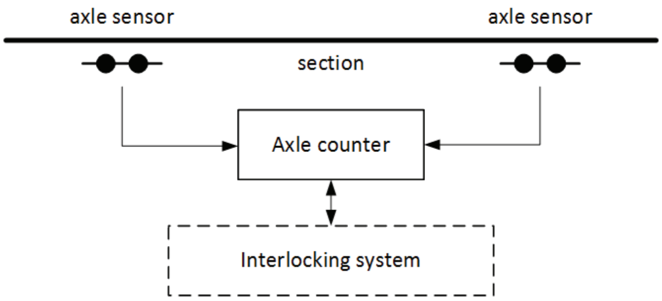

Fig. 4 Basic elements of axle counting system

Hardware faults may cause the section to be indicated occupied if the vehicle is not in the section. We are talking about the so-called apparent occupancy, which forces the operator to reset the track section and wait for the vehicle to pass through the section. As a result of a correct passage of rolling stock, which is carried out at a safe speed, the axles in the section are balanced. It should be pointed out, however, that the axle counting system should not allow sections to be zeroed in the event of permanent damage to the equipment. It should, therefore, generate reliable diagnostic information.

4. Verification of the Method

In the case of the analysed axle counting system, the study has been conducted for wheel sensors and counting cards, which failures may greatly reduce security level. The following failures have been adopted:

- f_1 - failure of the counter module;
- f_2 – the presence of a wheel above the sensor;
- f_3 - failure of the connection cable;
- f_4 - section seizure sequence error;
- f_5 - incorrectly adjusted wheel sensor;
- f_6 - incorrectly connected wheel sensor.

At the same time, the following symptoms were assumed:

- s_1 - incorrectness of occurrence of "sys" signal changes;
- s_2 - simultaneity of "sysA" and "sysB" signals;
- s_3 - no correlation between the "sysA" and "sysB" signals;
- s_4 - too long a "sysB" signal;
- s_5 - incorrect detection of vehicle presence by the wheel sensor;
- s_6 - too long a "sysA" signal;
- s_7 - pulsating "sys" signals;
- s_8 - error balance axle count for the section.

A technical analysis of an axle counting system, including removing symptom combinations that are not related to the occurrence of failures, allowed a final match of signatures and failures (Table):

In the case of most signatures we can clearly indicate the type of failure. Only for the signatures: $v_8 = \left(\bar{s}_1, \bar{s}_2, \bar{s}_3, s_4, \bar{s}_5, \bar{s}_6, \bar{s}_7, \bar{s}_8\right)$, $v_{17} = \left(\bar{s}_1, \bar{s}_2, \bar{s}_3, \bar{s}_4, \bar{s}_5, s_6, \bar{s}_7, \bar{s}_8\right)$ and $v_{25} = \left(\bar{s}_1, \bar{s}_2, \bar{s}_3, s_4, \bar{s}_5, s_6, \bar{s}_7, \bar{s}_8\right)$ we do not have such certainty, because there may be a failure: f_1, f_2 or f_3. However, we can, using the Bayes formula, calculate the probability of occurrence of each of these failures. In the analyzed case for these signatures the most probable is the occurrence of failure f_2.

Table

The final match of signatures and failures

	f_1	f_1	f_1	f_1	f_1	f_1	f_1	$f_1 \vee f_2 \vee f_3$	f_1	f_1	f_1	f_1	f_1	f_1	f_1	f_4	$f_1 \vee f_2 \vee f_3$
s_1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
s_2	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
s_3	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
s_4	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
s_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
s_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
s_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
s_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}	v_{13}	v_{14}	v_{15}	v_{16}	v_{17}

	f_1	f_1	f_1	f_1	f_1	f_1	f_1	$f_1 \vee f_2 \vee f_3$	f_1	f_1	f_1	f_1	f_1	f_1	f_1	f_6	f_5
s_1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	0
s_2	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
s_3	0	0	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0
s_4	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0
s_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
s_6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
s_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
s_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	v_{18}	v_{19}	v_{20}	v_{21}	v_{22}	v_{23}	v_{24}	v_{25}	v_{26}	v_{27}	v_{28}	v_{29}	v_{30}	v_{31}	v_{32}	v_{33}	v_{34}

5. Conclusions

The safety of railway traffic control systems is related to the notion of operation in a broad sense that takes into account a possibility of systems being in two operating conditions, including the inoperative status. The occurrence of failures requires maintenance of a technical object, which means restoring it to full operational status. This process is related to checking the system's condition, which belongs to technical diagnosis tasks, being an indispensable element of the operational process. The identification of a technical object's condition is accomplished, among others, with the help of models based on binary and probability diagnostic matrices. The authors of the article have presented results of research concerning diagnosing axle counting systems that are very crucial systems for keeping the safety of the railway traffic. Achieving positive results allows to state that this method can be used in the failure diagnosis of other railway traffic control systems so that they can ensure a necessary safety level.

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MS Temporary Bridge Damage at Chrastava

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Abstract

The paper deals about the operation of Czech Army Engineer Corps in the year 2010. The aim of this operation was to construct a temporary bridge after the flood. During this operation was constructed many bridges MS type. University of Defence designed project of the bridges and 15 Engineer Brigade built them. The paper describes and analyses the cause and damages on the temporary bridge at Chrastava, which have broken down after 11 months on service.
KEY WORDS: *Steel construction, FEM analysis, Temporary bridges, MS bridge type*

1. Introduction

The region of north Czech was affected by floods in August 2010 and there were damaged bridges mainly in Liberec and Ústí nad Labem region. The Corps of Engineer was deployed to restore transport infrastructure after declaring a state of emergency [1]. The Mandate for using Engineer Troops was up to 30th of September 2010.

Fig. 1 Car crane AD 28 load test

2. Replacement of the Damaged Bridge

The Corps of Engineer built the bridge from Bridge layer vehicle AM-50 for the first time. This type of bridge is only for military traffic. The crossing of civilian vehicles was tolerated after the request of the Chrastava mayor.

There was the intensive movement of trucks over the AM-50 type bridge. The engineer experts from the University of Defence came up with TMS temporary bridge design because of higher load classification. Construction of the bridge sets TMS was planned in the second half of September. The local authorities did not agree with this solution and asked to build a bridge for crossing school buses up to 1st September 2010. Then experts from the University of Defence prepare the design of MS bridge type, but this type is for maximum axe load – 10,3 t. The movement of pedestrians is prohibited over MS bridge type. The local authorities did not agree with this solution and requested the movement of pedestrians. Therefore the strip of concrete slabs was laid on the deck that defines the movement of vehicles, so as not to endanger pedestrians [2]. The local authorities promised that the City police would monitor compliance with restrictions on the bridge. After construction of MS bridge type was realized Load test by using car crane (Fig. 1) and then the commander of the construct unit inspected of the bridge construction. The bridge was put into use on 25th August 2010.

The bridge had been fitted with road signs prohibiting entry of vehicles with axle loads of over 10 t. (Fig. 2). Routine inspection of the bridge with an interval of one month was ordered by project documentation. Inspection range was specified this way: During inspections of temporary steel MS bridge type is particularly necessary to monitor [3]:

- tighten all pins and bolts and locking pins;
- apparent deformation of MS parts caused by traffic, including construction joints;

- presence of cracks for welded parts in the ends of the weld and the fillet contacts;
- position of construction on grillage, substrate condition, uniformity settlement of ramps;
- pillar: lateral slope across the bridge, tightness of nuts and buckling;
- excessive vibration, deflection, vibration and construction lifting of bearings;
- condition of the paint and possible corrosion in places difficult to reach a corrosion-prone;
- pollution state of the bridge deck (road) and the surface of curbs and guardrails and
- state of any declines of the lower structure.

It is compulsory for local authorities to ensure the repair for found significant defects immediately.

24.8.2010 18.7.2011

Fig. 2 The bridge was allowed entry of vehicles carrying capacity per axle 10 t.

3. Temporary Bridges Accident Description

The breach of the bridge deck was caused by the trailer truck on Saturday evening 16th July 2011. The truck were extricated and continued their journey. The actual weight of the load and the axes was not found. The extraordinary inspection of the bridge structure was made on 18th July 2011 with a conclusion - disrepair. The basic type of damage was a separation between the bridge deck and the stringers (Figs. 3-5).

Fig. 3 Start disorders - separation in the weld

Fig. 4 The development of cracks in the stringers

Fig. 5 The development of cracks continued to rupture the stringers

It was found that 450 trucks run over the temporary bridge every week. It is obvious that more then 20 000 trucks run over the bridge for 46 weeks (from 25th September 2010 to 16th July 2011). If only half of the vehicles run over the bridge with higher axle loads than 10 t – the temporary bridge was at least 10,000 times overloaded.

The periodic overloading of the bridge indicated stringers lateral buckling deformation (Fig. 6).

Fig. 6 Stringers lateral buckling

4. Model MS Structure Behavior under Eccentric Load

The simulation was carried on an accurate 3D geometric model of the bridge deck grate of the middle part of the MS bridge by ANSYS 14.5 software. The model was created by Autodesk Inventor software (Fig. 7).

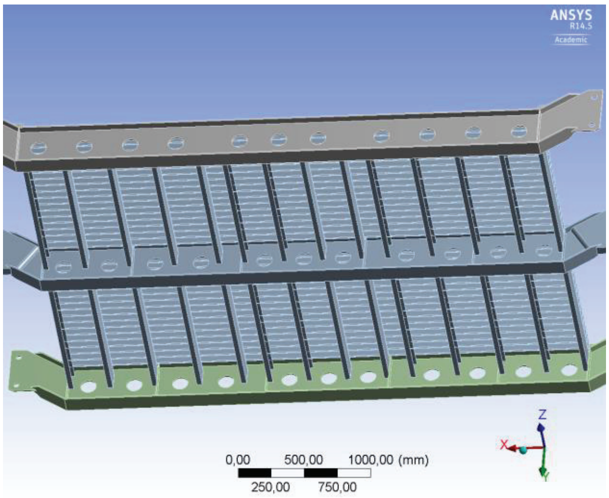

Fig. 7 Model for the assessment (transoms, stringers and bridge deck)

The simulation was carried out for 10 t axle load (without coefficients), geometry was considered according to EN 1991-2 Traffic loads on bridges. The calculation was made as linear. It means that the results can be multiplied by any combination of coefficients (dynamic load, material ...).

The whole assembly of the bridge grate was created by using volume elements of type tetrahedron, the total number of elements was 3.084 million and the total number of degrees of freedom 17.9 million. Contacts between the bridge deck and the transom and stringers were bonded type - it behaves as a weld. The calculation was carried out on a workstation HP Z800 and took about 40 minutes.

There are the most critical values of deflections and stresses are in Figs. 8-11.

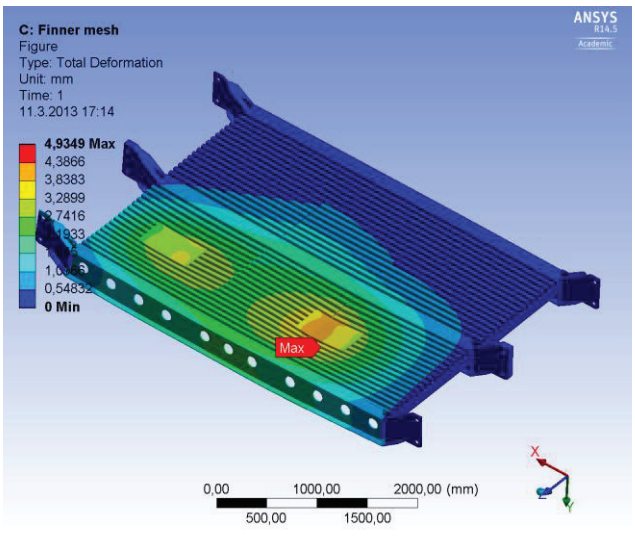

Fig. 8 Total deformation – max = 4,9 mm

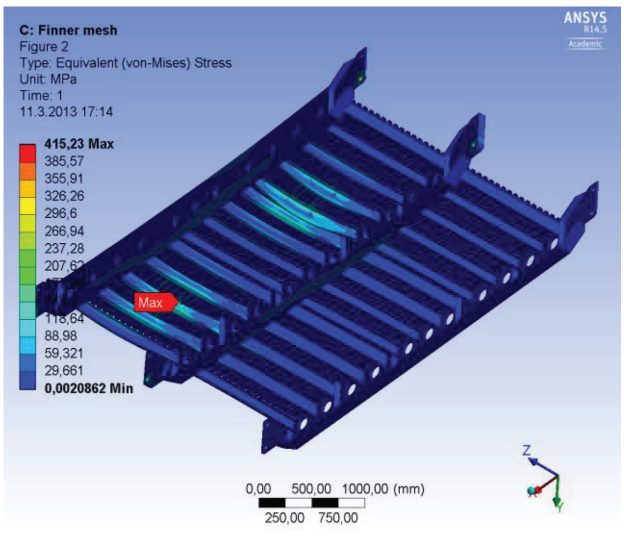

Fig. 9 Equivalent Stress - max = 415 MPa weld bridge deck – stringers

Based on these results it can be stated that for 10 tons of axle load the bridge deck can carry the load without any problems. The problem can cause the weld between the bridge deck and the stringers, which is a stress concentrator and in terms of fatigue behavior is inappropriate. On the other side bridge deck bound up firmly with the stringers helps to increase the stiffness of the deck grate and provides distributing stress from pressure on the wheel more runners and also prevent lateral buckling.

The placement of the pavement on the bridge deck does not have a significant influence on the stringer's stress. wheel pressure of Vehicles traveling along the pavement is distributed at least two stringers that are in that place even closer together to better transferred load from the bridge deck.

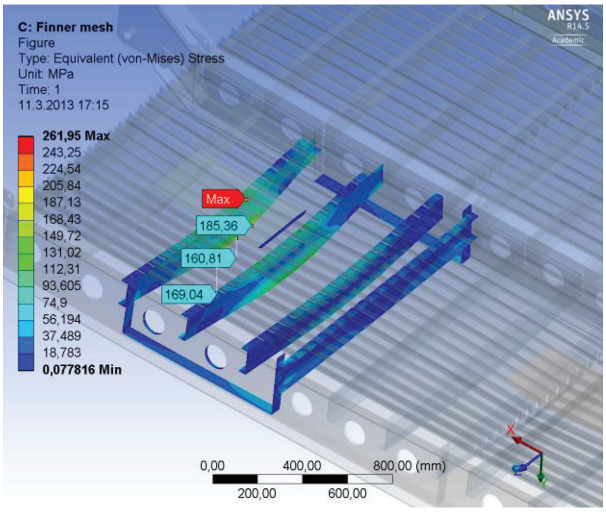

Fig. 10 Detail of stress on the lower flange of stringers – max = 185 MPa

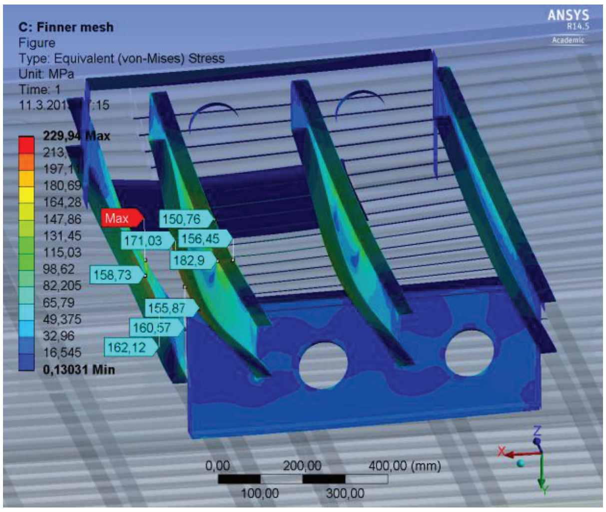

Fig. 11 Detail of stress on stringers next to the pavement – max = 170 MPa

5. Conclusion

The damage of the temporary bridge at Chrastava was due to periodic and long-term overloading of the bridge construction by at least 20% (at 12 tons axle load) but also possibly by up to 40% (at 14 tons axle load). This overloading initiated fatigue cracking in the weld between bridge deck and stringers. Crack spread led finally to the complete disruption of stringers in several places.

Placement of pavement on construction cannot be considered the cause of the damage. The damage would appear just maybe a little later, because the main reason of damage was overloaded construction.

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Investigation of the Operation of the Railway Track with Reinforced Concrete Sleepers in Curved Sections with Radius R ≤ 350 m

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Abstract

The article presents the results of the research on polygon extension for laying reinforced concrete sleepers under difficult conditions (R≤350 m, mountainous terrain) with ensuring safety traffic and reliable operation of the railway track. Changes in the geometry of the track in the plane with wooden sleepers and Д0 fastener as well as reinforced concrete sleepers with СКД65-Б fastener in the curve with the radius of 350 m were investigated. The results of the research allowed to obtain:

- method and algorithm for determining the tapping section of the track gauge extension on reinforced concrete sleepers in curves with radius R ≤ 350 m;
- comparative assessment of the track gauge change with the use of Д0 fastener (wooden sleepers) and СКД65-Б fastener (reinforced concrete sleepers) in curves with a radius R ≤ 350 m;
- factors impact on the track gauge extension under difficult operating conditions;
- empirical dependence of the process of the track gauge width change and the frequency of its adjustment in the cases of СКД65-Б fastener (reinforced concrete sleepers) and Д0 fastener (wooden sleepers) use in curves with radius R ≤ 350 m;
- conclusions on the probability and feasibility of concrete sleepers use under mountainous terrain conditions, including difficult operating conditions (R ≤ 350 m).

KEY WORDS: *railway track, rail fastener, rail track width, rail track hold in the plane*

1. Introduction

The train speed increase and axial loading require the increase of the railway track strength and stability. The possibility of further implementation of this approach depends significantly on the reliable operation of the elements of the railway track. It should be noted that, from the point of view of reliability, the most unpredictable and difficult for operation and maintenance is the railway track located in the mountains, including difficult operating conditions (R≤350 m). One of the important problems in maintaining such curves is the considerable length of track sections with wooden sleepers, which depends on a large percentage of curves with a radius of 350 ÷ 200 m. Such railway track is less reliable in curved sections than the railway track with reinforced concrete sleepers.

At the initial stages of operation, the track on wooden sleepers has small rigidity, which provides spatial elasticity of the elements of the upper track structure (hereinafter UTS) with simultaneous taking over both vertical and horizontal dynamic forces from the rolling stock. Despite its advantages, the railway track with wooden sleepers has a number of disadvantages that make it economically unprofitable for the use. In case of the increased train load on the track 75…130 kN in the horizontal plane, which is typical for curved sections of the track with R ≤ 350 m, frequent disorders of the track geometry in the plane take place [1-2]. In the track with wooden sleepers the main work is track levelling in the plane, as disorders shorten the life of wooden sleepers almost twice [3-4]. Due to mechanical damage, wooden sleepers in curves do not have time to rot and are removed from the track after about 5-7 years, which is 5 times less than the service life of concrete sleepers [3, 5-12]. Even today, wooden sleepers are in short supply, very expensive, and according to the scientists' research of Dnipro National University of Railway Transport (hereinafter referred to as DNURT), the cost for track maintenance with wooden sleepers increases by 25-31.5% [13].

Based on the above problem of railway track operation on wooden sleepers in curved sections with radius R ≤ 350 m, it is necessary to:

– to develop recommendations on the use of reinforced concrete sleepers in curved sections R ≤ 350 m with reliable retention of track gauge geometry in the plane;

– to develop the method of track geometry retention on reinforced concrete sleepers in the plane for curves with radii less than 350 m. The results of the researches will allow to substantiate more detailly the work of the railway track in the mountains, including difficult operating conditions.

2. Methodology and Algorithm for Section Determining of the Track Extension Tapping on Reinforced Concrete Sleepers in Curves with Radius R ≤ 350 m

Before assembling the rail-sleeper grid (hereinafter RSG), measurements are made to establish a clear position for the beginning and the end of the transition curve [14]. The next step is to determine where the track extends from the track width in the straight line (S_S) to the track width in the circular curve (S_{CK}). The scheme of tapping the track gauge extension within the transition curve by means of fastening is shown in Fig. 1.

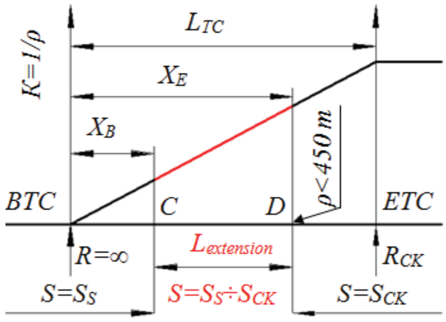

Fig. 1 The scheme of the position of track extension tapping in the transition curve

Symbols: BTC, ETC – respectively, the beginning and the end of the transition curve; X_B, X_E - respectively, the beginning and the end of the section of track extension tapping; S_S - track width in a straight section; S_{CK} - track width in a circular curve; L_{TC}, $L_{extension}$ - respectively, the length of the transition curve and the section of track extension tapping.

The end of the extension tapping is determined by the formula:

$$X_E = \frac{R_{CK} \cdot L_{TC}}{\rho}, \tag{1}$$

here R_{CK} - radius of a circular curve; L_{TC} - length of a transition curve; ρ - radius from which the track width begins in a circular curve.

The beginning of the extension tapping is determined by the formula:

$$X_B = X_E - k \cdot b, \tag{2}$$

here b - is the distance between adjacent sleepers, m, which depends on the number of sleepers per 1 km of the railway track; k - the number of sleepers in the section of track extension tapping.

Extension tapping is made in the section where k sleeper is laid. Thus, up to point *C*, which is situated at the distance X_B from the beginning of the transition curve, the width standard of the track is equal to the track width for straight sections ($S = S_S$). In section CD the smooth track widening is performed from the track width on the straight line to track width on the circular curve ($S = S_S \div S_{CK}$). From point *D* onwards on the transition and circular curves, the track gauge is S_{CK} (the standard gauge width for a particular curve). This technique is versatile because it can be used for different track gauge widths in both straight and curved sections.

3. Ground Tests of Track Gauge Width Changes on Wooden and Reinforced Concrete Sleepers in Curves with Radius of 350 m

The conducted researches were based on the comparative estimation of dynamics influence of track gauge change on wooden sleepers with Д0 fastening and reinforced concrete sleepers with СКД65-Б fastening in curved sections of the track with radius 350 m.

At present, with the appearance of СКД65-Б fastener [15-16], it is possible to use reinforced concrete sleepers in curved sections of the track of any radius without changing the construction of the reinforced concrete sleepers. The use of reinforced concrete sleepers and СКД65-Б fastener (Figs. 2-3) allows to avoid many problems arising in the railway track on wooden sleepers. СКД65-Б fastener can shape the track geometry in a curve section, namely, gradually extend the track from 0 mm to 14 mm, and narrow from 0 mm to 28 mm. This allows adjusting the track width within 1 mm when the rails are worn during operation. The principle of СКД65-Б fastener operation is based on the technique of smooth tapping the track gauge extension within the transition curve applying adjusting cards (see Fig. 1).

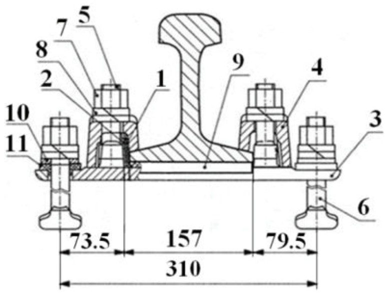

Fig. 2 СКД65-Б fastener structure

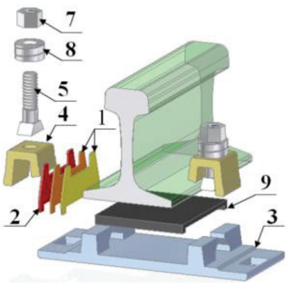

Fig. 3 3D-scheme of СКД65-Б fastener knot

Figs. 1-2 show: *1* – adjusting cards of 2 mm thick; *2* – adjusting card of 3 mm thick; *3* – metal lining; *4* terminals (2 pcs); *5* – bolts (2 pcs); *6* – bolts (2 pcs); *7* – nuts (4 pcs); *8* – double-thread washer (4 pcs); *9* – gasket; *10* –flat washer (2 pcs); *11* – insulating sleeve (2pcs).

Two curved sections of the track with 350 m radius of curves were selected. In one section, RSG was laid on wooden sleepers with Д0 fastener, and in the other section, RSG was laid on reinforced concrete sleepers with СКД65-Б fastener. Track gauge measurements have been performed from the time of the two RSGs laying for five months, every 10 m along the entire length of the curve. The average values of the track width change in two track sections with fasteners Д0 and СКД65-Б for five months of operation are shown in Figs. 4-5.

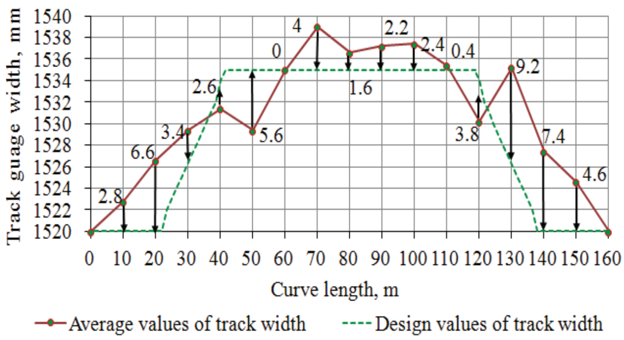

Fig. 4 Track gauge change on wooden sleepers with Д0 fastener for five months

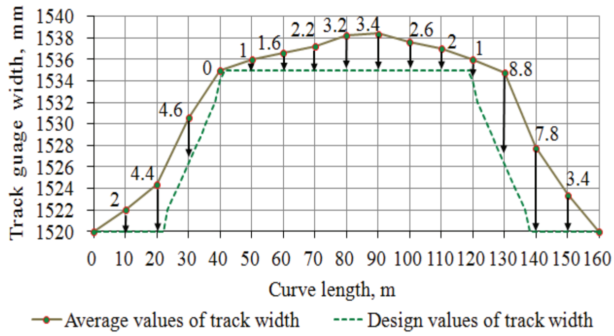

Fig. 5 Track gauge change on reinforced concrete sleepers with СКД65-Б fastener for five months

The results of observations for the track gauge width change in track sections with Д0 and СКД65-Б fasteners, depending on the time parameter, presented as a pair of coordinates « x » and « y », were approximated. The law of the track gauge width change on wooden and reinforced concrete sleepers in a curve of 350 m radius can be described by the function:

$$y = ax + b\,, \tag{3}$$

where a , b - constant parameters.

The function parameters (3), according to smallest squares [17], can be described with the following system of equations:

$$\begin{cases} a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} x_i y_i\,, \\ a\sum_{i=1}^{n} x_i + nb = \sum_{i=1}^{n} y_i \end{cases}, \tag{4}$$

where x_i , y_i - measured coordinates of any i -point; n - number of points with measured coordinates.

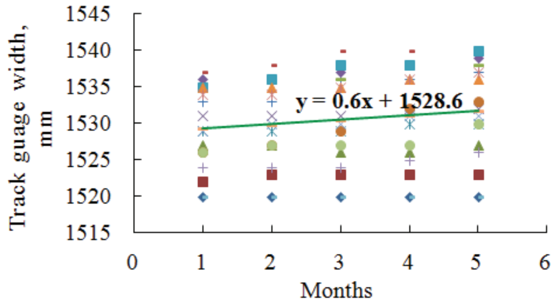

Fig. 6 Approximation of the change in the track gauge width on wooden sleepers for five months

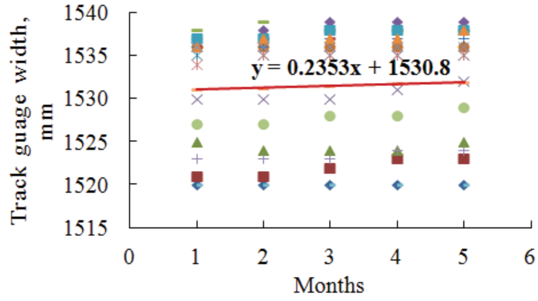

Fig. 7 Approximation of the change in the track gauge width on reinforced concrete sleepers for five months

According to the results of approximation by method [17] in Figs. 6 and 7, it can be seen that the change in the track gauge width with fasteners Д0 and СКД65-Б is linear.

4. Variance Analysis of the Factors Influence on the Change of the Track Gauge Width on Wooden and Reinforced Concrete Sleepers

During measurements in each section, additional factors were investigated, which probable appearance could affect the change in the track gauge width. In the case of RSG with wooden sleepers, the influence of the factors of lateral wear of the outer rail line and the nominal angle of rail inclination loss were observed, caused by the indentation of the metal lining into the body of the wooden sleeper. In the case of RSGs with reinforced concrete sleepers, there was mainly the change in the track width conditioned by the intense lateral wear of the outer rail line. This is due to the increased train load (75… 130 kN) on the track in the horizontal plane, which is typical for curved sections of the track R ≤ 350 m [1, 18].

For a visual representation of the factors of lateral wear of the head of the outer rail line and the nominal angle of rail inclination loss on wooden sleepers, the diagrams of mean values of the track gauge width change were constructed, depending on the influence of these factors (Figs. 8-9).

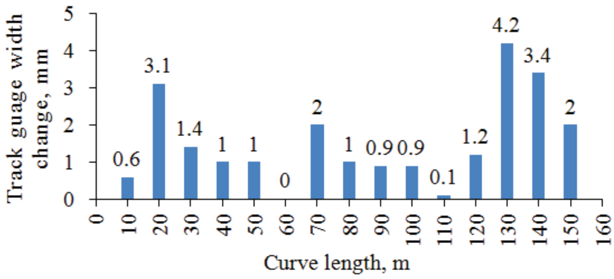

Fig. 8 Lateral wear influence on the track gauge width change

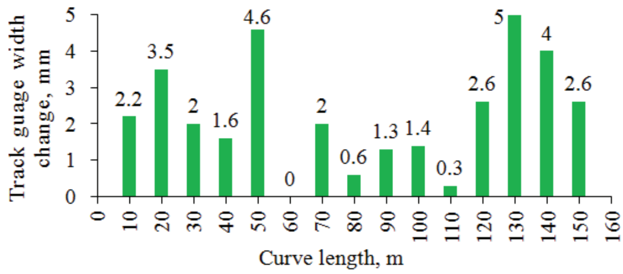

Fig. 9 Influence of the nominal angle of rail inclination loss on the track gauge width change

According to these diagrams (Fig. 8-9) it can be clearly seen that the influence of the nominal angle of rail inclination loss at each point of measurement of the track gauge width shows a much greater value than the lateral wear of the rail head. In the study of the influence of the nominal angle of rail inclination loss and the lateral wear of the rail head on the change of the track gauge width in a curve with radius of 350 m, all observations are presented in the form of a matrix [17].

The arithmetical mean of the entire set of observations:

$$\overline{X} = \frac{1}{n}\sum_{j=1}^{p}\sum_{i=1}^{q_j} X_{ij}, \tag{5}$$

where j - is the factor level number; p - number of factor levels; i - observation number; q_j - number of observations for j factor level; X_{ij} - meaning of the investigated value; n - total number of observations:

$$n = \sum_{j=1}^{p} q_j. \tag{6}$$

Arithmetical mean of the observation of j level:

$$\overline{X_j} = \frac{1}{q_j}\sum_{i=1}^{q_j} X_{ij}. \tag{7}$$

Factor scattering, i.e. the scattering of meanings of the observed value caused by the change in the factor level, is determined by the formula:

$$Q_f = \sum_{j=1}^{p}\left[q_j\left(\overline{X} - \overline{X_j}\right)^2\right]. \tag{8}$$

Residual scattering is the scattering due to unaccounted factors, characterizes differences in observations for one level:

$$Q_r = \sum_{j=1}^{p} Q_{rj}\,; \tag{9}$$

$$Q_{rj} = \sum_{i=1}^{q_i}\left(\overline{X_j} - X_{ij}\right)^2. \tag{10}$$

As a control for calculations performance, the general scattering acts:

$$Q = Q_f + Q_r. \tag{11}$$

Factorial and residual variance are:

$$\sigma_f = \frac{Q_f}{k_1}\,; \tag{12}$$

$$\sigma_r = \frac{Q_r}{k_2}, \tag{13}$$

where k_1, k_2 - degrees of freedom:

$$k_1 = p - 1\,; \tag{14}$$

$$k_2 = n - p. \tag{15}$$

The assessment of the degree of the studied factor influence on the observed value is a criterion *F*, which is determined from the expression:

$$F = \frac{\sigma_f}{\sigma_r}. \tag{16}$$

The greater the value of the criterion F, the stronger the influence of the investigated factor. According to the level of significance α [17] and degrees of freedom k_1 and k_2 there is such a critical value $F_{critical} = f\left(\alpha, k_1, k_2\right)$ that, under the condition $F < F_{critical}$, the investigated factor does not affect the observed value at all [19].

The results of the variance analysis on the influence of factors (rail inclination loss and lateral wear of the rail head) on the change of track gauge width on wooden sleepers are shown in the form of a table (Table).

Comparing obtained values of criteria with critical ones (Table), it can be seen that the influence of factors of the rail inclination loss and the lateral wear of the rail head significantly affects the track gauge width in a curve with the radius of 350 m with wooden sleepers.

According to the regulatory documents of the Ukrainian railways [20], the track width standard in circular curves with radii from 200 m to 450 m is 1535 mm. At the same time, in the presence of lateral wear of rail heads in the curves, the magnitude of deviation in the extension that needs elimination can be increased for the amount of actual wear of the inner face of the rail head of the outer line. At the same time, the width of the track gauge at curves with radii less than 650 m should not exceed 1545 mm. Assuming that the track gauge will change before its adjustment as well, using functions simultaneously (see Figs. 1-2), obtained by approximation, one can predict the time when the following track gauge adjustments will be required for wooden sleepers and reinforced concrete sleepers.

Table

Factors influence on the change of rail gauge width on wooden sleepers in a curve of radius 350 m

Parameters	Rail inclination loss					Lateral wear of a rail head			
$\overline{X}$	2,71					2,41			
$\overline{X}_j$	0,18	1,75	2,6	4,033	5	0,55	1,65	3,25	4,2
q_j	5	6	2	3	1	10	4	2	1
Q_f	48,122					78,633			
$Q_{r\,j}$	0,288	0,675	0	0,607	0	1,965	0,51	0,045	0
Q_r	1,570					2,520			
k_1	4					3			
k_2	12					13			
σ_f	12,031					13,871			
σ_r	0,131					0,194			
F	**91,973**					**71,556**			
$F_{critical}$	3,26					3,415			

In order not to penalize this curve after the track measurement car, the track width is made to correspond to the second degree of indentation [21], i.e. the track width of a circular curve along the entire length is 1543 mm, both on wooden and concrete sleepers. Taking this into account, a frequency graph of the track gauge adjustment in a curve of radius 350 m for wooden sleepers and reinforced concrete sleepers is presented in a visual form (Fig. 10).

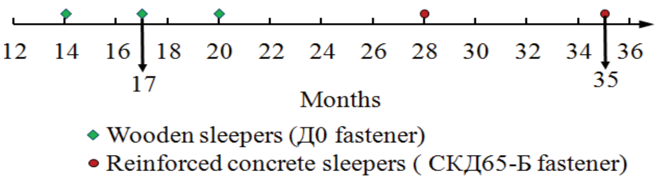

Fig. 10 Frequency of a track width adjustment in a curve of 350 m with wooden and reinforced concrete sleepers

According to the data (Fig. 10), it is established that after the first adjustment of the track width in a curve with wooden sleepers, the next adjustment is made every 3 months, and in a curve with concrete sleepers the adjustment is made every 7 months. The frequent cases of track gauge width adjustment on wooden sleepers can be clearly explained by studies [7, 9]. After the third track gauge adjustment with wooden sleepers, the holes for spike fastening (fastener Д0) have already been worked out, which practically makes it impossible to press the rail to the sub-base tightly. Taking into account the above studies, it is established that with the appearance of СКД65-Б fastener, it becomes possible to increase the range of reinforced concrete sleepers use in the mountains, including difficult operating conditions significantly. According to studies [5, 12, 22], this is the way to create a seamless structure in curves with radii of 350-200 m, as well as a reliable provision of railway transit services for Ukraine-European Union [23] with further use of the newest and perspective rail fasteners [24].

5. Conclusions

The method and algorithm for determining the tapping section for the track gauge extension on reinforced concrete sleepers in curves with radii less than 350 m are developed. This technique is versatile because it can determine the tapping section for the track gauge extension for transient curves of different radii and length when passing from a straight section to a curve. This makes it possible to use reinforced concrete sleepers in curves with radii less than 350 m, with an ordinary scheme of laying for straight sections. At the same time, this technique can be used for European standards of retaining the track geometry in the plane.

DNURT has developed the design of СКД65-Б rail fastener. This allows adjusting the track gauge width in a curve section, namely, gradually extend the track gauge from 0 mm to 14 mm, and to narrow it from 0 mm to 28 mm. This allows us to adjust the track width with accuracy up to 1 mm when the rails are worn during operation. The principle of the structure operation of СКД65-Б fastener is based on the above-described method of gradual tapping of rail track extension within the transition curve. This will reduce the operational cost of this track structure maintenance in comparison with the existing tracks on wooden sleepers in curved sections of a small radius ($R \leq 350$ m).

Studies have been carried out, on the basis of which the comparative assessment of the impact of the track gauge change with the use of Д0 fastener (wooden sleepers) and СКД65-Б fastener (reinforced concrete sleepers) was

performed. Two curved sections of the track with the same load capacity and radii of curves of 350 m were selected. On one section, the RSG on wooden sleepers with Д0 fastener was laid, on the other section, RSG on reinforced concrete sleepers with СКД65-Б fastener was laid.

The empirical dependence of the process of changing the track gauge width is presented, as well as the periodicity of its adjustment on reinforced concrete sleepers and wooden sleepers in a curve with a radius of 350 m. It is established that the track gauge width adjustment on wooden sleepers is made every 3 months, and in a curve with concrete sleepers' adjustment is performed every 7 months. The main factor influencing the intensive track extension on wooden sleepers is the rail inclination loss, which value in each of the track gauge measurement points is much greater than the value of the rail head lateral wear. As for the curve with a radius of 350 m on reinforced concrete sleepers concerned, the track width changes due to lateral wear of the outer rail line, which can be promptly corrected using the above mentioned СКД65-Б fastener.

Based on the above work and obtained results, it is possible to increase the range of reinforced concrete sleepers use in the mountains significantly, including difficult operating conditions. This is the way to create a seamless structure in curves with radii of 350 ÷ 200 m, ensuring the reliable operation of the railway track and the safety of train traffic.

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