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PREFACE

26th international scientific conference TRANSPORT MEANS 2022 was organized as a virtual event on 05-07 October, 2022. 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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Prof. V. Ostaševičius

Proceedings of 26th International Scientific Conference. Transport Means 2022.

Issues of Administrative Processing of Road Offences Detected by Weigh-in-Motion High-Speed Automatic System and Suggestions to Rationalising of this Administration

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Abstract

The paper is focused on administrative processing of road offences detected by the weigh-in-motion high-speed automatic (HS-WIM) system. The aim of the paper is to suggest steps rationalizing technological process of this administration. The software tool of Microsoft Project is applied in the methodological point of view. The suggestions have been evaluated by using of data from the municipal authority of Říčany u Prahy as the locality with heavy traffic in Prague agglomeration. Time of administration of an offence is possible to be reduced by about 30% by applying of these suggestions. This is possible to be applied for rationalization of work at authorities responsible for road offences.

KEY WORDS: *detection of offences; high-speed weigh-in-motion; road offences; technological process of administrative processing of road offences*

1. Introduction

Maximum permitted dimensions (height, width, length) of road vehicles, special vehicles and their car sets are defined by legal regulation of the European Union as well as of the Czech Republic. Maximum weight of vehicle and maximum weight per axle (drive as well as driven) are also limited. These limits are defined regarding parameters of roads, traffic constructions (bridges, underpasses, tunnels, railway crossings etc.) as well as regarding traffic safety.

The limits for dimensions and maximum weights of vehicles are defined by the Council Directive 96/53/EC of 25 July 1996 laying down for certain road vehicles circulating within the Community the maximum authorized dimensions in national and international traffic and the maximum authorized weights in international traffic in current consolidated version [1]. This directive is valid for vehicle categories of M2, M3 (buses) and for their trailer vehicles (category of O). It is valid also for categories of N2, N3 and their trailer vehicles (trailer, semitrailer) of O3, O4 categories.

Dimension and operating weight limits for the vehicles of the category Le (marked as L in the Czech Republic) are defined by the Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles in current consolidated version [2].

Selected parameters based in the Council Directive 96/53/EC and in the Regulation (EU) No 168/2013 of the European Parliament and of the Council are transposed in the Decree No. 209/2018 Coll. of the Ministry of Transport in the Czech Republic in current consolidated version. This decree is focused on weights, dimensions, and connectivity of vehicles [3]. The possibilities to define some limits for vehicles in different way from the Directive 96/53/EC and the Regulation (EU) No 168/2013 are applied in this decree. Some exceptions for domestic operation are defined in this way. Dimensions and weight for other vehicles and their car sets are also defined by the Decree No. 209/2018 Coll. (e.g., for tractors and tractor trailers).

The problem is that carriers and drivers do not respect defined limits and overloading of vehicles and car sets occurs. It occurs often by mass substrate transportation (e.g., sand, clay, gravel). Traffic safety is threated by this. Roads and objects – first, bridges and overpasses are damaged by this as well. Check weighing of vehicles has been introduced by selected categories of vehicles due to such reasons.

Check weighing of vehicles is regulated by the § 38a of the Act No. 13/1997 Coll. for roads in current consolidated version [4] in the Czech Republic. It is carried out on highways, roads as well as local roads. Vehicles belonging to the categories of M2, M3, N, T, C, O, R, S, SS and the sets of these vehicles are weighed. Specification of these categories is based on Regulation (EU) 2018/858 of the European Parliament and of the Council of 30 May 2018 on the approval and market surveillance of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles, amending Regulations (EC) No 715/2007 and (EC) No 595/2009 and repealing Directive 2007/46/EC in current consolidated version [5] in the European Union. There are more detailed local specifications are based on the Appendix 2 of the Decree 341/2014 Coll. for approving of technical compliance and about technical conditions for operation of vehicles on the roads in current consolidated version [6] in the Czech

Republic. Maximum limits for dimensions, weights of vehicles and car sets are defined in the Decree No. 209/2018 Coll. for weights, dimension, and connectivity of vehicles in current consolidated version [3].

Check weighing of vehicles is divided into low-speed, high-speed and combined. This paper is focused on weigh-in-motion high-speed automatic (HS-WIM) system and on road offences related to exceeding of defined limits.

2. High-Speed Check Weighing of Vehicles

High-speed check weighing of vehicles, known also as weigh-in-motion high-speed automatic (HS-WIM) system, is carried out for ensuring of safety and fluency of road traffic and for protection of roads and objects on roads against damages caused by overloading.

High-speed check weighing (dynamic weighing) is weighing of vehicles by using of high-speed scales without need to detour of vehicles out of the route. These scales are permanently mounted in the road infrastructure. It is so called HS-WIM - weigh-in-motion system allowing weighing with no need to stop the vehicles [7]. The driver is obligated to pass this check weighing. The driver may not change the route deliberately to avoid weighing. The driver may not know that weighing is in progress.

The publications in this field are often focused on technical design of scales as well as of technical process of weighing [8]. Accuracy of weighing is also taking a part [9]. There are discussed statistics about change of traffic flows after building of weighing points in Poland [10]. Drivers go around these points and this system is not as efficient there. Legal and organisational conditions for weighing are discussed very marginally [11]. It is not discussed how to use data obtained by weighing in as complex way as possible. It is not solved how to automate management of documentation in relation to technological processes of enforcement of sanctions for road offences connected with exceeding of defined weight limits. One of proposals, how this topic can be solved, is taking a part of this paper due to this.

2.1. Example of High-Speed Check Weighing

The paper contains a specific example of high-speed check weighing on the second-class road. The owner of this road is the Central Bohemia Region (region surrounding the capital city of Prague). This region had founded the organisation named Regional Administration and Maintenance of Roads of the Central Bohemian Region (Krajská správa a údržba silnic Středočeského kraje, p.o. - KSÚS in abbreviation) in the way of Deed of Foundation. This organisation is responsible also for high-speed weighing, for regular checking of weighing point as well as for regular certification of applied scaling device CrossWIM. The certification is provided by the Czech Metrology Institute (in Czech - Český metrologický institut) and declared by “Confirmation of verification of defined measuring device”, what is valid for 1 year.

Weighing is provided automatically by using sensors built in a road. The outputs are wheel, axle and total values of individual road vehicles or sets of vehicles. Weighing is carried out for each driving lane, for 24 hours per day. The scale is equipped by an infra-detector and illumination for ensuring function also in the case of unsuitable lighting conditions (darkness). Cameras are also incorporated. Registration plates are recorded by a detail camera and vehicles by a surveillance camera. Documented road offences are sent automatically to the KSÚS organisation in an electronic form. These data are processed by trained and authorized persons only there [12]. These people print out “weighing tickets of high-speed check weighing” and send them together with photos of weighed vehicles to the administration of a municipality with extended powers (in Czech - obec s rozšířenou působností, ORP) responsible for processing of these road offences.

2.2. Recording of Road Offences by High-Speed Weighing

Exceeding of limits defined by the Decree No. 209/2018 Coll. of the Ministry of Transport in the Czech Republic in current consolidated version [3] about weights, dimensions and connectivity of vehicles has been recorded by the high-speed weighing system. The KSÚS is obligated to issue the weighing ticket of high-speed check weighing. This obligation is according to the § 38d of the Act No. 13/1997 Coll. for public roads in current consolidated version [4].

Authority of the municipality with extended powers (ORP) will take over the notification from KSÚS consisted of these documents:

- confirmation of verification of defined measuring device;
- authorisation of employees of the Department of the KSÚS to processing of weighing tickets of high-speed check weighing;
- label of measuring device - a producer of applied scale is the company CROSS Zlín a.s.;
- transfer protocol with a list of road vehicles with recorded violating the § 38d of the Act No. 13/1997 Coll., for public roads in current consolidated version [4], including weighing tickets of high-speed check weighing;
- CD-ROM with weighing tickets in electronic form and photos of vehicles is taking a part of the transfer protocol. Nowadays this is gradually replaced by the central data storage (server) accessible to authorities of the municipalities with extended powers (ORP).

The official of the Department of the sectional speed measuring and vehicle weighing at the authority of the municipality with extended powers (ORP) will perform the lustration of vehicle registration plates in the Central register of vehicles and will identify the operator of the vehicle. Following information to the vehicle, trailer or semitrailer are collected:

- vehicle type and manufacturer of the vehicle;
- count of axles;
- value of maximal technically allowed weight per axle;
- wheelbase;
- wheels and tires (including doubled ones).

When data are collected successfully, the official will add them in the software SYDO Traffic PEN. Potential exceeding of defined limits is evaluated by the system. When the offence occurred, the official will make a document about result of high-speed check weighing equipped by data of vehicle operator. This document is also a check that all preconditions for start of administrative processing of a road offence are fulfilled.

Authority of the municipality with extended powers (ORP) will establish file documentation containing:

- road offence notification;
- transfer protocol;
- weighing ticket;
- data from vehicle card, eventually from card of trailer;
- authorisation of authorized persons of the KSÚS for weighing;
- confirmation of verification of defined measuring device;
- document about result of high-speed check weighing.

The offence is then registered into the software for file documentation called ELISA by the official. The system generates proceedings number. The official can decide if the processing should start directly or if additional information (e.g., Decision about special utilization of a road) will be requested from the vehicle operator. It depends on type of vehicle or type of goods conveyed. For example, an exception was valid for transport of wood in the year of 2021. It was due to bark beetle calamity. Exceeding of weight limits defined by the Decree No. 209/2018 Coll. of the Ministry of Transport in the Czech Republic in current consolidated version [3] about weights, dimensions, and connectivity of vehicles was allowed in the way of issued permissions. Vehicle operator was asked to declare this permission to special utilization of road first in the case when transport of wood had been detected. When the vehicle operator proved this, the processing was terminated.

The "order" is issued directly in the case of provable road offences. This order is issued according to the § 90 of the Act No. 250/2016 Coll., about responsibility for offences and for processing of offences in current consolidated version [13]. Vehicle operator is marked as guilty for this road offence according to the provision § 42b paragraph 1 point (u) of the Act. No. 13/1997 Coll., about roads in current consolidated version [4]. It is due to the fact, that the operator operates a vehicle with values exceeding the limits defined by the Decree No. 209/2018 Coll. of the Ministry of Transport in the Czech Republic in current consolidated version [3] about weights, dimensions, and connectivity of vehicles.

Limits for maximal weight of (whole) vehicle as well as maximal weight per axle may not be exceeded as follows from the Decree No. 209/2018 Coll. of the Ministry of Transport in the Czech Republic in current consolidated version [3] about weights, dimensions, and connectivity of vehicles. Both conditions must be fulfilled.

Amount of the fine, due date, the account number and variable symbol used to identify the payment are listed in the "order". This is for traceability. Administrative discretion of the official is impossible in the case of the amount of the fine. The fines are exhaustive according to the provision §43 of the paragraph of the Act No. 13/1997 Coll., about road in current consolidated version [4]. Fine is strictly defined for the offence according to the provision § 42b paragraph 1 point (u) as CZK 9,000 (ca. € 360) for each commenced tone exceeding maximal limit of weight of vehicle of set of vehicles. When the maximal limit for vehicle (of set of vehicles) weight is exceeded about less than 500 kg, the amount of fine is CZK 5,000 (ca. € 200) only. When both limits for individual vehicle weight as well as for weight of set of vehicles are exceeded, the amount of fine is defined according to maximal exceeding.

For example, higher exceeding of the limit is identified by total weight of vehicle about 3,132 kg, it means 4 commenced tonnes. The amount of fine is $4 \cdot 9{,}000$ = CZK 36,000 (ca. € 1,440).

„Call for driver communication" is send to vehicle operator together with the order into the operator's data box or as a recommended letter in own hands (it the operator hasn't a data box). The driver who was driving a vehicle or set of vehicles by high-speed check weighing must be told. Appendix to the number of proceedings related to drier's (driving in the time of offence) identification data is taking a part of this call.

In the case that vehicle operator pleads quilty and pays the fine, the processing is terminated. Income from the fine is divided according to the provision § 43 paragraph 3 of the Act No. 13/1997 Coll., about roads in current consolidated version [4] in following way:

- 40% belongs to the owner of the road on which the weighing was proceeded. It the owner is state, income is dedicated for the State transport infrastructure fund (in Czech - Státní fond dopravní infrastruktury);
- 45% belong to the region, where the weighing was proceeded;
- 15% belongs to the authority processing the road offence.

Vehicle operator has 8 calendar days after delivery for submitting of possible opposition to the authority issuing the „order". If the opposition is submitted in time, the „order" is cancelled. The official, who issued the "order", will continue in processing of this road offence.

Vehicle operator is obligated to communicate, who was driving a vehicle at the time the offence was identified, in 10 days after delivery of the "Call for driver communication". If the operator does not, the official send the "Call for driver communication" once again. The amount of fine can be maximally CZK 50,000 (ca. € 2,000) for the offence to not communicate the driver. In this case the official will conduct 2 proceedings - one with vehicle operator (who submitted an opposition) and the second with specific driver.

Vehicle operator can have an opportunity to access to the documentation file and to suggest adding of evidence according to the Act No. 500/2004 Coll., administrative procedure in current consolidated version [14]. Vehicle operator is appealed by the official to get acquainted with the file in defined time limit of 10 calendar days. In the case that vehicle operator or his attorney will not use this time limit, the decision on the offence will be issued according to the provision § 42b paragraph 1 point (u) of the Act No. 13/1997 Coll., about roads in current consolidated version [4]. It is related to the fact that this vehicle operator operates a vehicle exceeding the limits defined according to a special legal act - the Decree No. 209/2018 Coll. of the Ministry of Transport in the Czech Republic in current consolidated version [3] about weights, dimensions, and connectivity of vehicles. The operator should submit an appeal against this decision in 15 calendar days to the authority issued the decision.

The official starts administrative processing and the "order" for a road offence according to the provision § 42a paragraph 4 point (c) of the Act No. 13/1997 Coll., about roads in current consolidated version [4] will be send to a driver. The fine with maximal amount of CZK 30,000 (ca. € 1,200) will be imposed by the "order" according to the provision § 42a paragraph 8 point (k) of the Act No. 13/1997 Coll., about roads in current consolidated version [4]. The driver has time limit of 8 calendar days after delivery of the "order" to submit an opposition to the authority, which issued the „order". If the opposition is submitted in time, the "order" is cancelled. The official, who issued the "order", will continue in processing of this road offence. The driver is appealed by the official to get acquainted with the file in defined time limit of 10 calendar days. In the case that the driver or his attorney will not use this time limit, the decision on the offence will be issued according to the provision § 42a paragraph 1 point (u) of the Act No. 13/1997 Coll., about roads in current consolidated version [4]. It is related to the fact that the driver was driving vehicle or set of vehicles non-compliant with limits or conditions defined by the Act about route transport operation. The driver should submit an appeal against this decision in 15 calendar days to the authority issued the decision.

There are 4 variants of a technological process for solution of selected road offence:

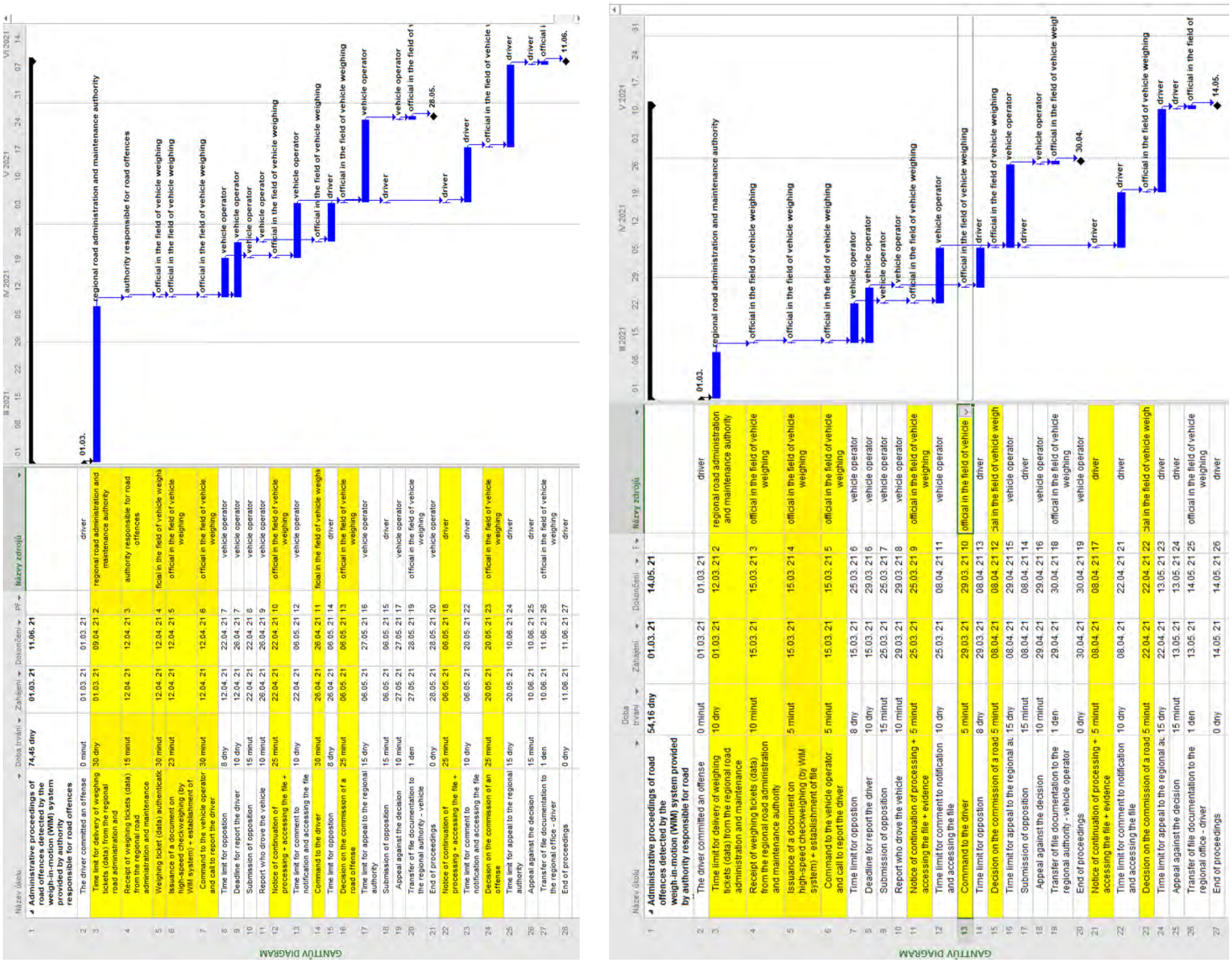
- vehicle operator and drivers agree with committing a road offence;
- vehicle operator agrees with offence, but the "Call for driver communication" was disobeyed;
- vehicle operator disagrees with offence and will declare "Decision about special utilization of a road";
- vehicle operator as well as driver do not agree with an offence.

One of these technological processes is discussed in detail in this paper due to limited extend of the paper. This discussion is focused on the process when vehicle operator as well as driver do not agree with the offence, see Fig. 1a. On the other hand, this process is the most complex, so that the other processes should be modified in derived way if needed. The software Microsoft Project was applied for elaboration.

2.3. State-of-Art Way of Road Offence Processing by High-Speed Weighing - Vehicle Operator and Driver Do Not Agree With the Offence

The case when vehicle operator as well as driver do not agree with a road offence identified by high-speed check weighing is common. Technological process, when both subjects will use their right and when they submit an opposition against the "order", is displayed in the Fig. 1, a. There is visible that the processing continues with both subjects individually and in a parallel way in the Fig. 1a. The process of administrative processing is based on the Act No. 500/2004 Coll., administrative procedure in current consolidated version [14]. The "Decision about commission of a road offence" is issued in both cases. Vehicle operator as well as driver do not agree with decision once again and they appeal against the decision. The complete documentation file is sent to the appeal body - to regional authority according to the location of responsible municipality with extended powers (ORP). The municipality of Říčany (20 km to the South-East from the city centre of the capital Prague) and Central Bohemia Region as the appeal body are taking part in case study mentioned in this paper.

Delivery of documents is based on the act No. 500/2004 Coll., administrative procedure in current consolidated version [14]. In the case, when a data box is at disposal, an official must use delivery of documents into the data box. Vehicle operators usually have data boxes. When they are legal entities, it is obligatory for them. Vehicle driver is usually an individual and the individuals usually do not have a data box. It is not obligatory for individuals, but it is also possible to have it. When a driver has data box, the documents are delivered in this electronic way as well. If not, the documents are delivered as a recommended letter in own hands to address stored in the Information system of evidence of inhabitants. Original version of documentation file is delivered to the appeal authority in an envelope with delivery note.



a b

Fig. 1 Gantt's diagrams of technological process of road offence processing: a – state-of-art; b – proposed

Duration time of road offence processing is 74.45 days (ca. 74 days and 11 hours) from offence committing by state-of-art procedure.

2.4. Proposal of a Change of Road Offence Processing by High Speed-Weighing - Vehicle Operator and Driver Do Not Agree with the Offence

Automatization and solution in electronic form of a whole technological process is a very important step by administrative processing of a road offence related to high-speed check weighing of road vehicles by the authority of the municipality with extended powers (ORP). Development of a specialized software tool is proposed by the authors of this paper. This software tool should simplify to work to an official at the Department of the sectional speed measuring and vehicle weighing. The aim is to automate the agenda of the authority of municipality with extended powers (ORP) related to the processing of road offences in the filed on high-speed check weighing (weigh-in-motion). The software tool will be focused on input data processing, preparation of documents during processing of a road offence and on integration of communication to other systems in surroundings.

Targets of proposed software tool:

- compatibility with operator of the weighing point - with KSÚS of Central Bohemia Region;
- lustration of vehicle registration plate - automated identification of a vehicle operator, check of an address of a vehicle operator, finding of a way how to deliver documents to the vehicle operator;
- mass generating of documents (Document about result of high-speed check weighing, Order, calls, notifications, postponements, explanations, decisions, resolutions, printing of addresses on letter envelopes etc.);
- process-based controlled processing of road offences with detailed overview about progress in processing of individual cases;
- register of offences and possibility to search any combination of items stored in register;
- demonstrable processing of offences;
- automated processing - automatic operations with integrated systems, controlling of state of offence processing, tracking of defined deadlines;

- integration with a system for administration of financial claims - automatic administration, checking of payment, identification of unusual statuses and cases;
- integration with a system for documentation files named ELISA - automated administration of documentation file, storage of documents in an electronic form, dispatches of documents.

Next process will be influenced by an approach of vehicle operator to a road offence. Proposed software tool will track defined deadlines and in the case that the deadline has passed, a "notification" will be displayed (pointed out). Individual forms and templates (order, "Call for driver communication", decision, resolution) will be created and updated in regular time periods according to valid legal acts.

The whole technological process will be automated.

The processing should be shortened from 74 to 54 days by implementation of the proposal (see chapter 2.4.) as it follows from the Fig. 1, b. Please, let compare it to the Fig. 1, a. The parts of processing (lines in the Fig. 1, a and b) able to be shortened are marked by yellow colour. Time saving is ca. 20 days.

3. Conclusions

The publications in the field of high-speed check weighing of road vehicles (weigh-in-motion) are usually focused on technical aspects of applied scales and weighing processes. Accuracy of measured weights is also often occurred topic. Automating of administration of documents about weighing in relation to technological processes by enforcement of sanctions related to road offences connected to exceeding of defined limits. Analysis of technological process by administrative processing of such road offences is taking part of this paper due to this reason. Data coming from measuring of processing times at the authority of municipality with extended powers in Říčany were applied for evaluation of state-of-art and proposed solutions. There are 4 variants how the road offence can be administrated. The most frequent and the most complex variant when vehicle operator and driver do not agree with a road offence is presented. The duration of processing is 74 days by state-of-art way. It can be shortened to 54 days by using modified procedure proposed and presented in this paper. Time saving is 20 days in this case of road offence.

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The Determination of Power Losses in the Traction Electric Drive Converter of the Electric Locomotive

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Abstract

The study of electrodynamic processes in the traction electric drive of electric rolling stock requires taking into account the loss of power in its components. In electric locomotives with asynchronous traction motors, one of the elements of the traction electric drive is the output converter. An autonomous voltage inverter is used as such a converter. IGBT modules are mostly used as electronic keys in autonomous inverters. Power losses in the autonomous voltage inverter lead to an increase in the temperature of the IGBT modules, which, in turn, leads to an increase in thermal noise in the traction electric drive system. An increase in thermal noise leads to a deterioration in the operation of the traction drive control system. Certain difficulties arise when determining the thermal properties of IGBT modules, which are associated with the short duration of transient processes in these devices. The authors proposed a method for determining losses in the IGBT module, which includes the application of algebraic equations representing the shapes of the voltage and current curves during the switching process based on the fact that the current and voltage shapes during switching are a function of the voltage before, after and during switching . The parameters of these equations are derived from the equations of voltage, current and other physical quantities before and after switching. Modelling of energy losses during diode shutdown, during switching on and off of the IGBT transistor of the module, which is used in the output converter of the DS-3 series electric locomotive, was performed. The proposed method makes it possible to determine with high accuracy the energy losses during switching of the specified power devices and can be used in the construction of a thermal model of the output voltage converter of electric rolling stock.
KEY WORDS: *autonomous voltage inverter, thermal power losses, commutation, traction electric drive*

1. Introduction

The study of electrodynamic processes in the traction electric drive of electric rolling stock requires taking into account power losses in the elements of the traction drive [1, 2]. Consideration of losses in the elements of the traction electric drive should also be taken into account when creating its simulation model.

In electric locomotives with asynchronous traction motors, one of the elements of the traction drive is the output converter. An autonomous voltage inverter [3-5] is used as such a converter. The vast majority of IGBT modules are used as electronic keys in autonomous inverters [6-7]. Power losses in the autonomous voltage inverter lead to an increase in the temperature of the IGBT modules, which, in turn, leads to an increase in thermal noise in the traction drive system.

An increase in thermal noise leads to a deterioration in the operation of the traction drive control system. This factor, in turn, leads to an increase in control error and, as a result, to an increase in losses in the traction drive system, which leads to a decrease in the efficiency of the traction drive as a whole [8].

When determining losses in IGBT modules, namely in their component power transistors and diodes, certain difficulties arise. These difficulties are associated with the short duration of transient processes in these devices, lasting several hundreds of nanoseconds [9]. The interval between the switching of the transistor and the diode is of the order of several milliseconds. To obtain an adequate result, it is necessary to choose a step equal to several picoseconds, which will lead to a large amount of calculations [10].

Many works have been devoted to the problem of modelling the determination of losses in an autonomous voltage inverter. Thus, the authors in their work [11] proposed the definition of non-uniform power losses in an autonomous voltage inverter based on the method of three-dimensional thermal modelling of transient processes. But in this work [11] switching losses in transistors and diodes and the mutual influence of device temperatures on losses in devices are not considered , which will lead to an incorrect determination of losses at the specified moments of inverter operation.

The next work [12] proposed a method for determining heat losses in the elements of IGBT modules, which allows taking into account the mutual influence of devices when determining heat losses, but the mentioned work did not consider the issue of determining losses in IGBT modules at the time of switching.

The authors of the analyzed article [13] proposed a method that allows taking into account heat losses at the time of switching. They also established a relationship between the parameters of the thermal characteristics and the operating parameters of the IGBT modules. But in this work, the authors did not take into account the mutual influence of the temperature of the devices on the losses in the IGBT module.

In the other investigation [14], a method for determining the temperature of the IGBT modules of the inverter is proposed. It takes into account the energy in the IGBT modules, taking into account the switching, taking into account the mutual influence of the temperature of the devices on the energy losses in the module. But the question of determining power losses in an autonomous voltage inverter as a function of the sampling frequency during the implementation of pulse width modulation (PWM) in an autonomous voltage inverter remains open.

Thus, the determination of power losses in the output converter of the traction drive of electric rolling stock with induction motors, which is an autonomous voltage inverter, is an urgent task.

2. The Determination of Power Losses in an Autonomous Voltage Inverter

2.1. The Object of Research

The object of the research is the output converter of electric locomotives with induction traction motors, made according to the three-phase bridge circuit of the autonomous voltage inverter on IGBT modules.

2.2. The Model of Losses in IGBT Module

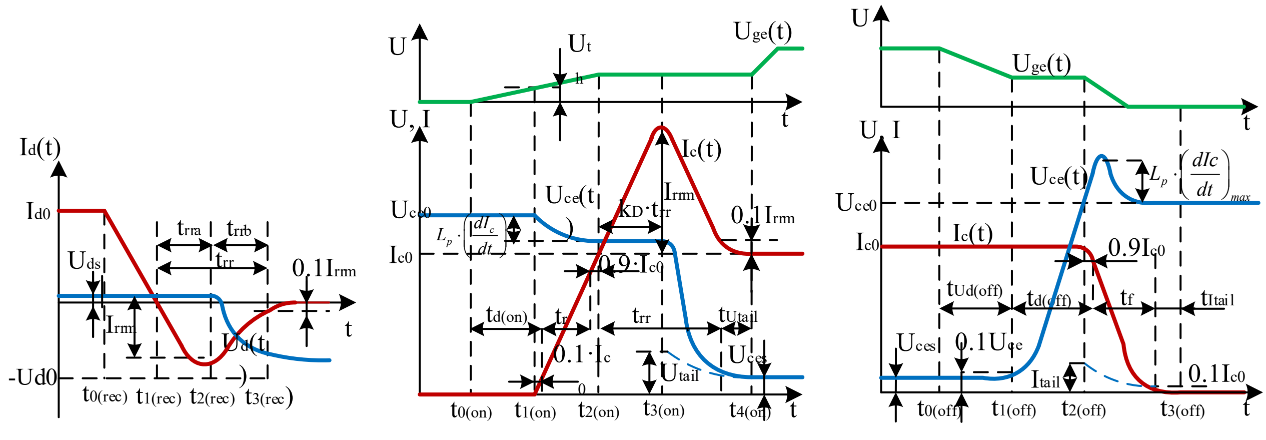
The losses in the IGBT module can be divided into losses in the conduction mode, losses in the closed state, and losses during switching. Heat losses in the conduction mode and the closed state are determined by the formulas [15].

$$P_{cond} = I_C \cdot U_{CE(set)}; \quad P_{blok} = I_{CES} \cdot U_{CE}, \tag{1}$$

where P_{cond} - losses in conduction mode; P_{blok} - losses in the closed state; I_C - collector current; $U_{CE(set)}$ - forward saturation voltage; I_{CES} - leakage current; U_{CE} - blocking voltage.

The authors proposed a method for determining losses in the IGBT module, which includes the application of algebraic equations representing the shapes of the voltage and current curves during the switching process based on the fact that the current and voltage shapes during switching are a function of the voltage before, after and during switching. The parameters of these equations are derived from the equations of voltage, current and other physical quantities before and after switching. Since energy is analytically calculated as the time integral of the product of voltage and current, thermal energy losses are calculated by integrating the product of the obtained voltage and current equations. Thus, the simulation of heat losses can be carried out with a large time step, providing an estimate of energy losses at each switching.

In the above mentioned investigation [14] idealized curves of currents and voltages when the diode is turned off (Fig. 1, a), the transistor is turned on (Fig. 1, b) and the transistor is turned off are given (Fig. 1, c).



a b c

Fig. 1 Idealized current and voltage curves of the transient process of turning off the diode (a), when the transistor is turned on (b) and turned off (c)

Fig. 1 shows the voltage and current curves when the diode is turned off (a), when the transistor is turned on (b) and turned off (c).

When switching off the diode in the interval $[t_{0(rec)} - t_{2(rec)}]$ (Fig. 1, a) current I_d is modelled as a linear slope, and the voltage U_d is modelled by a straight line:

$$I_d(t) = -I'_{1(rec)} \cdot \left(t - t_{1(rec)}\right) \cdot e^{-\alpha_1(rec) \cdot \left(t - t_{1(rec)}\right)^2}; \quad U_d(t) = U_{ds} = U_{CE}, \tag{2}$$

with

$$k_D = \frac{I_{rrm} \cdot \sqrt{e}}{t_{rr} \cdot \left(\left. \frac{dI_d}{dt} \right| t_0 \right)}; \quad \alpha_{1(rec)} = \frac{1}{\left(t_{rr} \cdot k_D\right)^2}; \quad I'_{1(rec)} = \sqrt{2 \cdot \alpha_{1(rec)}} \cdot I_{rrm} \cdot \sqrt{e}, \tag{3}$$

in the interval $t > t_{2(rec)}$ current I_d and voltage U_d are modelled as follows:

$$I_d(t) = I_{rrm} \cdot e^{-2 \cdot \alpha_2(rec) \cdot \left(t - t_{1(rec)}\right)^2}; \quad U_d(t) = \left(U_{ds} + U_{d0}\right) \cdot e^{-\alpha_2(rec) \cdot \left(t - t_{1(rec)}\right)^2} - U_{d0}. \tag{4}$$

Reverse diode recovery current I_{rrm} will decrease to 10% after time provided that:

$$\alpha_{2(rec)} = \frac{\ln(10)}{t_{rrb}^2} = \frac{\ln(10)}{\left(1 - k_D\right)^2 \cdot t_{rr}^2}, \tag{5}$$

intervals $t_{1(rec)}$, $t_{2(rec)}$ and $t_{3(rec)}$ are defined in accordance with the expressions

$$t_{1(rec)} = t_{0(on)} + t_{d(on)} - \frac{1}{8} \cdot t_r; \quad t_{2(rec)} = t_{1(rec)} + \frac{10}{8} \cdot t_r; \quad t_{3(rec)} = t_{2(rec)} + k_D \cdot t_{rr}, \tag{6}$$

where $t_{d(on)}$ - switch-on delay time; t_{rr} - reverse recovery time. These values are passport data of the diode.

The transient process of turning on the transistor is divided into three intervals $\lfloor t_{1(on)} - t_{2(on)} \rfloor$, $\lfloor t_{2(on)} - t_{3(on)} \rfloor$ and $\lfloor t_{3(on)} - t_{4(on)} \rfloor$ (Fig. 1, b). The boundaries of time intervals were determined by formulas:

$$t_{1(on)} = t_{0(on)} + t_{d(on)} - 0.25 \cdot t_r; \quad t_{2(on)} = t_{1(on)} + 1.25 \cdot t_r; \quad t_{3(on)} = t_{2(on)} + k_D \cdot t_{rr}; \quad t_{4(on)} = t_{2(on)} + t_{rr} + t_{U_{tail}}, \tag{7}$$

where t_r - rise time (passport data of the transistor).
In interval $\lfloor t_{1(on)} - t_{2(on)} \rfloor$ current I_C and voltage U_{ce} are defined by expressions:

$$I_c(t) = I_{c1(on)} \cdot \left(1 - e^{-\alpha_{1(on)} \cdot \left(t - t_{1(on)}\right)}\right); \quad U_{ce}(t) = U_{ce0} - U_{1(on)} \cdot \left(1 - e^{-\lambda_{1(on)} \cdot \left(t - t_{1(on)}\right)}\right). \tag{8}$$

Since the current I_C grows almost linearly, it is assumed that $I_{1(on)} \approx 100 \cdot I_{C0}$, where I_{C0} - the current of the on state of the transistor. Then

$$\alpha_{1(on)} = \frac{1}{1.25 \cdot t_r} \cdot \ln\left|\frac{1}{0.99}\right|. \tag{9}$$

Value $U_{1(on)}$ is obtained taking into account the average value dI_C / dt due to parasitic inductance L_p:

$$U_{1(on)} = \frac{8 \cdot I_{c0}}{9 \cdot t_r} \cdot L_p. \tag{10}$$

Coefficient $\lambda_{1(on)}$ is obtained basing on the condition of 90% voltage drop $U_{1(on)}$ during the analyzed period:

$$\lambda_{1(on)} = \frac{1}{1.25 \cdot t_r} \cdot \ln 10. \tag{11}$$

In interval $\lfloor t_{2(on)} - t_{3(on)} \rfloor$ the collector current is the sum of the load current and the recovery current of the reverse diode (3), whereas U_{ce} remains at the voltage level U_{cep}, defined below:

$$I_c(t) = I_{c0} + I'_{rec} \cdot \left(t - t_{2(on)}\right) \cdot e^{-\alpha_{1(rec)} \cdot \left(t - t_{2(on)}\right)^2}, \quad U_{cep}(t) = U_{ce0} - \frac{0.8 \cdot I_{c0}}{t_r} \cdot L_p. \tag{12}$$

After $t_{3(on)}$ the recovery current of the reverse diode gradually decreases according to (3), while U_{ce} drops to its saturation value U_{ces}. It has been suggested that U_{ce} consists of two components that decay at different rates. Thus the current and voltage after time $t_{3(on)}$ were determined according to the expressions:

$$I_c(t) = I_{c0} + I_{rrm} \cdot e^{-\alpha_{2(rec)}\cdot\left(t-t_{3(on)}\right)^2}, \quad U_{ce}(t) = U_{2(on)} \cdot e^{-\alpha_{2(rec)}\cdot\left(t-t_{3(on)}\right)^2} + U_{3(on)} \cdot e^{-\lambda_{3(rec)}\cdot\left(t-t_{3(on)}\right)^2}. \tag{13}$$

Coefficient $U_{3(on)}$ - it is a component of slow decline U_{ce} and it is equal to the voltage U_{tail} (Fig. 1, b) and looks approximately proportional to the level voltage U_{cep}. Coefficient $k_{U\infty} = [0-1]$ is determined by the formula:

$$U_{tail} = k_{U\infty} \cdot U_{cep}. \tag{14}$$

Then the magnitude of the rapidly decaying component is equal:

$$U_{2(on)} = (1 - k_{U\infty}) \cdot U_{cep}. \tag{15}$$

From the condition of the voltage drop at the end of the characteristic to the level U_{ces}, at $t_{4(on)}$ it was received:

$$\lambda_{3(on)} = \frac{1}{\left((1-k_D)\cdot t_{rr} + t_{U_{tail}}\right)^2} \cdot \ln\left|\frac{k_{U\infty}\cdot U_{cep}}{U_{ces}}\right|. \tag{16}$$

Expressions for the current and voltage when the transistor is turned off are determined taking into account two intervals $\left\lfloor t_{0(off)} - t_{2(off)} \right\rfloor$ and $\left\lfloor t_{2(off)} - t_{3(off)} \right\rfloor$ (Fig. 1, c), where:

$$t_{2(off)} = t_{0(off)} + t_{d(off)} - \frac{1}{8}\cdot t_{rr}, \quad t_{3(off)} = t_{2(off)} + \frac{9}{8}\cdot t_r + t_{Itail}. \tag{17}$$

In interval $\left\lfloor t_{0(off)} - t_{2(off)} \right\rfloor$ current I_C remains equal I_{C0}, while U_{ce} increases starting from its saturation value according to the expression:

$$U_{ce}(t) = U'_{1(off)} \cdot t + U_{ces} \cdot e^{-\lambda_{1(off)}\cdot\left(t-t_{1(off)}\right)}, \tag{18}$$

with

$$t_{1(off)} = t_{0(off)} + k_{Ud}\cdot\left(t_{d(off)} - \frac{1}{8}\cdot t_f\right), \quad U'_{1(off)} = \frac{0.1\cdot U_{ce0} - U_{ces}}{k_{Ud}\cdot\left(t_{d(off)} - \frac{1}{8}\cdot t_f\right)}, \quad \lambda_{1(off)} = \frac{\ln\left|\left(U_{ce0} - U'_{1(off)}\cdot t_f\right)\cdot U_{ces}^{-1}\right|}{(1-k_{Ud})\cdot\left(t_{d(off)} - \frac{1}{8}\cdot t_f\right)}, \quad k_{Ud} = \frac{t_{U_d(off)}}{t_{d(off)}}. \tag{19}$$

In interval $\left\lfloor t_{2(off)} - t_{3(off)} \right\rfloor$ current I_C falls according to the expression:

$$I_c(t) = I_{1(off)} \cdot \mathrm{e}^{-\alpha_{1(off)}\cdot\left(t-t_{2(off)}\right)^2} + I_{2(off)} \cdot \mathrm{e}^{-\alpha_{2(off)}\cdot\left(t-t_{2(off)}\right)^2}. \tag{20}$$

The magnitude of the current component $I_{2(off)}$ is equal to the final value of the current I_{tail}, shown in fig. 1, c.:

$$I_{tail} = k_{1\infty} \cdot I_{c0}, \tag{21}$$

where $k_{I\infty}$ - coefficient, which depends on the design and type of IGBT. The magnitude of the component $I_{1(off)}$ is:

$$I_{1(off)} = (1 - k_{1\infty}) \cdot I_{c0}, \tag{22}$$

coefficients $\alpha_{1(off)}$ and $\alpha_{2(off)}$ were found taking into account a certain point on the current curve as:

$$\alpha_{1(off)} = \frac{64}{t_f^2} \cdot \ln\left|\frac{1-k_{1\infty}}{0.9-k_{1\infty}}\right|, \quad \alpha_{2(off)} = \frac{1}{\left(t_f + t_{tail}\right)^2} \cdot \ln\left|100 \cdot k_{1\infty}\right|. \tag{23}$$

Change U_{ce} is obtained taking into account the voltage drop on the parasitic inductance:

$$U_{ce}\left(t\right) = U_{ce0} - L_p \cdot \frac{dI_c}{dt} = U_{ce0} + U_{2(off)} \cdot e^{-\alpha_1(off)\cdot\left(t-t_{2(off)}\right)^2} + U_{3(off)} \cdot e^{-\alpha_2(off)\cdot\left(t-t_{2(off)}\right)^2}, \tag{24}$$

with

$$U_{2(off)} = 2 \cdot \alpha_{1(off)} \cdot I_{1(off)} \cdot L_p, \quad U_{3(off)} = 2 \cdot \alpha_{2(off)} \cdot I_{2(off)} \cdot L_p. \tag{25}$$

Energy losses when switching devices are calculated according to the formulas:

$$W_{rec} = \int_{t_{0(rec)}}^{t_{3(rec)}} U_d\left(t\right) \cdot I_d\left(t\right) dt, \quad W_{on} = \int_{t_{1(on)}}^{t_{4(on)}} U_{ce}\left(t\right) \cdot I_c\left(t\right) dt, \quad W_{off} = \int_{t_{0(off)}}^{t_{3(off)}} U_{ce}\left(t\right) \cdot I_c\left(t\right) dt, \tag{26}$$

where W_{rec}, W_{on}, W_{off} - energy losses when turning off the diode, turning off and turning on the transistor, respectively.

The average power loss value was calculated using the formula:

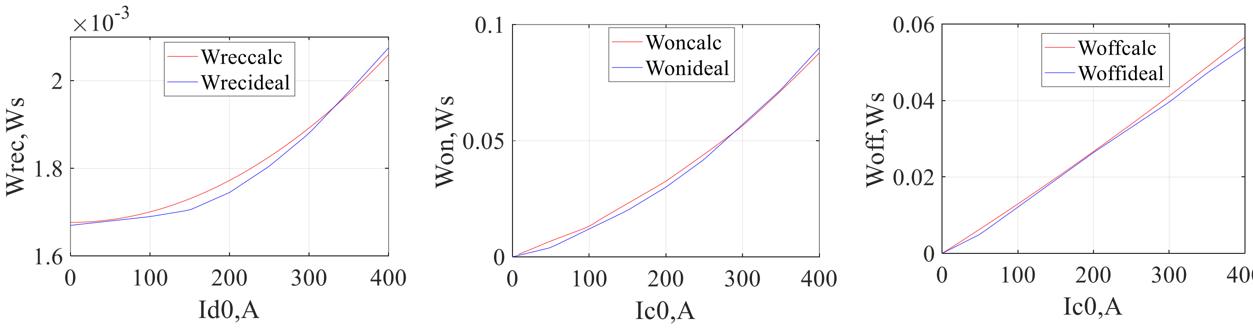
$$\Delta P_{th} = P_{cond} + P_{blok} + \left(W_{rec} + W_{on} + W_{off}\right) \cdot f_{max}, \tag{27}$$

where f_{max} - the maximum switching frequency of transistors and diodes.

3. Results of Modelling Traction Induction Motor

In order to check the adequacy of the proposed method of determining heat losses in the IGBT module, the simulation of energy losses when the diode is turned off, the transistor is turned on and off, was performed. The simulation results were compared with the characteristics given in the passport documentation by the manufacturer of the specified devices.

The modules are used as IGBT modules in the autonomous voltage inverter of electric locomotives of the DS-3 series BSM200GA120DN2. The simulation results were compared with the results given in the passport documentation of the specified devices. By changing the value of the current flowing through the transistor from 50 A to 400 A, at $U_{ce0} = 600\text{V}$ the curve of energy loss when the diode is turned off (Fig. 2, a), the transistor is turned on (Fig. 2, b) and turned off (Fig. 2, c) is created.



a b c

Fig. 2. Energy loss curves when the diode is turned off (a), and the transistor is turned on (b) and turned off (c): $W_{reccalc}$, $W_{offcalc}$, W_{oncalc} - are calculated and $W_{recideal}$, $W_{offdeal}$, W_{ondeal} passport energy losses when turning off the diode, turning on and turning off the transistor, respectively.

The errors in determining losses when switching devices are calculated according to the formula:

$$\sigma = \frac{1}{N} \cdot \sqrt{\sum_{i=1}^{N} \left(W_{calc} - W_{ideal}\right)^2} \cdot 100\%, \tag{28}$$

The error in determining the energy loss when the diode was turned off was 12%, when the transistor was turned on - 3.77%, when the transistor was turned off - 1.5%. The obtained results indicate the high reliability of the obtained results and the adequacy of the proposed method of determining heat losses in an autonomous voltage inverter.

4. Conclusions

A method of determining heat losses in an autonomous voltage inverter, taking into account the losses during the switching of power transistors and diodes, is proposed.

The proposed methodology is based on filling the switching intervals with integrated functions that describe the shape of the curves of currents and voltages of power electronic devices at the corresponding switching intervals.

Modelling of energy losses during diode shutdown, during switching on and off of the IGBT transistor of the module, on which the output converter of the DS-3 series electric locomotive is assembled, was performed.

A comparison of the simulation results with the characteristics given in the passport documentation of the IGBT module was performed. The modelling errors were the following: when the diode was turned off, 12%, when the transistor was turned on, 3.77%, when the transistor was turned off, 1.5%, which indicates the high reliability of the obtained results.

The proposed technique can be used in the development of a thermal model of the inverter to take into account heat losses when studying the electrodynamic processes of the traction drive of electric rolling stock.

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Using Cargo Bikes in Personal Logistics – Conditions and Possibilities in the Czech Republic

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Abstract

This paper analyses the possibilities to integrate cargo bikes into personal logistics in the Czech Republic. Cargo bikes for personal use are relatively popular in some European countries, such as Netherlands, Denmark, and Germany, also including sharing systems. In the Czech Republic, this kind of use of cargo bike is sporadic. The most common purpose to use cargo bike, is the transport children and shopping. This paper deals with factors, which can influence the level of the use of cargo bikes in various conditions.
In the example of the city of Pardubice, the model of the use of cargo bikes for shopping will be created and the efficiency of this kind of transport will be compared with the use of cars.
KEY WORDS: *cargo bikes; personal logistics*

1. Introduction

The use of cargo bikes for personal purposes in Europe has been on the rise in recent years. This applies especially to countries where cycling has a long tradition, and the bicycle is perceived by the population as a common means of transport. In addition to private ownership of cargo bikes, bike sharing systems and cargo bike rentals are also becoming increasingly popular.

A survey of 38 truck wheel manufacturers [1] conducted in 2021 shows up to a 66% year-on-year increase in cargo bike sales, mainly in Belgium, Germany, and France. Most cargo bikes were sold in Germany (103,000 in total, 124 per 100,000 inhabitants), while Denmark leads sales per 100,000 inhabitants (25,000 in total, 429 per 100,000 inhabitants). The increasing availability of e-bikes may be one of the important factors in this growth. Manufacturers report up to 92% share of e-bikes in total cargo bike sales in Europe. ZIV reports about 72 % share of sales of electric models within Germany [19]. The COVID-19 pandemic also appears to have had an impact on the increase in cycling traffic in some countries [4, 13], including the use of cargo bikes. Another factor is the possibility of obtaining subsidies related to climate protection for the purchase of cargo bikes in some countries (regions). Sales prices currently start at about 1500 Eur per bike with mechanical drive and about 2000 Eur per bike with electric drive. Buying your own bike may not always be economically advantageous, especially for people who would not use a cargo bike daily, even if they are inclined to bicycle traffic. In this case, there is significant potential for the use of shared cargo bikes [2, 7]. Bike sharing systems are already relatively well established practically throughout Europe. Cargo bike sharing systems are mainly widespread in countries with a traditionally high share of cycling, such as Germany, where these systems operate in more than 150 cities [14].

The analysis shows that there are some regional differences in the sales and use of cargo bikes. The motivation to use a cargo bike is very closely related to the perception of cycling transport in the certain region and to the linked background and support. In the context of current trends in sustainable mobility and reducing environmental burdens (CO2 emissions), cargo bikes for personal use are important in the micromobility sector. Cargo bikes for commercial use are considered to be an environmentally friendly means of transport, especially for last-mile delivery [18]. The quality of transport infrastructure also has a significant impact on the level of use of cargo bikes [2, 8]. Traditional "cycling-friendly" countries such as Denmark, the Netherlands or Germany support the use of cargo bikes directly, e.g., in the form of subsidies and project financing, but also indirectly, e.g., through transport measures in cities. The bike is a common part of daily activities, such as trips to school, work, shopping, and the level of infrastructure corresponds to this trend. Cargo bike can even be perceived as a symbol of a certain social status, but this also entails negative consequences in the form of a differentiation of opinion in society [3]. In countries strongly focused on individual motoring, such as the US or Australia, the motivation to use bicycles is lower in the adult population. However, studies suggest that even in these communities, cargo bikes have the potential to replace some car trips [5, 12, 17].

2. Analysis of Factors Influencing Private Use of Cargo Bikes

The Czech Republic is quite specific in residents' relation to cargo bikes and cycling in general. The bicycle is perceived here mainly as a means for sports and recreation, although there are some regional differences. Surveys from the period 2020-2021 show that the "pandemic" trend of increasing bicycle traffic has had very little effect in the Czech Republic [9]. Demand for e-bikes has increased, but cargo bikes are still on the fringes of interest [10]. In 2021, a cargo bike rental company operated in a test project in the city of Brno. The results of the project indicate that there was interest in this mode of transport in the city of Brno [15], but it should also be considered that the system was free.

The question is therefore: “What is the potential for the use of cargo bikes in the Czech Republic and what are the possibilities/factors of increasing interest in this mode of transport?”

The main criteria for the transport mode choice can be divided into three basic groups:

- Objective – criteria that can be quantified and can be used to clearly compare different modes of transport – e.g., cost, travel time.
- Subjective – criteria that cannot always be quantified. The user evaluates them himself based on experience (often transferred), possibilities and abilities. Decision-making is often influenced by current feelings or moods.
- Social – e.g., low ecological footprint, low road wear, low externalities, healthier populations.

If the user decides what mode of transport to use before travelling, his subjective criteria may often outweigh the objective criteria in the evaluation. If we would like the user to take more account of the social criteria, it is necessary for him to consider them as his own. Essentially, it is a "relocation" of the criterion from the social group to the subjective group. This is possible only by education, explanation, and ideally from an early age. It is important for children to "embrace" that it is normal to walk, ride a bike, use public transport. If a young person learns to use a bicycle to move from an early age, he/she will also be able to use it, for example, for shopping trips. It is also important to see the bicycle as an equal alternative to the second car in the household.

If we want cargo bikes to be taken into account as an alternative to a car, it must be accepted that the user wants to satisfy his needs:

- immediately and always – it is therefore necessary for the user to have the cargo bike available for 24 hours;
- anywhere;
- with the least possible time required;
- with maximum comfort;
- risk-free;
- with the lowest possible price for transport.

From the user's point of view, it is therefore important to either own the bike or be able to share it in an acceptable availability and at acceptable prices. Furthermore, the quality of the transport infrastructure for cargo bikes is very important (see Section 3).

It is also important to consider the elasticity of demand, i.e., how quickly the demand for cargo bike trips can change in response to a change in entry conditions. Currently, the growth of the price of fuel, respectively price elasticity, may have a positive effect to using a cargo bike. However, other factors also play an important role in transport, most notably travel time. Thus, elasticity manifests itself as cross-shaped elasticity, not its own.

To decide which mode of transport to use, the user must know his possibilities and the resulting utility. The deterministic part of the utility (travel time, charges, fares, etc.) can be described by a linear function. The stochastic part of the utility then reflects the user's personal preferences. From the user's point of view, the utility of choosing a mode of transport is reflected in the so-called user equilibrium, i.e., the state when the user achieves the lowest costs (these costs reflect all the costs associated with the choice of mode of transport).

3. Model Example of the Use of Cargo Bikes for Shopping in the City of Pardubice

The city of Pardubice lies in a lowland, total area is 83.6 km^2 and the population was 91,755 in 2021.

A survey of traffic behavior conducted in Pardubice before the coronavirus pandemic [11] confirmed that individual modes of transport are used equally (car transport accounts for 33%, public transport 22%, cycling 14% and pedestrian transport 31%). The city of Pardubice is close to the ideal of a "city of short distances", so the traffic behavior of the city's inhabitants and visitors fulfills the goals of the transport strategies of western European cities.

The survey revealed other important information. More than half (54%) of all journeys is shorter than 3 km and more than half (54%) of journeys up to 3 km is made on foot. At the same time, the inhabitants of the city themselves generate almost half of the car traffic. Switching from a car to a bicycle or public transport for journeys up to 3 km would mean a fifth reduction in the traffic from cars in this distance.

The city of Pardubice still lacks important parts of the infrastructure for car traffic, especially parts of the NE and SE bypasses. The existing system of roads consists of a cross centered in the city center. An important limiting factor in the construction of roads are the rivers that flow through the city. Users of cars must count on delays in queues during rush hours.

The city has a relatively extensive infrastructure for cyclists, which is very often based on the minimum dimensions defined in TP 179 (technical regulation). The dimensions of the dedicated and protective bike lanes and the lanes within the cycle paths thus suit only the cargo bikes of smaller size. It is the infrastructure tailored to the users that will significantly affect the use of certain transport mode. Its integrity, surface quality, etc. are important. However, a feeling of safety, the possibility of comfortable driving, free movement is also very important. For this reason, it is advisable not only to widen the cycling infrastructure with other sections, but also to improve the existing parameters. An example is in the city of Berlin. [16]. The bicycle lines also include protective pillars that separate a sufficiently wide space for cyclists from the area for motor traffic.

Space for cyclists can also be gained at the expense of space for motor transport. The necessary width of the lane is related not only to the size of the vehicle, but also to the speed limit. For a car, a lane width of 2.40 m is required at a speed of 50 km/h (only 2.25 m at a speed of 30 km/h). If buses and small trucks also use the road, they can share the extra space they need (about 0.7 m) with the bicycle space, the so-called shared space.

Especially in cities where there is a lack of space, it is necessary to use the space thoughtfully, economically. It is certainly important to give space to all modes of transport within the city service, to get the individual modes of transport into balance within the modal split. To do this, it is necessary to realize that a car driving at fifty km/h requires the space of 130 m^2 including spacing distance, while a cyclist takes 3 m^2, a pedestrian 1 m^2 and a passenger in a bus or tram 0.5 m^2. And here is the opportunity to replace a car with a cargo bike, for example, for shopping purposes.

3.1. Origins and Destinations

In the city of Pardubice there are six larger shopping zones, mainly in the outskirts, two shopping malls in the city center, several larger supermarkets, and several smaller stores in residential complexes of the city. The 2017/2018 Survey of traffic behavior in Pardubice shows that the most shopping trips in Pardubice are made on foot (45%), by car it is 24%, by bike 16% and by public transport 15% [11]. Virtually there is at least one supermarket and several smaller stores in the walking distance for every residential area in Pardubice where you can buy food and and basic consumer goods. For shopping by bike, mainly standard bicycles equipped with a basket are used, only a few private users currently have a cargo bike in Pardubice. It can be assumed that future potential users of cargo bikes would be formed mainly from current users of standard bicycles, pedestrians, and possibly public transport users. But even for a certain part of current users of cars, an interesting argument could be the time availability when using an e-bike, which is "more comfortable" and less demanding on physical exertion than a standard bike. [6] lists up to about 5 km distance (10-20 min) for cargo bikes in commercial use as comparable to cars. If we consider using the bike for private purposes, this distance could be slightly different. According to the survey [11], up to 71% of trips in Pardubice are within 5 km.

To compare the time availability for shopping, we have selected large shopping zones as destinations where it is possible to buy a wider range of goods (food, drugstore, textiles, household and workshop supplies, animal supplies).

3.2. Time Availability Comparison

To create a model of time availability, we used the GIS software on OpenStreet Maps and CUZK maps. Figure 1 shows the time availability of individual shopping zones when using a bicycle up to a maximum time of 10 minutes, with a resolution of two-minute areas and an average driving speed of 15 km/h. This speed is achievable for most users on a standard bike in local conditions during normal traffic. The situation also considers the possibility of using the existing cycling infrastructure, which is not accessible to motor vehicles.

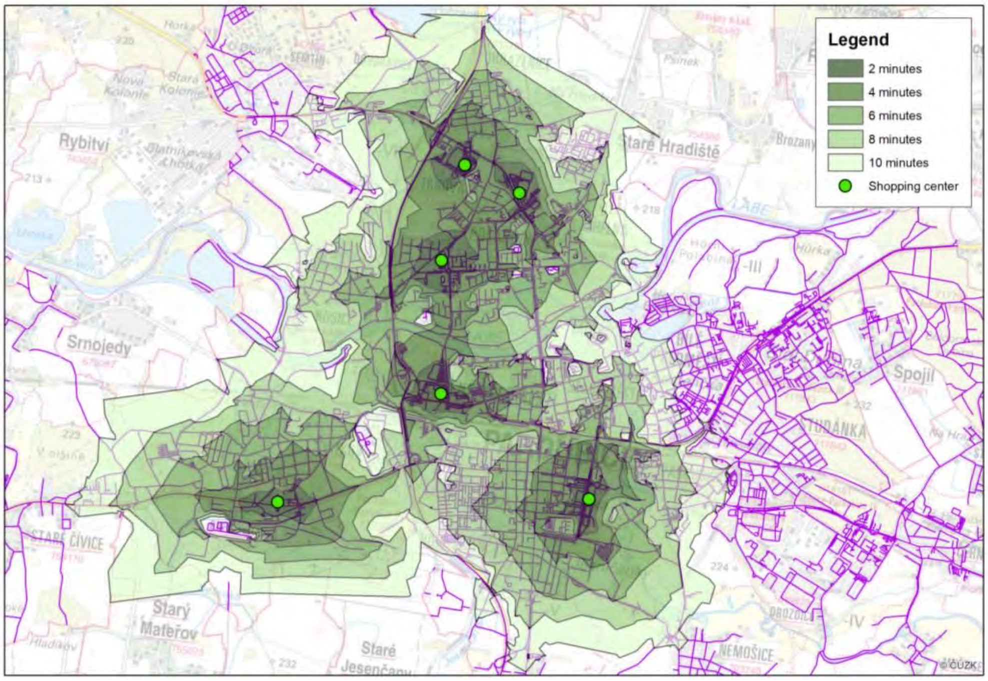

Fig. 1 Time availability of shopping zones using a bicycle

Fig. 1 shows that at least one shopping area can be reached by bike from most of the city districts within 10 minutes. A bicycle paths (shared with pedestrian traffic) lead directly to five of the six destinations. The best situation is in the northwestern part of the city, where there are more shopping zones situated and more than one destination is reachable within 10 minutes. The residential area in the eastern part of the city is the least covered. There are three ordinary supermarkets, but no shopping zone with a wider range of goods. The nearest shopping zone, including the hobby market, can be reached from eastern part of town by bike within about 20 minutes and by car within 11-15 minutes in normal traffic. The advantage of a bike on this route is that 60% of the route are paths shared with pedestrian traffic and the rest are ordinary roads with a maximum driving speed of 30 km/h. All roads along this route also allow the movement of cargo tricycles. In the case of using an e-bike, it can also be considered with a higher average speed and thus with the coverage of a larger area in terms of time availability.

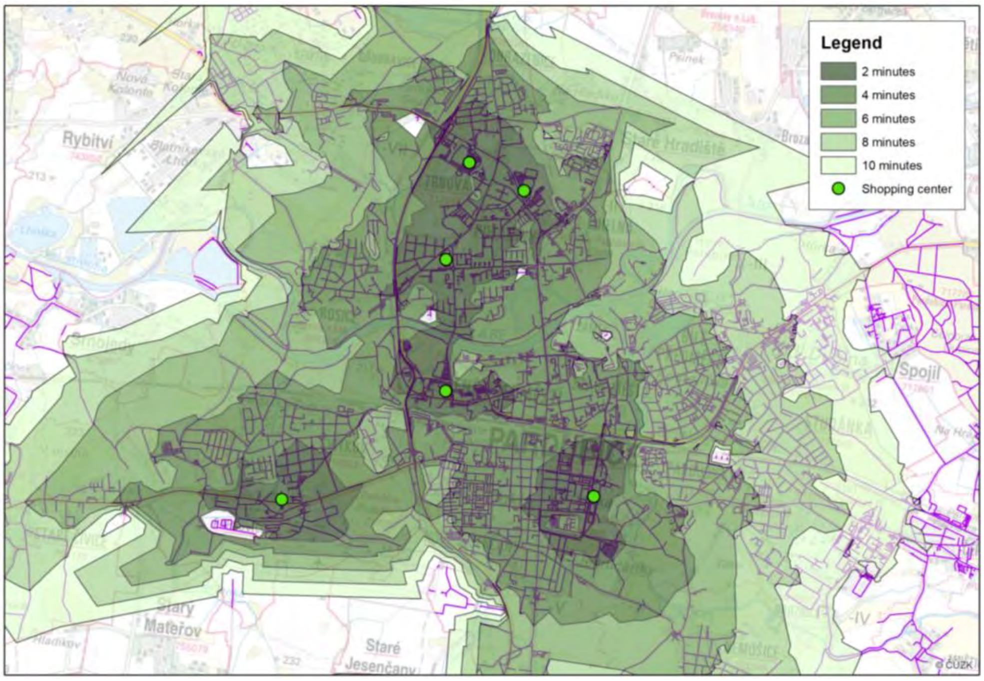

Fig. 2 Time availability of shopping zones using a car

Fig. 2 shows a maximum time availability of 10 minutes for the same shopping zones using a car and an average speed of 30 km/h which is achievable in normal (smooth) traffic. The time coverage of individual city districts is larger, although the route by car may be longer. For example, cyclists have more opportunities to cross rivers using roads that are not accessible to motor vehicles. As mentioned at the beginning of Chapter 3, during rush hours, the average speed of a car may decrease due to congestion and the time required to reach a given destination may increase by several minutes. In this case, therefore, the time availability can be comparable with the bike, especially in the case of using an e-bike.

For the sake of completeness, it is also appropriate to mention the time availability when using public transport, which is determined by the routing of individual lines. The public transport stop is located directly at five of the six surveyed destinations, the last one is within walking distance of about 5 minutes. In the case of public transport, the central part of the city is best covered. Five of the six destinations can be reached within 10 minutes by direct connection from city center. From the eastern part of the city, the nearest shopping zone can be reached by direct connection from 16 minutes.

4. Conclusions

The modern cargo bike represents a relatively small and specific market segment, but its potential in the Czech Republic is not yet fully exploited. The use of cargo bikes is influenced both by objective conditions, such as terrain, infrastructure, weather, time availability, and by subjective and social factors. In the Czech Republic, these conditions are characterized by regional differences. The city of Pardubice shows a high level of fulfilment of objective conditions, yet this mode of transport is used here minimally. The results therefore indicate a significant influence of subjective and social factors on which the further work will be focused.

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Performance Tests of the Tesla Autopilot and VW Travel Assist on a Rural Road

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Abstract

The number of SAE Level 2 equipped vehicles is steadily increasing. The systems are designed to perform the longitudinal and lateral control of the vehicle for a certain time interval, while the driver must constantly monitor the system and be ready to take over. In the event of a traffic accident, the question for accident analysts increasingly arises whether the corresponding system could have been jointly responsible for leaving the vehicle`s own lane in the event of a head-on collision. This was investigated by equipping a Tesla Model 3 and VW ID.4 with measuring equipment and carrying out performance tests on a rural road. Particularly in tight curves, it was determined that the systems leave its own lane. The systems also react differently and inconsistently at the time of failing which makes it difficult for the driver to control the situation. In addition to the test results, recommendations for the use of these systems will also be given to be able to increase overall vehicle safety. Furthermore, the generated data serve as possible indicators for the forensic clarification of the cause of the accident.
KEY WORDS: *Accidents Analysis, SAE Level 2 Systems, VW Travel Assist, Tesla Autopilot, Performance test*

1. Introduction

In 2020, in Germany, 554 road users were killed in a collision with an oncoming vehicle [1]. Furthermore, a published report by ADAC Accident Research [2] stated that a high number of road casualties on rural roads are killed in accidents in curves. In addition to leaving the own lane to the left, one reason for this is the so-called verge accident. When leaving the own lane to the right, the driver often steers too intensively in the opposite direction, which causes the vehicle to move back onto the road abruptly. The consequence of this reaction is usually a drift into oncoming traffic or an uncontrollable skid.

The introduction of the "Active Driving Assistance System" is intended to significantly reduce the number of such traffic accidents in the future [3]. The system is an SAE Level 2 Advanced Driver Assistance System (ADAS) [4], marketed by VW as "Travel Assist" [5] and by Tesla as "Autopilot" [6]. These are intended to assist the driver in performing his driving task by taking over both the longitudinal and lateral guidance of the vehicle over a longer period of time. The system is technically realized by linking various individual systems, such as the Adaptive Cruise Control (ACC) system and the Lane Centering Assistance (LCA) system. The ACC system is used to guide the vehicle longitudinally by either keeping the local speed limit constant or adapting the speed to a vehicle ahead [7]. According to the functional requirements of ISO 15622, the ACC system may brake or accelerate within the limits of a_{min} = -3,5 m/s² to a_{max} = 2,5 m/s² [8]. According to the United Nations Economic Commission for Europe (UNECE) Regulation No. 79 [9], the LCA system is an automatic steering function of category B1 that keeps the vehicle centered in the lane and thus assists the driver in maintaining the selected lane. The driver can override the system's steering action at any time via steering wheel actuation while the system can remain activated in standby mode. A maximum value of 3 m/s² for lateral acceleration ($a_{y,zul}$) must not be exceeded by a steering intervention of the LCA system [9]. To realize the function, a camera is usually used to identify the marking lines on the road surface. With a calculation model that considers the lane width, lane curvature, curvature change, and the position of the vehicle within the lane and the camera tilt angle, the course of the lane can be predicted [10]. However, the camera's visibility is insufficient, especially at high speeds and on curvy roads, to design the driving course safely and dynamically. To compensate this limitation, digital maps are used [8]. This additional information about the course of the road can be used to adjust the driving speed in such a way that the vehicle can master the upcoming curve radius without exceeding the maximum permissible value of the lateral acceleration.

As the Active Driving Assistance System is a SAE Level 2 system the driver must be able to control his vehicle at all times. To increase driving comfort, the driver can take his hands off the steering wheel for up to 15 seconds until he is visually prompted to keep his hands on the wheel again [9]. Due to the system monitoring to be permanently performed by the driver, he must have the possibility to immediately take over the vehicle control if this becomes necessary [11]. Accordingly, the manuals of a VW ID.4 and a Tesla Model 3, for example, point out possible automation risks due to the activated system, which can lead to a dangerous driving situation [12]. Among other things, they state that the ADAS can only operate within the system limits and that technical limitations can sometimes occur on narrow and curvy roads, whereby this is not specified further.

If a vehicle equipped with an "Active Driving Assistance System" is involved in an oncoming traffic accident, the initial suspicion arises that the SAE Level 2 system could have influenced the course of the accident, as a recent case in the district of Reutlingen, Germany, shows [13]. Accordingly, the aim of this study was to analyze the system behavior of an activated "Active Driving Assistance System" during cornering. In particular, it was investigated whether the system can cause the vehicle to leave its own lane without deactivating itself in advance and prompting the driver to take over the steering immediately. For this purpose, several functional tests with both vehicle systems were carried out on a curvy country road to ensure reproducibility. A literature search revealed that, to the best of our knowledge, this investigation has not yet been carried out.

2. Method and Materials

The tests were conducted with a VW ID.4 "Travel Assist" (first registration 06/2021, software version 3.3.0) and a Tesla Model 3 "Autopilot" (first registration 11/2021, software version 10.2).

For recording the system behavior during the test drives, the respective vehicle under test (VUT) was equipped with video cameras (GoPro Hero 8). A video camera attached to the test driver with a chest harness filmed the display or instrument panel of the VUT in order to be able to record the system messages as well as the driving speed (see Fig. 1, a). In parallel, this video camera filmed the steering wheel to be able to differentiate between the system-induced and driver-induced steering movements in the evaluation. Another GoPro Hero 8 filmed the pedals of the VUT in order to be able to track during the evaluation whether the test driver braked or accelerated while the Active Driving Assistance System was activated (see Fig. 1, b). In order to track the position of the test vehicle on the road, its driving trajectory was also recorded. For this purpose, a GoPro Hero 8 was used to film the rear of the VUT through the windshield of a vehicle immediately following the VUT during the test runs (see Fig. 1, c).

a b c

Fig. 1 Camera setup of the VW ID.4 (Tesla Model 3 analog)

For analyzing the driving trajectories, in addition to the video cameras installed in the VUTs, video recordings were made in selected curves from a bird's eye view at the height of approx. 70 m using a DJI Mavic Pro 2 drone.

The individual video recordings were synchronized in the "Shotcut" program by means of an acoustic signal, which was generated after each test start by actuating the horn of the VUT. The drone recordings were again synchronized with the remaining videos via stationary points. As a result, the video recording exemplarily shown in Fig. 2 was created for each test run.

In addition to the video recordings, the driving speed as well as lateral and longitudinal acceleration of the VUT were also recorded during each test drive. For this purpose, the measuring device 2D Datenlogger from the Karlsruhe (Germany)-based company 2D - Debus & Diebold Meßsysteme GmbH was used, which can measure the measurands in a range of +/- 4 g with an accuracy of +/- 2 %. This device was mounted on the windshield in the center of each test vehicle and then aligned as well as calibrated using an integrated spirit level. The evaluation of the measured values was based on csv files exported from the 2D data logger via the "WinARace" software. The synchronization of the measured values with the associated video recordings was carried out optically via a special button that was connected to the measuring device and whose actuation can be seen in a video image. The actuation generates a measurement pulse, which can be synchronized in time with the actuation of the button in the video.

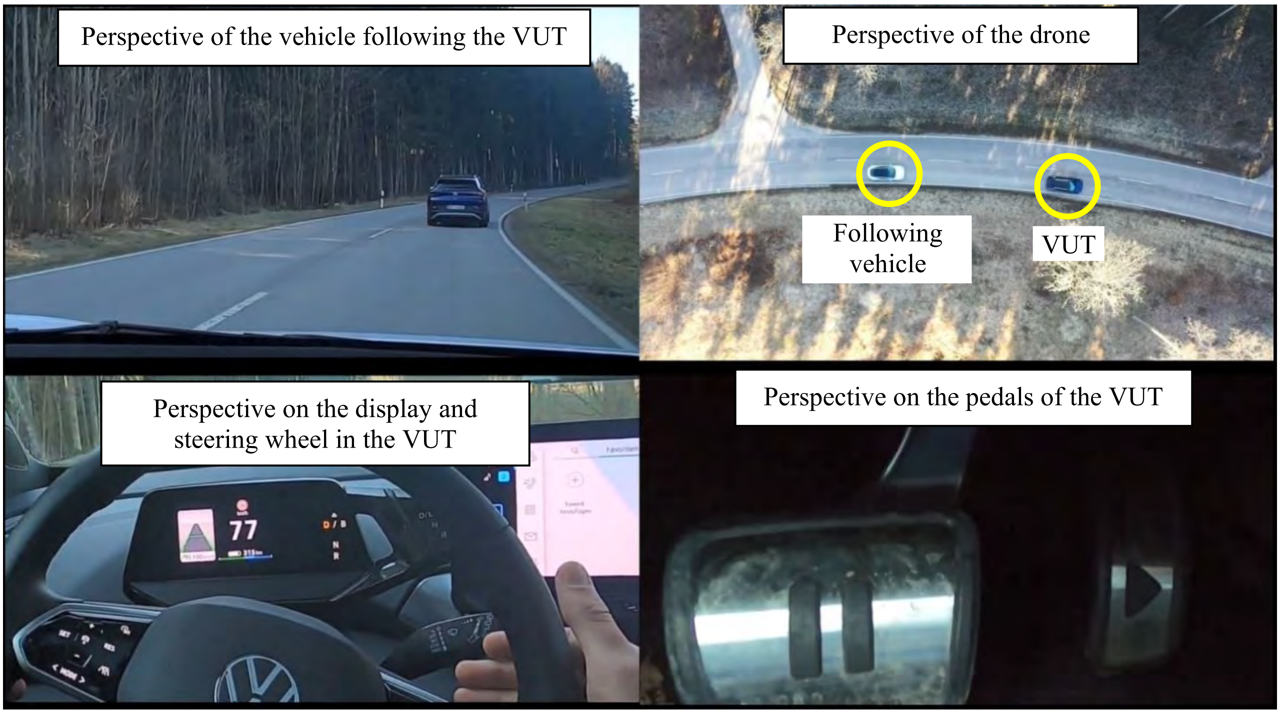


Fig. 2 Synchronized video recordings

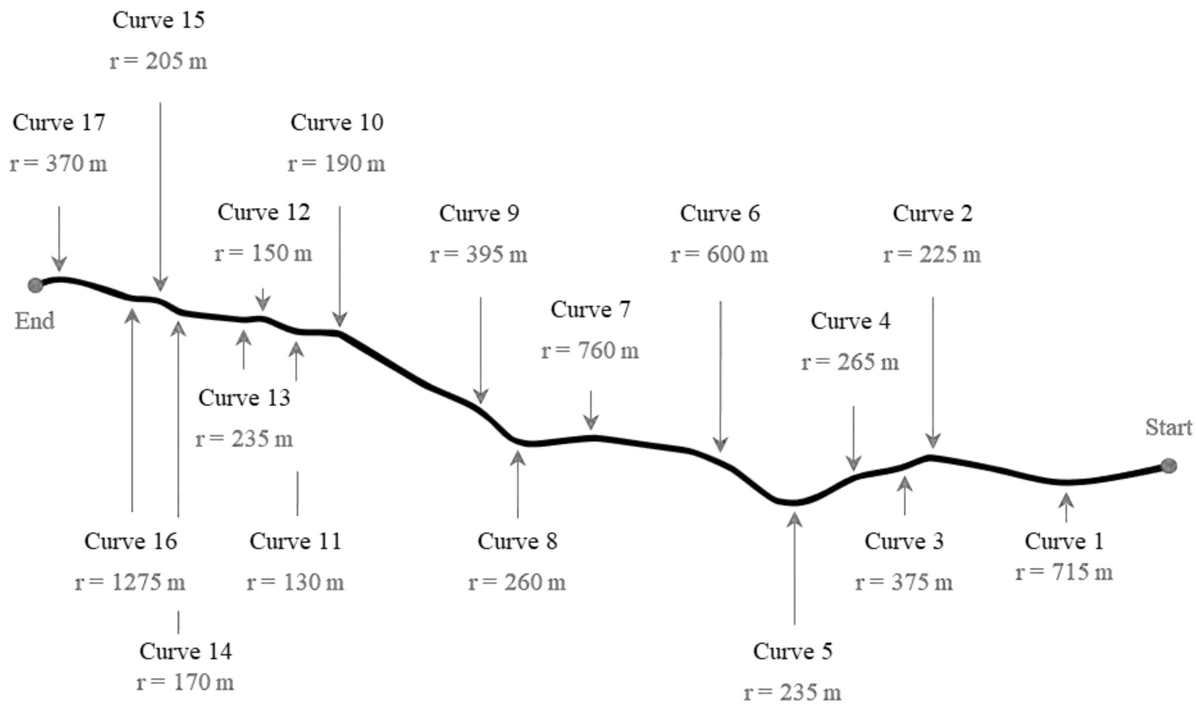


Fig. 3 Test track

The tests were carried out on a curvy country road near Ingolstadt (see Fig. 3). Each test series was started at a parking lot adjacent to the test track. The test track had a total length of approx. 11 km with a total of 17 curves. 9 of them were left hand curves and 8 were right hand curves. Each test run ended shortly before reaching a town entrance. Fig. 2 shows that the country road was continuously marked with a solid and clearly visible white lane marking toward the right edge of the road. The lane was visually demarcated from the oncoming lane by a clearly visible white dashed center line. The test was always carried out during dry conditions and daylight with clear visibility. The curve radii were determined using aerial photographs taken from the online tool "BayernAtlas" of the Bavarian Surveying Administration [14]. To verify the dimensions, a large number of high-resolution images were taken of five curves using a camera attached to a drone. These images were processed with the image processing software Agisoft Metashape Professional [15] to create a scaled orthogonal view of the individual curves.

Neglecting the transverse inclination of the road, which seems acceptable for the present curve topology, the limit value of the curve radius can be calculated in a good approximation from the target speed of 100 km/h (v_{zul}) specified for the ACC system and the maximum lateral acceleration ($a_{y,zul}$ of the LCA system of 3 m/s² with the aid of formula 1, up to which it should be possible for the ADAS to negotiate the curve within its own lane without any problems. This limit curve radius is, therefore, in the range of approx. 260 m.

$$r = \frac{(v_{zul})^2}{a_{y,zul}}. \quad (1)$$

Before each test start, the measurement technology was calibrated, tested and activated on the parking lot. The SAE Level 2 system was activated by the driver after the start to ensure that curve 1 was reached at v_{zul} = 100 km/h during all test runs. In order to ensure that the driver could not influence the system behavior to be analyzed, he did not apply the accelerator or brake pedal. The driver also took his hands off the steering wheel and only confirmed his presence every 15 s by slightly turning the steering wheel after being prompted to do so by the system in accordance with UNECE Regulation No. 79. The driver did not take any steering or braking action until a dangerous driving situation occurred.

Four test runs were conducted with both the Tesla Autopilot and the VW Travel Assist. During one test run with the Tesla, the Autopilot had to be deactivated by the test driver due to the high traffic volume, so an evaluation of this test series was deemed inappropriate. During a test run with the VW Travel Assist, no measurement data were recorded by the 2D data logger. Thus, for both the Tesla Autopilot and the VW Travel Assist, a total of three test runs each could be analyzed and evaluated for all 17 curves.

3. Results

Based on the previous calculation that the limit curve radius is theoretically in the range of approx. 260 m, up to which it should be possible for VW Travel Assist or Tesla Autopilot to drive through the curve within its own lane without any problems, an evaluation of curves with a radius $r \leq 260$ m was carried out in the first step. For this purpose, curves 11 and 14 are described in detail since they also represent the narrowest curves and thus the "worst case" scenarios. Based on this, the performance in the other curves is explained and discussed.

3.1. Evaluation of Curve 11

According to Fig. 3, curve 11 with a curve radius of r = 130 m is the narrowest curve of the test track. When driving through the right turn with the VW Travel Assist, it was observed in all test runs that the vehicle moved from its own lane to the left into the oncoming lane. The behavior of the VW Travel Assist during the passage of curve 11 is described and illustrated below in individual steps in terms of time and location.

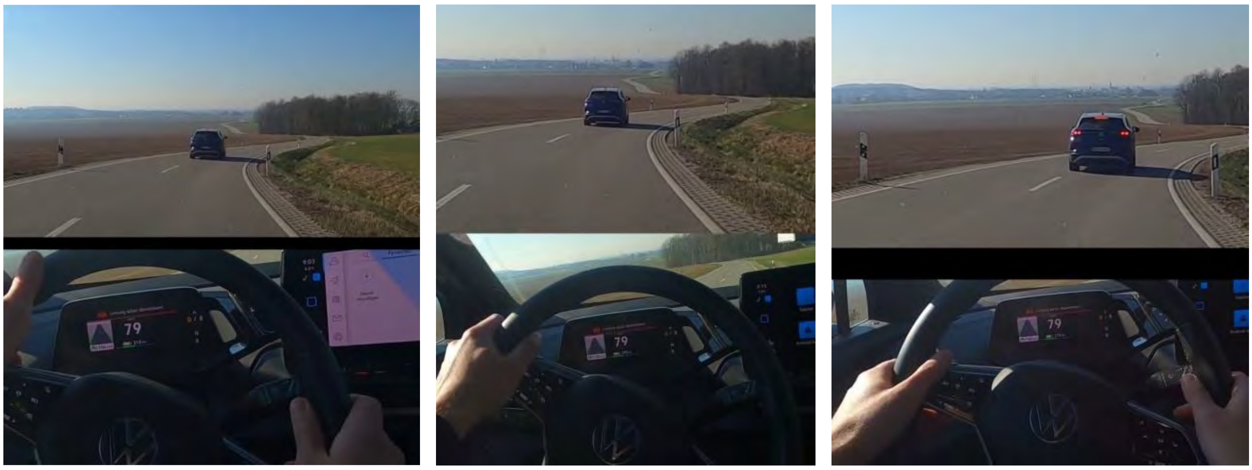
The test evaluation showed that in all three tests, the message "Curve ahead 80 km/h" appeared on the display of the VW ID.4 before the entry of curve 11 was reached. In the first test run, the message appeared approx. 200 m before reaching the entry of curve 11. At this point, the driving speed was 97 km/h (v_tachometer) according to the tachometer and around 94 km/h (v_data_logger) according to the measured values of the data logger. In test runs 2 and 3, the message was shown on the display about 180 m before reaching the entry of curve 11. At this point in time, the vehicle speed was 95 km/h according to the tachometer and around 93 km/h according to the data logger measurements.

The speed deviation between the indicated tachometer speed and the measured speed by the 2D data logger of 2 - 3 km/h is due to the fact that the speed indicated in the tachometer is usually a few km/h higher than the real driving speed due to the legally prescribed tachometer advance as well as filtering measures to avoid jumps in the display [16].

Further on, it might have been expected that the ADAS would decelerate the vehicle on its own in response to the message "curve ahead 80 km/h" to reach the entry of the right-hand curve with this target speed. Consequently, in the second step, the positions on the road with the associated measured values of the VW ID.4 were analyzed until the point of reaching the curve entry. In the course of the evaluation of the measurement data, it could be determined for all test runs that the ADAS did not perform any significant deceleration for approx. 3 - 4 s after the message "Curve ahead 80 km/h". After this period, a deceleration in a range of 1.4 - 1.6 m/s² was executed by the system in test 1. In test 2, a deceleration in a range of 1.0 - 1.3 m/s² was executed by the system, and in test 3, a deceleration in a range of 1.2 - 1.5 m/s² was executed. The brake output speeds in all tests were 93 - 95 km/h according to the tachometer and 92 - 93 km/h according to the data logger. It is also interesting that the position of the vehicle when the brakes are applied is almost identical in all test runs. Therefore, in all tests, the curve entry area was reached approx. 75 m or 3 s after the brakes were applied, with a speed of 85 - 87 km/h according to the tachometer or 82 - 84 km/h according to the data logger.

Based on the positions of the test vehicle when entering the curve, the next step was to analyze the system while driving through the curve. In all three test runs, an almost identical system behavior could be determined. Here, the vehicle crossed the lane marking approximately 1.6 s or 32 m after reaching the curve entry. The displayed tachometer speed of the VW ID.4 at this position was around 80 km/h. The speed recorded by the data logger was approximately 77 km/h. Likewise, longitudinal deceleration in a range of approx. 1.2 m/s² continued to be executed in all tests until the position was reached when the vehicle crossed the center line. The maximum transverse acceleration performed by the system during cornering was 2.2 - 2.3 m/s². Furthermore, it was possible to observe the identical system behavior in all tests, after crossing the center line. The vehicle drove on the opposite lane for approx. 0.6 s or approx. 13 m with a lateral acceleration of approx. 2.1 - 2.2 m/s² until the warning message "Take over steering immediately!" prompted in the display (see Fig. 4). During this period, the longitudinal deceleration of the vehicle was also reduced to approx. 0.4 - 0.7 m/s². An acoustic warning could not be documented. There was also no deactivation of the ADAS by the vehicle itself at the time of leaving its own lane.

In all tests, the test driver immediately overrode the ADAS at the time of the warning message "Take over steering immediately!" by steering for returning to its lane.



Test 1 Test 2 Test 3

Fig. 4 Positions of the VW ID.4 at the time of the warning "Take over steering immediately!"

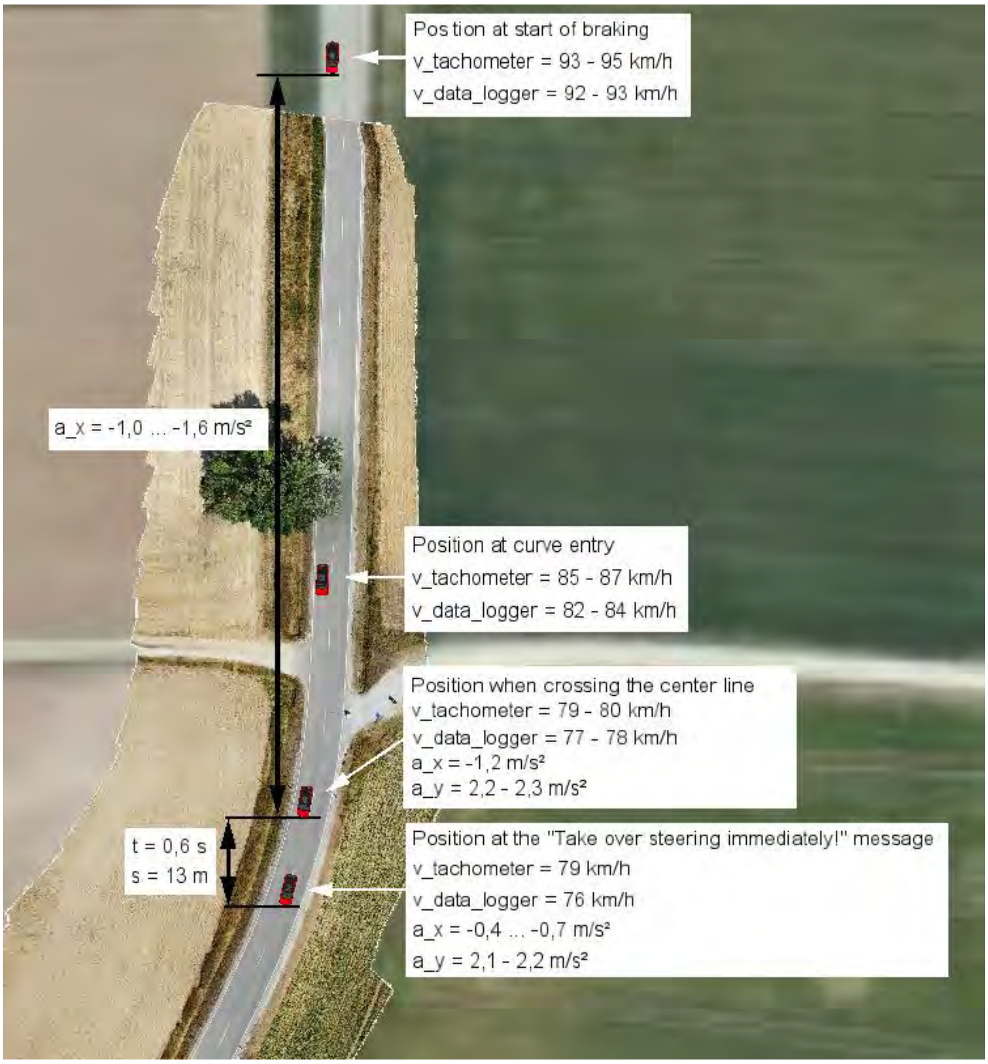


Fig. 5 Positions of the VW ID.4 on the roadway during the passage of curve 11

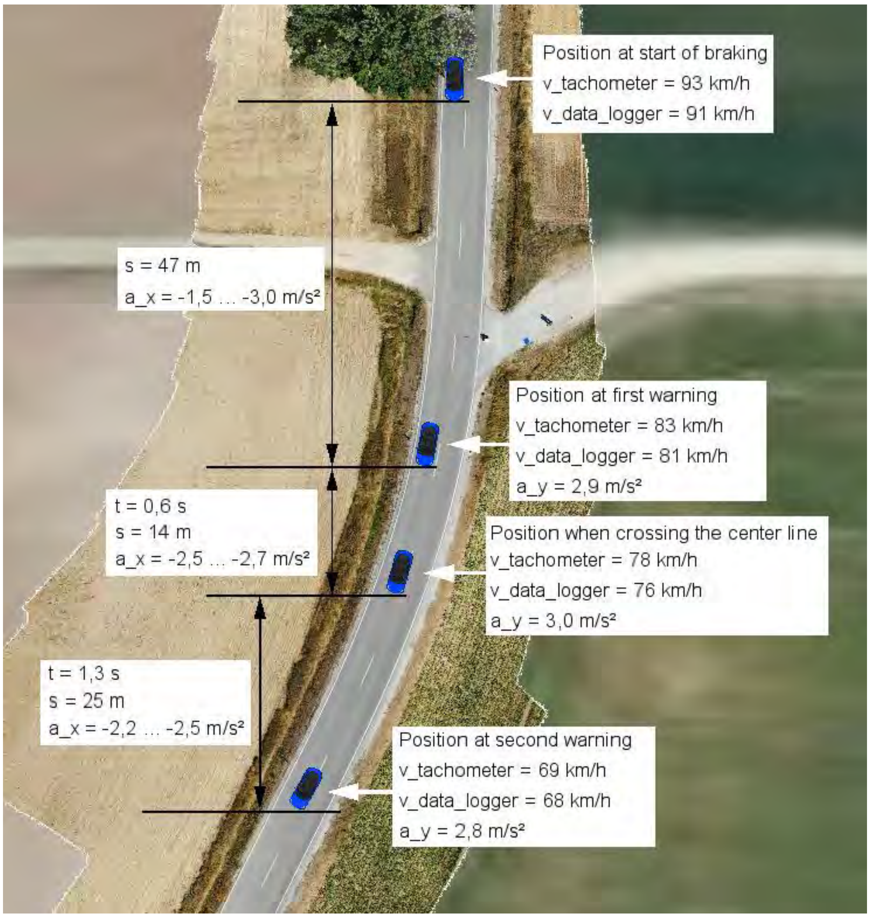


Fig. 6 Driving trajectory of the Tesla Model 3 during test runs 1 and 2

It can be stated that according to formula 1, considering the curve radius $r = 130$ m as well as the permissible lateral acceleration ($a_{y,zul}$ of the LCA system of 3 m/s² in accordance with UNECE R 79, the curve limiting speed is 71 km/h. That the VW Travel Assist moved into the opposite lane in all test runs can consequently be attributed to the fact that the tachometer speed at the time of crossing the center line was around 80 km/h and additionally only a lateral acceleration of 2.2 - 2.3 m/s² was induced.

The test results of the VW Travel Assist are summarized in Fig. 5.

The identical test series was also executed with the Tesla Autopilot. Again, when passing through curve 11, a departure from the own lane to the left to the oncoming lane could be detected in all test runs. Differences in the warning concept between Tesla and VW were also identified during the test evaluations. While the VW Travel Assist displayed the message "curve ahead 80 km/h" approx. 180 - 200 m before reaching the entry of curve 11, the Tesla Autopilot did not give any notification.

During the test evaluation, an almost identical system behavior was determined in two test runs. Before entering the curve, the Tesla Autopilot initiated a deceleration in a range of 1.5 - 3.0 m/s², which was also continued while driving through the curve. Further, the videos with the synchronized measurements showed that the Tesla Autopilot not only reduced the speed while driving through the curve, but also increased the lateral acceleration at the same time until reaching $a_{y,zul} = 3$ m/s². At the time when the permissible lateral acceleration was reached, an acoustic and visual warning was issued to the driver, displaying a text field with the statement that the driver should take over the steering wheel, together with a yellow warning triangle. At the time of these warnings, the test vehicle was in its lane. Another 0.6 s later, the road marking was crossed, and the test vehicle moved into the oncoming lane. After another 1.3 s, a loud, fast, and aggressive warning sound was emitted. In parallel, the display showed a red steering wheel with a request to take over the steering immediately. The almost identical driving trajectory of the autopilot during test runs 1 and 2 is shown in Fig. 6.

Moreover, based on the position of the vehicle at the time of the second warning in Fig. 6 as well as in the videos, Tesla Autopilot intended to actively steer the vehicle back into its lane. In the third test run, the system was able to achieve this, which can be attributed to a lower braking output speed before the curve entry. The position of the vehicle at the first warning was almost identical to those in the first two trials, but the tachometer speed was 75 km/h. Due to an identical deceleration behavior, the vehicle crossed the lane marking about 5 m later with a tachometer speed of about 71 km/h. The autopilot further decelerated the vehicle to a tachometer speed of 60 km/h and then steered the vehicle back into its lane. The long, fast, and aggressive warning sound from the first two tests was not activated during this test. Nor did the display show a red steering wheel with a request to take over the steering immediately.

Overall, the tests in curve 11 showed that the activated "Active Driving Assistance System" caused the vehicle to leave its own lane in all test runs. Despite partially diverging speeds and decelerations, it could be deduced from the tests according to Fig. 7 that the vehicles always left their lane around the curve apex.

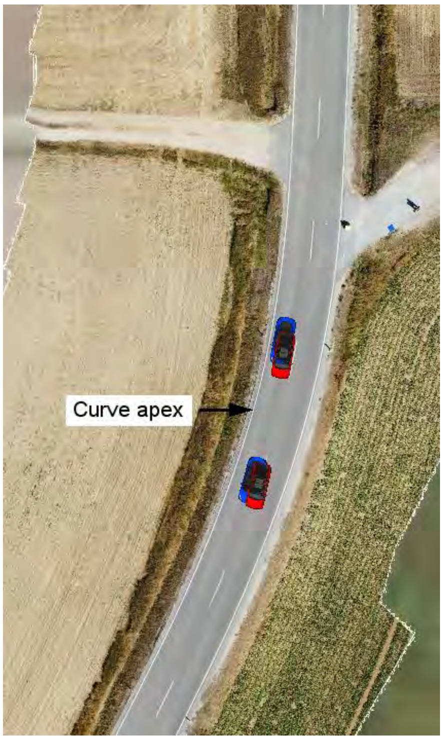


Fig. 7 Leaving the lane around the curve apex

A deactivation of the system by the vehicle when reaching the system limits could not be observed in any test run. The different warning concepts of the Tesla Autopilot and VW Travel Assist are also very interesting. While the Tesla Autopilot prompted the driver to take over the steering wheel about 0.6 s before crossing the lane marking, the VW Travel Assist warned the driver only about 0.6 s after crossing the lane marking. Furthermore, it can be seen in Fig. 7 that the VW Travel Assist left its own lane at a more acute angle than the Tesla Autopilot. This resulted in an almost complete movement of the VW ID.4 into the oncoming lane requiring the test driver to perform an intensive counter steering movement. Physically, this can be explained by the fact that the VW Travel Assist, compared to the Tesla Autopilot, does not utilize the available lateral acceleration of $a_{y,zul}$ = 3 m/s² while executing a low braking deceleration.

3.2. Evaluation of curve 14

To reproduce the test results from curve 11 (r = 130 m), the test runs in the second narrowest curve of the test track (curve 14; r = 170 m) were analyzed using the identical evaluation procedure. When driving through this right-hand curve, in all test runs, both the VW Travel Assist and the Tesla Autopilot caused the vehicle to move from its own lane over the lane marking to the left into the oncoming lane.

First, the activities of the VW Travel Assist while driving through the curve shall be illustrated and analyzed. In all three tests, the display of the VW ID.4 showed the message "Curve ahead 75 km/h" at a driving speed of approx. 83 km/h according to the tachometer (approx. 79 km/h according to the data logger). At this point, the position of the VUT is always about 200 m from the entrance of the curve during the three test runs. Within the following approx. 5 s or approx. 90 m, the vehicle initially accelerated up to approx. 88 km/h according to the tachometer (data logger: approx. 86 km/h) before a slight longitudinal deceleration in the range of 0.4 m/s² was initiated by the system.

At the entrance of the curve, the vehicle moves correspondingly with a longitudinal speed of approx. 84 km/h (tachometer) or approx. 81 km/h (data logger). The curve entrance was defined based on the driving trajectory of the VUT and the associated generation of the lateral acceleration. About 2.3 s later, at a speed of about 76 - 77 km/h according to the tachometer (data logger approx. 74 - 75 km/h), the car leaves its own lane to the left and drives over the lane marking into the oncoming lane. At this point, the data logger records a lateral acceleration of approx. 2.0 - 2.1 m/s².

After leaving its own lane into the oncoming lane, the lateral acceleration directed to the right increases to approx. 2.4 m/s² in all tests. Around 1.0 s or 12 m after crossing the lane marking, the message "Take over steering immediately!" appears in the display of the instrument cluster. The positions of the vehicle at this point in time in the three test runs are shown in Fig. 8. Again, there was neither an acoustic warning nor a deactivation of the ADAS on the vehicle side.

Test 1 Test 2 Test 3

Fig. 8 Video recordings of the positions of the VW ID.4 at the time of the warning message "Take over steering immediately!" during driving through curve 14

The explanations are summarized in Fig 9.

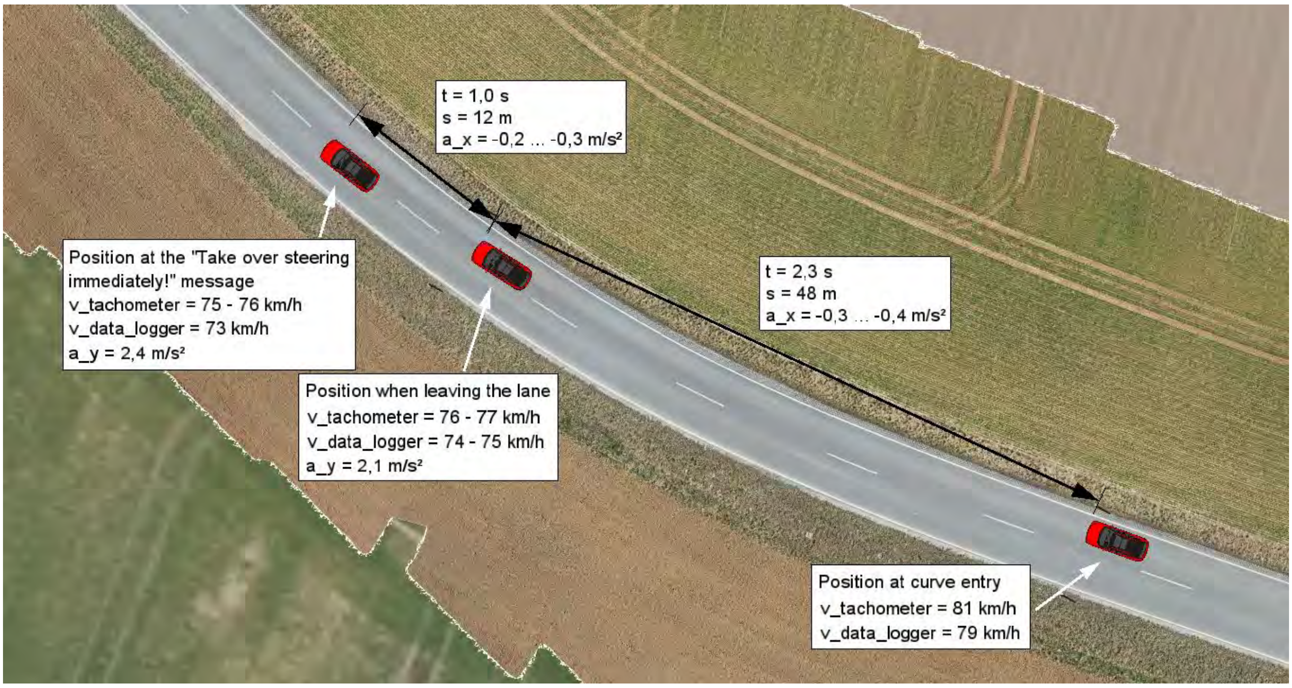
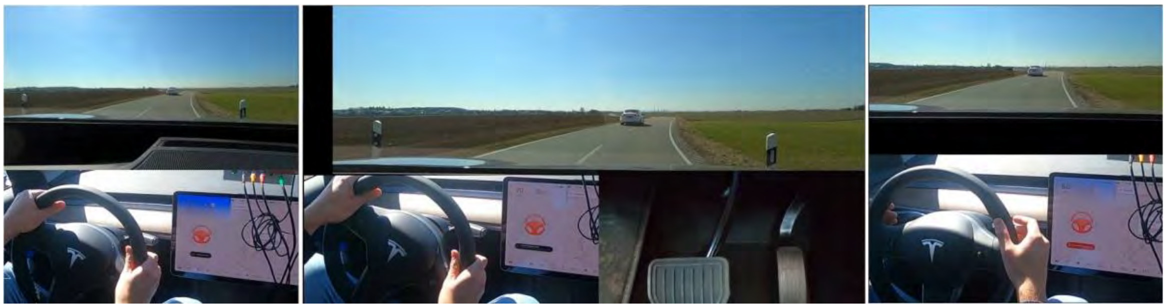


Fig. 9 Positions of the VW ID.4 on the roadway during driving through curve 14

The Autopilot of the Tesla Model 3 shows a different system behavior. It does not issue a message when approaching the curve, nor does it reduce the speed. Accordingly, the Tesla Model 3 enters the right curve during the three test runs at speeds between about 88 km/h and 94 km/h (tachometer) respectively about 88 km/h to 92 km/h (data logger). Again, the start of driving through the curve is determined based on the recorded lateral accelerations. When entering the curve, only slight braking occurred with decelerations in the range of approx. 0.2 m/s^2.

About 2 s or approx. 40 m later, the VUT departs from its own lane to the left into oncoming traffic by crossing the lane marking. Almost at the same time, a low-threshold warning message with a yellow warning triangle and a request to take over the steering is shown on the vehicle display. At this point, the maximum lateral accelerations achieved by the autopilot in the range of approx. 2.9 m/s^2 to 3 m/s^2 are also recorded. Furthermore, a braking maneuver with a deceleration in the range of approx. 1.6 m/s^2 to 2.7 m/s^2 is initiated when driving at speeds between approx. 82 km/h and 86 km/h (tachometer) respectively 78 km/h to 86 km/h (data logger).

About 1 s to 2 s or approx. 25 m later, the VUT is already completely in the oncoming lane. At this point, a long, fast and aggressive warning sound is emitted with a clear request for the driver to take over the steering wheel immediately (see Fig. 10). At this point, the driving speed is in a range of about 66 km/h to 73 km/h (tachometer) respectively about 62 km/h to 69 km/h (data logger).



Test 1 Test 2 Test 3

Fig. 10 Video recordings of the positions of the Tesla Model 3 at the time of the warning message "Take over steering immediately!" during driving through curve 14

The explanations are summarized in Fig 11.

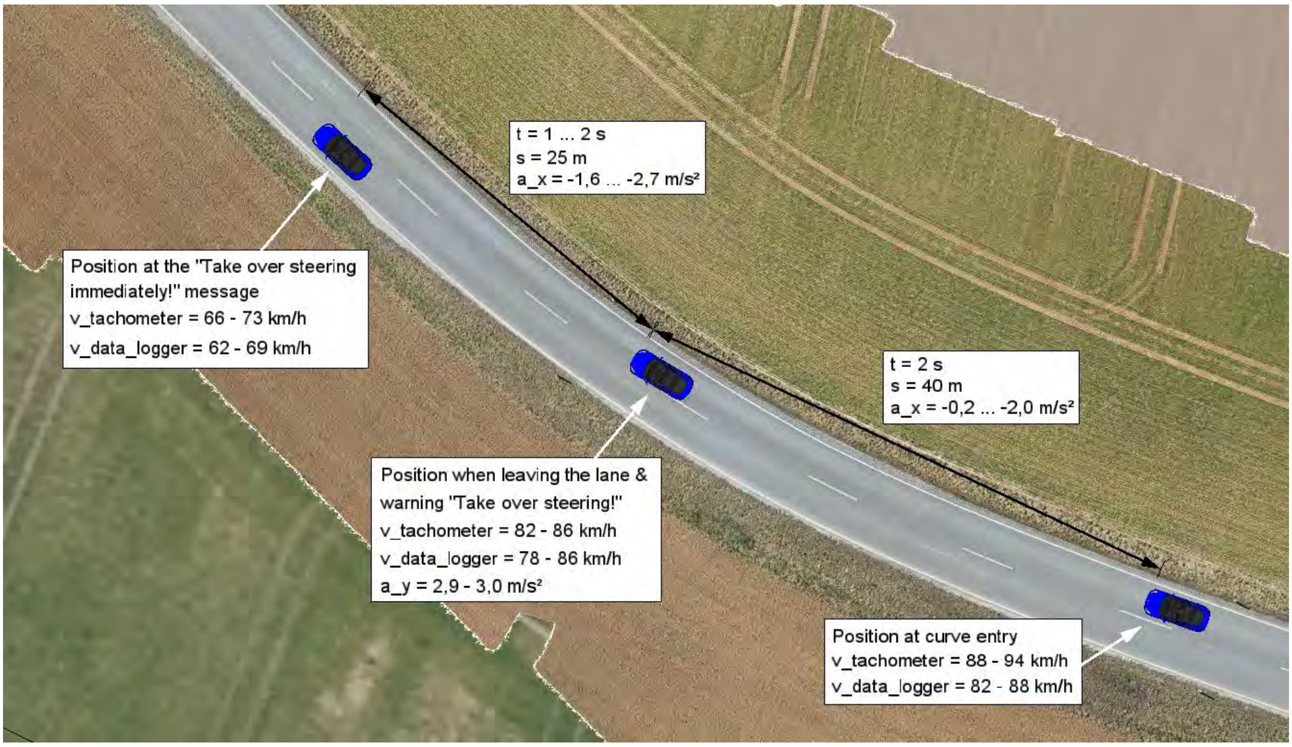


Fig. 11 Positions of the Tesla Model 3 on the roadway during driving through curve 14

Overall, the tests in curve 14 showed that the activated "Active Driving Assistance System" caused the vehicles to leave their own lane in all test runs. Despite partially diverging speeds and braking decelerations, it could be deduced from the tests that the vehicles always left their lane in the area of the curve apex. This system behavior could also be reproduced in curve 11.

It can be stated that according to formula 1, considering the curve radius $r = 170$ m and the maximum permissible lateral acceleration ($a_{y,zul}$ of the LCA system of 3 m/s² according to UNECE R 79, the curve can be driven with a maximum speed of approx. 81 km/h. This speed was reached in all tests by the VW Travel Assist when entering a curve. However, at the time of leaving the lane, the VW Travel Assist performed a lateral acceleration of only approx. 2.1 m/s². The fact that the VW Travel Assist - as already in curve 11 - did not perform the permissible lateral acceleration of $a_{y,zul} = 3$ m/s² over the entire time of driving through the curve should have been compensated with a significant speed reduction, which, however, was not performed. The Tesla Autopilot, on the other hand, was executing the permissible lateral acceleration ($a_{y,zul}$ of the LCA system of 3.0 m/s² at the time of leaving the lane. However, the speed was above the curve speed limit over the entire distance between the curve entrance and the point where the vehicle left the lane. In this case, a higher lateral acceleration than permitted would have been necessary to drive safely through the curve.

3.3. Evaluation of the Remaining Curves

In addition to curves 11 and 14, the measurements and videos from the runs in all other curves of the test track were also analyzed.

As already explained, the test driver always had to override and thus deactivate the ADAS while driving through curves 11 and 14 to be able to ensure a safe test drive. Due to the short time sequence until reaching curve 12 (r = 150 m) as well as curve 13 (r = 235 m) and curve 15 (r = 205), it was not possible for the test driver to reactivate the system in time. As a result, it was not possible to record any measurements for the passage through curves 12, 13 and 15 that would allow a well-founded evaluation.

In curve 10 (r = 190 m), the Tesla Autopilot and VW Travel Assist behaved identically to curves 11 and 14. It should be mentioned that curve 10 was a left-hand curve. Accordingly, the test driver had to execute a counter steering movement shortly before or during the departure from the lane to the right around the curve apex in order to avoid leaving the paved lane. In the three test runs, VW Travel Assist performed a maximum lateral acceleration of 1.8 - 1.9 m/s² at a speed of around 94 km/h when leaving the lane. Tesla Autopilot performed a lateral acceleration of 2.7 - 3.0 m/s² at a speed range of 90 - 93 km/h. At a curve limiting speed $v(a_{y,zul})$ of approx. 86 km/h, it is obvious that the speed of the vehicles was too high for a safe passage of the curve.

The radius of right-hand curve no. 8 was measured at around 260 m. To drive through the curve with 100 km/h, a constant lateral acceleration of approx. 3 m/s² would be necessary from the curve entry to the curve exit. In all test runs of the VW and Tesla, no lane departure could be detected. The VW Travel Assist reduced the speed to about 75 km/h at the apex of the curve with a lateral acceleration of about 2.1 m/s². Tesla Autopilot reduced the speed to a range of 82 - 89 km/h, with a lateral acceleration of 2.4 - 2.7 m/s².

In curve 2 (r = 225 m), curve 4 (r = 265 m) and curve 5 (r = 235 m), a departure from the lane was observed in all test runs of the VW Travel Assist. This can be attributed to insufficient lateral acceleration in combination to high speed. With the Tesla Autopilot, no departure could be detected during driving through these three curves.

As expected, due to the large curve radius, no lane departure was detected at curve 1 (r = 715 m), curve 3 (r = 375 m), curve 6 (r = 600 m), curve 7 (r = 760 m), curve 9 (r = 395 m), curve 16 (r = 1275 m), and curve 17 (r = 370 m).

4. Discussion and Conclusions

The tests carried out were intended to provide information on whether an activated "Active Driving Assistance System" can lead to the vehicle leaving its own lane without deactivating itself in advance and prompting the driver in time to take over the steering immediately. The tests carried out for this purpose with a VW Travel Assist and a Tesla Autopilot clearly showed a departure from the own lane in curves with a radius of about 130 - 190 m. In the examined curves with a radius of about 225 - 265 m, the Tesla Autopilot did not deviate from its own lane. The VW Travel Assist, on the other hand, left its lane in three out of four curves with this radius range because, in contrast to the Tesla, it did not fully utilize the permissible lateral acceleration of 3m/s². In the curves with a radius ≥ 370 m, no departure was observed for these two systems.

Lane departure towards the outside of a curve is caused by a speed that is too high in relation to the technically permissible lateral acceleration of the LCA system when entering the curve. Various approaches are possible to avoid lane departure in the future, especially in tight curves. On the one hand, the permissible lateral acceleration ($a_{y,zul}$) of 3 m/s² that can be applied by the LCA system according to UNECE R 79 could be increased. Alternatively, considering the curve radii that can be determined from digital maps, the speed of the vehicle would have to be reliably reduced by the Active Driving Assistance system even before entering the curve to such an extent that the curve can be safely passed within its own lane while maintaining the prescribed maximum lateral acceleration. Furthermore, in order to increase road safety, it seems plausible to check the system behavior during driving through tight curves in the future as part of the homologation process.

On the other hand, it can be argued that the driver must be able to control his vehicle at any time and, due to the system monitoring that he has to perform permanently, must be able to control the vehicle immediately if a takeover request appears. The vehicle manufacturers also highlight this in their manuals, as well as the fact that system limitations can occur, particularly in tight curves. However, the test results showed that it is not possible for a technical layman to assess whether the curve ahead is below the threshold of the system-side curve limit radius. In addition, according to the test results, VW Travel Assist did not visually prompt the driver to take over the steering until approx. 0.6 - 1.0 s after the vehicle had crossed the lane marking into the oncoming lane. There was no acoustic warning. With Tesla Autopilot, a low-threshold visual and acoustic message to the driver to take over the steering was usually given about 0.6 s before, but latest at the time of crossing the lane marking. However, a clearly perceptible indication was also only given when the vehicle was already in the oncoming lane. Considering a corresponding reaction time of the driver, the assumption is obvious that a departure from the own lane cannot be avoided by the driver if he only reacts to the takeover request. This also does not consider the fact that the driver technically has the option of taking his hands off the steering wheel for about 15 s, which would increase the reaction time even more. Overall, based on the test results, future studies should investigate whether a lane departure due to the system limitation of the SAE Level 2 system is at all controllable for the driver by a braking / steering maneuver and whether an accident can be avoided if the driver is not warned earlier about a possible exceeding of the system limits.

In order to ensure that, in the event of an oncoming traffic accident, the system activities in combination with the driver's actions can be fully and legally clarified by independent third parties, there is a mandatory need to store not only the driving dynamics parameters (e.g., lateral acceleration) but also the time and type of warning in combination with the vehicle's position in the lane in an extended Event Data Recorder (EDR). In order to clarify whether the system or the driver was controlling the vehicle at the time of the lane departure, as well as how the system and the driver interacted with each other, the Data Storage System for Automated Driving (DSSAD) should be mandatory not only in SAE Level

3 - 5 vehicles, but also in vehicles equipped with SAE Level 2 systems.

Acknowledgement

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Determining the Set of Elements for Automatic Monitoring and Diagnosing the Relay Interlocking System

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Abstract

The majority of train movement control within a station in Ukraine railways is achieved by the relay interlocking system (RI). There is no self-diagnosing in RI systems. Therefore, the time spent on failure recognition, localization and correction (especially those that occurred in the RI tower) is significant. Most RIs have been operating for more than 30 years, yielding a gradual increase in the failure rate and, consequently, delays. Failure effects can be reduced by automating the process of failure localization in RI applying the appropriate automatic monitoring and diagnosing (AMD) system. A subset of input signals of the latter is composed of signals from the sensors that measure the states of RI's elements. A large number of RI elements and limitations on the resources regarding the AMD system installation stipulate the virtual impossibility to equip all RI elements with corresponding sensors. The purpose of this research is to determine a set of elements in the tower-located part of RI to be equipped with corresponding sensors intended to be used in the AMD system, considering the limitations on the resources regarding the AMD system installation. In this research, we propose to apply fuzzy logic to consider assessing the appropriateness of including particular elements in the tower-located part of RI to the elements-under-monitoring (EM) set obtained from a single individual (Mamdani fuzzy inference system) or a group (rank ordering) of experts in the field of the RI operating. Research results yielded recommendations regarding the process of selecting the elements in the tower-located part of RI to be included in the EM set, considering the limitations on the resources regarding the AMD system installation. The AMD system development is out of the scope of the current research. Further studies are needed to provide an economic justification of the AMD system operation based on the EM set.
KEY WORDS: *relay interlocking system, failure, monitoring, diagnosing, fuzzy logic*

1. Introduction

Railway transport is the important component of Ukraine's economy. This is confirmed by the fact that in 2021 the Joint-stock company “Ukrainian Railway” (national carrier of cargos and passengers in Ukraine) transported 314.3 million tons of cargo [1]. As a rule, effective control of train traffic is achieved through the use of railway automation systems. In Ukraine, the control of train traffic within the railway station is carried out by the system of electric interlocking (EI). Most EI systems that used in the railway network of Ukraine are implemented on a relay element base (relay interlocking – RI). Specialists that maintain the RI systems report a gradual increase in the failure rate of such systems. According to specialists, one of the reasons for this is the excess standard service life of the RI systems (source: own survey at stations equipped with RI).

In RI systems, most failures are detected only after an attempt to use a failed element, instead of the failure occurrence [2]. Thus, in the general case, elimination of the failure requires a delay in the movement of trains (distortion of the train schedule), i.e. leads to increased risk of delays in the transportation of passengers and cargos.

Currently, prompt failure localization in the indoor equipment of the RI system and the determination of the failure causes are implemented through the actions of employees that maintain the RI system. A high level of qualification and extensive experience in the RI system are the mandatory requirement for these employees. Additionally, employees must reside in the RI tower (indoor) at the time of the failure recognition. That is difficult to achieve because the professional responsibilities of the employees also include outdoor operations, e.g. maintenance of the track objects in the railway station.

Alternatively, the failure localisation time may be reduced with automatic monitoring and diagnosing (AMD) of the actual state of RI elements. The AMD is implemented in modern EI systems based on microprocessors [3]. Application of AMD for the RI elements provides the following benefits: requirements for the qualification and experience of employees maintaining RI are simplified; the residence of the employee in the RI tower at the time of the failure recognition is not required; the failure recognition at the time of its occurrence is feasible. These benefits will reduce possible train delays. The development of the AMD system is beyond consideration in this paper.

Among the problems arising in the development of AMD systems for the indoor equipment of RI, there is a selection of the set of elements, which will be equipped with sensors to monitor their state (elements under monitoring – EM). Similar issues are considered in the field of technical diagnostics (see, for example [4]). A comprehensive solution is to assign all elements (relays) of indoor RI equipment to the set of EM. Large railway stations may include more than one thousand relays. Therefore, the cost of AMD equipment is expected to be relatively significant. On the other hand, in the case when the EM set includes relays having a relatively low degree of influence on the failure recognition in the RI indoor equipment, a sufficient level of the AMD system efficiency won't be achieved (a significant number of failures may not be detected).

There are various methods to determine the set of EM. In paper [5], a method to determine the EM set for the track equipment of the RI system, based on the statistical data, was proposed. This method considers the statistics of the following parameters [6]: the average delay duration of one train, the average delay duration of the train per one failure, the average number of delayed trains per one failure, etc. Paper [7] states that in the case of developing the AMD system for RI indoor equipment, the determination of the EM set is performed by the method of expert evaluations. Unfortunately, the literature review did not reveal an explicit description of the possible implementation of the expert evaluations. Therefore, the topic of this paper, which is devoted to determining the elements of RI indoor equipment that should be included in the EM set of AMD system, is relevant. The purpose of this paper is to define elements of the RI indoor part that must be equipped with appropriate sensors for use in the AMD system, considering the resource constraints regarding the installation of the AMD system.

Since a detailed description of the expert evaluation implementation to determine the EM set of the RI indoor equipment wasn't found in previous papers, the application of fuzzy logic to consider the expert evaluation has been proposed. Fuzzy logic has many applications for solving problems related to railway transport, e.g.: fault detection and identification for point machines [8], bearing fault diagnosis and degradation assessment [9], improving image processing to increase safety at the level crossings [10], tool for supporting decision-making in planning transport development on a strategic level [11]. However, the literature review did not reveal the application of fuzzy logic to determine the EM set of RI indoor part for use in the AMD.

To achieve the aim of investigation in this paper the following tasks have been solved.

1. Seven properties of the element by which the expert evaluated the appropriateness of including the elements of RI system in the set of EM have been determined. Appropriate evaluation scales, based on the method of semantic differentials (SD), have been selected [12].

2. The Mamdani fuzzy inference system (FIS) [13], considering the one expert's opinion (E1P) on the appropriateness of including elements of the RI system in the EM set and based on previously selected seven properties has been designed.

3. To consider the opinions of the expert group (EGP), the membership function (MF) of the “The most significant property” fuzzy set for certain elements of the RI, using the rank ordering procedure, has been defined. Obtained results were used to set to the inputs of Mamdani FIS that developed in the previous step.

4. Comparison of the results obtained from Mamdani FIS in cases of E1P and EGP has been carried out.

2. Methods

2.1. Determining the Properties of RI Elements

We performed the initial steps of the SD method [12] to determine properties and corresponding scales for the expert’s evaluation of the appropriateness of including particular elements in the tower-located part of RI to the EM set for the AMD system. The SD method implies the use of bipolar scales with semantically opposite statements located at their ends. In this paper, we assumed the S scale as the following set

$$S = \{-3 \quad -2 \quad -1 \quad 0 \quad 1 \quad 2 \quad 3\}. \tag{1}$$

An employee of the JSC “Ukrainian railways” participated in this research as a volunteer expert with a high level of qualification and significant expertise in RI systems. The expert’s survey determined 7 properties designated as $a_1, a_2 \ldots a_7$ and corresponding opposite values in the “Positive value” and “Negative value” columns.

In the Ukrainian railway network, data about the failure rate (the a_3 property) of elements in the tower-located part of RI are collected centrally as an aggregated record (in a single field of a report). Therefore, it's quite problematically to obtain the corresponding value for a particular element in the tower-located part of RI from the official reports (for internal use only). However, data related to faulty elements are stored in the corresponding station logs. This allows to identify the failure rate for each element.

During the estimation of time (property a_5) spent on the failure correction of the element in the tower-located part of RI, the expert should consider the following:

1. The time of failure localization significantly depends on the presence of monitoring of the element's state through the dependencies in the RI system.

2. Failure category: systematic failure or intermittent failure.

Table 1

Properties to evaluate the elements in the RI system

Property ID	Property name	Property description	Positive value	Negative value
a_1	Impact of the element's failure on the rail traffic safety	The influence degree of the failure of the element in the tower-located part of RI	Impact is low	Causes hazardous failure
a_2	Impact of failure on the up state of RI system	The influence degree of the failure of the element on the up state of tower-located part of RI.	Up state is not lost	The system is in the down state
a_3	Failure rate	The failure rate of particular element in the tower-located part of RI	Failures are virtually absent	Failure rate is the highest
a_4	Deviations in the train schedule and delays in train movements within a station	The influence degree of the element in the tower-located part of RI on the train delay in case of this element's failure	Delays in train movements are absent	Delays in train movements are the biggest
a_5	Down time	The time spent on the failure correction of the element in the tower-located part of RI	Is the lowest	Is the highest
a_6	Indirect monitoring	The degree of monitoring of the state of the element in the tower-located part of RI that is provided through other elements.	Is possible	Is impossible
a_7	Maintenance time	The time and periodicity of testing the state of the element in the tower-located part of RI	Is minimal	Is maximal

2.2. Developing the Fuzzy Inference System that Considers the Opinion of a Single Expert

To consider the E1P the Mamdani FIS was developed (see the structure in Fig. 1).

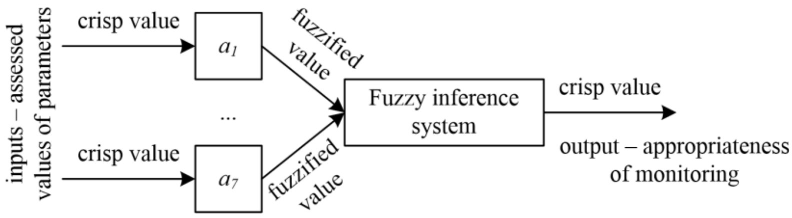


Fig. 1 Structure of Mamdani fuzzy inference system

A number from the S set (see Eq. (1)) was set to inputs of each property (Table 1) in Mamdani FIS (Fig. 1). One expert evaluated numeric values of inputs for the $a_1, a_2 \ldots a_7$ properties of a particular element in the RI system, which should be evaluated for the appropriateness of including in the EM set. At Mamdani FIS's output, the numeric value in a closed interval of real numbers $[0,1]$ was returned, where 0 means the "element is not appropriate to be included in the EM set", 1 - the "element is appropriate to be included in the EM set".

Sets of linguistic values and linguistic variables [13] in the Mamdani FIS (Fig. 1):

1. Inputs were set according to Table 1: $a_i \in \{$"Positive value" "Negative value"$\}$.
2. Output ("Appropriateness of monitoring"): $b \in \{$"Element is not monitored" "Element is monitored"$\}$.

The output value of Mamdani FIS was additionally defined by:

1. MFs of inputs: $\mu_{ai,j}(x)$, where $i \in \{1,2\ldots7\}$ – number of the input (property), $j \in \{1,2\}$ – index designating the values "Positive value" and "Negative value", correspondingly. The $x \in S$ was assumed.
2. MF of the output: $\mu_{b,1}(y)$ – "Element is not monitored", $\mu_{b,2}(y)$ – "Element is monitored". The $y \in [0,1]$ was assumed.
3. Rules in the "IF-THEN" form, mapping the inputs to the output.

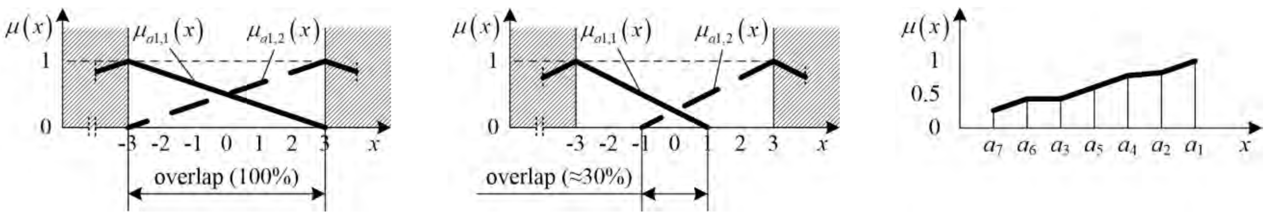
In this study, it was assumed that $\mu_{ai,1}(x)$ and $\mu_{b,1}(y)$ ($\mu_{ai,2}(x)$ and $\mu_{b,2}(y)$) are monotonically decreasing (increasing) and linear over the domain. I.e. the "convex" and "normal" [13].

MFs of inputs and output were implemented in a "triangle" form:

$$f\left(x;a,b,c\right)=\max\left(\min\left(\frac{x-a}{b-a},\frac{c-x}{c-b}\right),0\right), \tag{2}$$

where a, b, and c are numeric parameters, which define the position and shape of a triangle function.

The MFs' shape $\mu_{a1,1}\left(x\right)=f\left(x;-9,-3,3\right)$ and $\mu_{a1,2}\left(x\right)=f\left(x;-3,3,9\right)$ according to Eq. (2) for a_1 is shown in Fig. 2, a. The dashed area on the Fig. 2, a and b plots – values that are out of the domain.



a b c

Fig. 2 Membership functions: a – for the a_1 property in E1P (100 % MF domain overlapping); b – for the a_1 property in E1P (approx. 30 % MF domain overlapping); c – for the "The most significant property" fuzzy set in EGP after being normalized to 1

Expert defined 24 conjunctive rules for the Mamdani FIS. Example of the rule: IF a_1 is "Negative value" AND a_2 is "Positive value" AND a_3 is "Negative value" AND a_4 is "Negative value" AND a_5 is "Positive value" AND a_6 is "Positive value" AND a_7 is "Positive value" THEN b is "Element is monitored".

2.3. Using the Fuzzy Inference System that Considers the Opinion of a Group of Experts

To consider the EGP, we developed the MF for the "The most significant property" fuzzy set by the rank ordering method [13]. To achieve this, 15 experts made a pairwise comparison of the properties for each RI element (Table 1). After comparing the a_i and a_j ($i \neq j$), each expert preferred one property to another. Results of comparisons were presented to the "antisymmetric" matrix. That allowed to order ranks for the properties and create the MF $\mu_{r,k}\left(z\right)$, where k – the number of RI element, $z \in \left\{a_1, a_2 \ldots a_7\right\}$. The MF value of each element was set to Mamdani FIS inputs (Fig. 1).

3. Results

We considered the following task: develop the AMD for RI system having the structure defined by the station's neck (Fig. 3). This part of the station includes 14 switches and 22 light signals. To ensure their operation the 678 relays are used. Table 2 contains the results of the expert's evaluation of the properties of 7 elements (relay) in the RI system having the structure shown in Fig. 3.

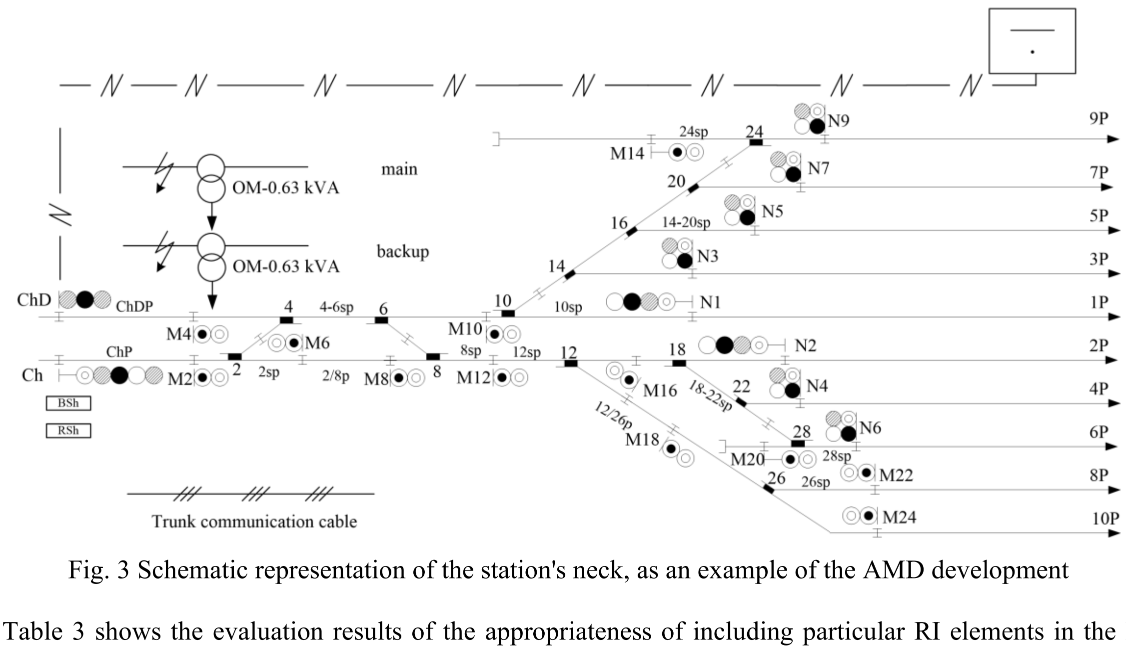


Fig. 3 Schematic representation of the station's neck, as an example of the AMD development

Table 3 shows the evaluation results of the appropriateness of including particular RI elements in the EM set.

Data in the "E1P-1" column correspond to 100% overlap of the MF domain (Fig. 2, a), and data in the "E1P-2" column – to 30% overlap of the MF domain (Fig. 2, b).

Table 4 shows the evaluation results for the "relay KS ChP" RI element provided by the group of 15 qualified experts, who worked with RI at different stations and participated in this research as volunteers. Analogous tables were obtained for the rest of six elements in the RI system. The "Total" column presents the row-wise sums of the experts' preferences. The "Fraction" column is a fraction of the sum in a row relative to the total number of comparisons (the "Total" row of the "Total" column). Considering the values in the "Fraction" column (maximum value ranked as 1, see Table 4) the rank ordering ("Rank order" column) was done and the MF of the "The most significant property" fuzzy set was defined. We normalised values in the "Fraction" column considering the maximum value (see the "Fraction norm." column visualised in Fig. 2, c) to map the MF domain in the $[0,1]$ interval. Values from the "Fraction norm." column were mapped in the S set (shifted, scaled and quantized), then presented in the "Fraction norm. mapped to S" column, and set to the corresponding inputs of the Mamdani FIS (Fig. 1) considering the 100% (EGP-1) overlap of the MF domain. The results were presented in Table 3.

Table 2

Evaluation results of the RI system elements

No.	Name of an element (relay)	a_1	a_2	a_3	a_4	a_5	a_6	a_7
1	NKN of the Ch light signal	3	2	1	2	-1	-2	-1
2	NKN of the N9 light signal	-1	-2	0	0	-1	-2	-1
3	S of the M2 light signal	1	1	0	1	-1	-1	-2
4	S of the M10 light signal	1	1	2	2	-1	-1	-2
5	S of the M14 light signal	-2	-2	-2	-2	-2	-2	-2
6	KS ChP	2	2	0	1	1	0	-2
7	KS 28SP	0	-2	-2	-2	1	0	-2

Table 3

Evaluation results of the RI system elements appropriateness of including in the EM set

No.	Name of an element (relay)	E1P-1	E1P-2	EGP-1
1	NKN of the Ch light signal	0,62	0,75	0,61
2	NKN of the N9 light signal	0,45	0,28	0,59
3	S of the M2 light signal	0,55	0,72	0,61
4	S of the M10 light signal	0,62	0,75	0,61
5	S of the M14 light signal	0,36	0,22	0,59
6	KS ChP	0,59	0,72	0,59
7	KS 28SP	0,41	0,28	0,58

Table 4

Evaluation results for the "relay KS ChP" RI element provided by the group of 15 experts

Properties to be compared with	Number of experts, who preferred these properties							Total	Fraction	Rank order	Fraction norm.	Fraction norm. mapped to S
	a_1	a_2	a_3	a_4	a_5	a_6	a_7					
a_1	–	10	14	8	12	13	15	72	0,23	1	1,00	3
a_2	5	–	11	7	10	12	14	59	0,19	2	0,83	2
a_3	1	4	–	5	6	7	10	33	0,10	5	0,43	0
a_4	7	8	10	–	9	11	13	58	0,18	3	0,78	2
a_5	3	5	9	6	–	9	11	43	0,14	4	0,61	1
a_6	2	3	8	4	6	–	9	32	0,10	6	0,43	0
a_7	0	1	5	2	4	6	–	18	0,06	7	0,26	-1
Total	–							72	1,00	–	–	–

4. Conclusions

In this study, we determined the set of elements in the tower-located part of RI, which is appropriate to equip with sensors that monitor the state of these elements and send corresponding signals to the AMD system inputs (the EM set). To achieve this, the qualified expert determined seven properties that were used in the evaluation of elements in the tower-located part of RI to determine the appropriateness of their including in the EM set. The evaluation scale for each property included the following values: –3, –2, –1, 0, 1, 2, 3. Values at the scale ends were selected semantically opposite (considering the SD method). Additionally, the expert developed 24 rules for the Mamdani FIS and evaluated seven RI elements (Table 2) considering the $a_1, a_2 \ldots a_7$ properties. Thus, the opinion of a single expert was considered – E1P.

Alternatively, the same Mamdani FIS was used to consider the opinion of the group of experts – EGP. To achieve this, we determined the MF for the "The most significant property" fuzzy set by the rank ordering method used for each of the same elements, which were considered to evaluate with E1P. Obtained evaluations of membership of the $a_1, a_2 \ldots a_7$ properties were normalised, mapped in the S set and sent to the corresponding Mamdani FIS inputs.

The results of Mamdani FIS (Table 3) were validated by the expert. In the expert's opinion, the degrees of the monitoring appropriateness among considered RI elements were best represented in the single expert's preference (E1P-2) for the MFs with the 30% (approx.) domain overlap (Fig. 2, b).

The results of evaluations with EGP-1 (Table 3) for elements No. 1, 3, and 4 were equal (the same is true for No. 2, 5, and 6). That was caused by the normalisation of the MF by its maximum value (the "Fraction norm." column in Table 4). Consequently, obtained MF and corresponding evaluations of properties always include at least one property equal to one. This may not correspond to the expert's evaluation of a particular element (e.g. see the second row in Table 2).

Application of the proposed process to select elements for AMD of the tower-located RI considering the single expert's preference (E1P-2), who maintains this system, allows assigning priorities of the appropriateness to monitor mentioned elements. That allows selecting the EM set considering limitations on the resources regarding the AMD system installation for a particular RI system.

Evaluation with E1P-2 was good enough in representing the evaluation of one expert. Further studies are mandatory to provide an economic justification for the AMD system developed with the proposed selection process.

Additionally, further studies may include the identification of the MF's shape impact on the result and an application of the cluster analysis to validate the Mamdani FIS results.

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Thermodynamic Analysis of the Conversion of the Auxiliary Power unit AI-9 to a Turboprop Engine

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Abstract

The primary function of the auxiliary power unit is to start the main engine or, for example, to supply electrical power to the instruments on-board the aircraft and auxiliary power units when the aircraft engines are shut down. However, the auxiliary power unit is capable, after appropriate engineering modification, of generating sufficient thrust to become a full propulsion unit for the propeller of the airplane. The object of research is to design an experimental solution for using an auxiliary energy unit and subsequently verify the functionality of the proposal. On the theoretical level, the manuscript describes the creation of an experimental engine. The design incorporates parts of other power units, namely the auxiliary power unit Ivchenko AI-9 and a free gas turbine with a reducer and a propeller from a Walter M601 B turboprop engine. By analytical calculations, the manuscript obtains thermodynamic analysis also for the experimental engine composed of the auxiliary power unit AI-9, supplemented by a free gas turbine and a reduction gear from the power unit M601 B. Consequently, the thermodynamic analyses of both investigated units were compared. Finally, the necessary changes to modify the experimental engine to be capable of producing maximum potential thrust.
KEY WORDS: *the Auxiliary Power Unit, AI-9, Turbo Propeller Engine, Experimental Engine, Thermodynamic Analysis*

1. Introduction

The Walter M601 engine is an inverted airflow turboprop engine, with one rotor, two shafts, and a free gas turbine. This type of power plant was manufactured by Walter Aircraft Engines in the Czech Republic since 1967, and Malorlet since 1975. Approximately 4,500 units have been produced and eighteen different types of engine models have been certified M601. It was primarily designed for the L-410 Turbolet aircraft [1-3]. The propulsion unit is composed of two basic parts, the first one is the gas generator section and the second part of the engine is the propulsion section in a tandem arrangement. The engine is also made up of non-classified elements such as the starter - generator, ignition unit, and accessory drive [4-5].

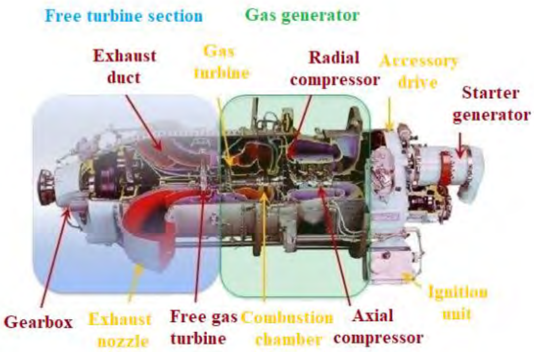

Fig. 1 Overview cross-section of the M601 B engine [3]

There were two parts of the M601 B engine used for the experimental engine. The first part was a free gas turbine, the second one was a reducer. The free gas turbine in the M601 B engine is located directly behind the gas generator turbine, which drives the compressor and auxiliary engine units directly, and thus the free gas turbine is the second stage of the gas turbine in the M601 B engine. It consists of a stator and a rotor. The reducer is located on the

M601 B motor and attached to the front flange of the output housing. It is used to transmit torque through the shaft to the propeller and also to reduce the speed to an acceptable value or level. Usually, the speed ratio is in the range of 1:10 to 1:20, here specifically 1:14.91. The ratio depends on the RPM on the gas turbine and the required RPM on the propeller [1-2].

The Auxiliary Power Unit or APU (The Auxiliary Power Unit) is a stand-alone device that is most commonly used aboard aircraft, ships, or heavy goods vehicles to supply power in various forms when we do not have the main power supply is not available. The most common form of APU in aviation is the gas turbine with a simple cycle. Compared to a reciprocating engine due to the weight per unit of shaft power output, it delivers better performance. It is these devices that ensure that the aircraft is independent of electrical power from ground generation units at airports [6-10].

1.1. APU Ivchenko AI-9

The AI-9 auxiliary power unit, shown in Fig. 2, was designed in 1966 by A. G. Ivchenko under Progress. It has been used in commercial aviation since 1969. It powers the launch systems of aircraft such as the Yak-40, M-15 and helicopters such as the Mi-17, Mi-24 [11-13].

The AI-9 auxiliary power unit consists of a drive cabinet, inlet gearbox, compressor, combustion chambers, turbine, exhaust system, header air by-pass valve, and the units serving the engine operation [14].

Fig. 2 Auxiliary Power Unit Ivchenko AI-9 [11]

2. Methodology

The basic thesis of this experiment is to prove the effectiveness and functionality of the experimental engine composed of an AI-9 auxiliary power unit and a free gas turbine and reducer from the WALTER M601 engine. In this part of the paper, the analytical thermodynamic properties. The calculation of the parameters is illustrated by a clear procedure, on the basis of the calculations of the values of the air in the inlet section, the radial compressor, the total gas pressure in the section downstream of the combustion chamber, the gas parameters in the gas turbine section for the AI-9 APU and for the free turbine, and in the outlet system M601 power unit. Values for specific thrust F_m, thrust F_t are also calculated and specific fuel consumption c_m. [10]

The values are calculated for maximum engine operation at ground power, at zero height, $H = 0$ m and at zero speed, $c = 0$ ms^{-1} and $M = 0$. The thermodynamic analysis was performed for 6 engine sections marked from section "0-0" to section "6-6". [10] The design of the experimental engine is shown in Fig. 3. In the figure, the different parts of the experimental power unit, such as the added free gas turbine or reducer, can be clearly observed.

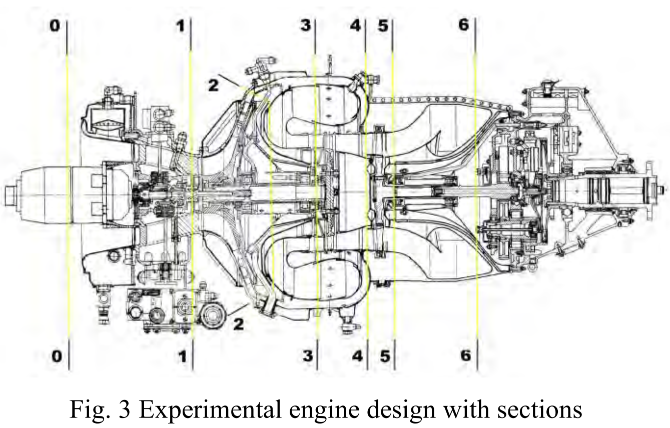

Fig. 3 Experimental engine design with sections

2.1. Calculation of the Thermodynamic Analysis

For the M-601 B turboprop engine, a thermodynamic auxiliary calculation of basic parameters of individual engine parts. On the basis of auxiliary calculations, conclusions were drawn and a comparison of performance with the experimental engine was made. The known basic parameters of the power unit have been obtained from the L410 UVP Aircraft Power plant Manual and from the Calculation Exercises of the Gas Turbines and Turbochargers. The actual calculations for the experimental engine were based on the theoretical knowledge of the specified basic parameters for the AI-9 auxiliary power unit and the M601 B turboprop aero-turbomachinery engine. The calculations for the experimental engine account for the air parameters upstream of the AI-9 APU inlet, at the compressor inlet, downstream of the compressor, compressor work, and gas parameters downstream of the combustion chamber and at the gas turbine outlet. They further calculate the gas parameters downstream of the free turbine added from the Walter M601a engine at the outlet. Lastly, the specific characteristics of the proposed machine are calculated and compared with those of the M601 B engine.

3. Results

The results of the thermodynamic analysis of the M601 B turboprop aircraft engine is compared with the results of the thermodynamic analysis of the experimental engine consisting of an inlet, compressor, combustion chamber, and gas turbine the auxiliary power unit AI-9, and the free gas turbine and reducer from the already the aforementioned M601 B power unit. Firstly, in Table 1 can be observed the parameters of the total pressures and total temperatures in the sections of the M601 B engine and the experimental engine.

Table 1

Comparison of Thermodynamic Analysis in Sections of the M601B and Experimental Engine

Temperature							
	T_{0c} [K]	**T_{1c} [K]**	**T_{2c} [K]**	**T_{3c} [K]**	**T_{4c} [K]**	**T_{5c} [K]**	**T_{6c} [K]**
	"0-0"	**"1-1"**	**"2-2"**	**"3-3"**	**"4-4"**	**"5-5"**	**"6-6"**
M601	288,150	288,150	526,024	1 225,150	1 017,667	828,550	811,279
Exp. engine	288,150	288,150	417,834	1 152,750	1 023,150	940,212	922,941
Pressure							
	p_{0c} [Pa]	**p_{1c} [Pa]**	**p_{2c} [Pa]**	**p_{3c} [Pa]**	**p_{4c} [Pa]**	**p_{5c} [Pa]**	**p_{6c} [Pa]**
	"0-0"	**"1-1"**	**"2-2"**	**"3-3"**	**"4-4"**	**"5-5"**	**"6-6"**
M601	101 325,600	100 312,34	647 014,619	627 604,180	276 439,519	111 341,183	110 303,860
Exp. engine	101 325,600	99 299,088	287 967,355	269 700,000	159 493,229	109 975,791	109 186,989

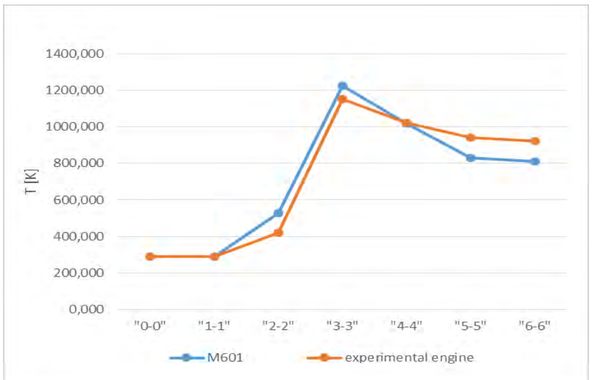

Fig. 4 Temperature analysis of M601B and experimental engine

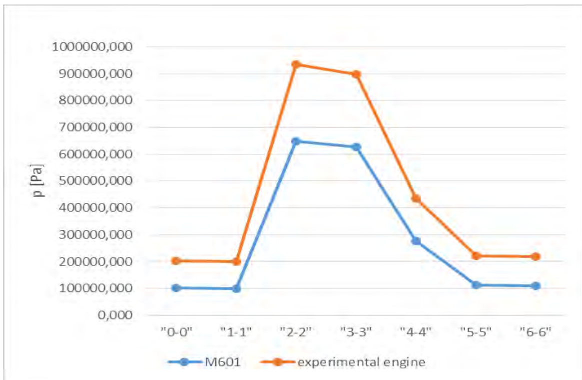

Fig. 5 Pressure analysis of M601B and experimental engine

In the '0-0' section - before entering the inlet of the power units, the total temperature T_{1c} for both engines is identical, equal to 288,15 K (Fig. 4). In the cut "1-1", upstream of the compressor, the total temperature difference is again zero. The total temperature T_{1c} for both power units is equal to 288,15 K. However the is a little difference between the total temperatures of compressors in section "2-2" it differs by 108,191 K, which stands for approximately 20,5%. The total temperature before gas turbine T_{3c} in sections "3-3" differs by 72,4 K. The hot gases leaving the combustion chamber expand in a gas turbine, where the heat and pressure energy is converted into kinetic energy. For this reason, a radical drop in temperature behind the combustion chamber in the "4-4" section can be observed, therefore, the total temperature behind the T_{4c} gas turbine has a value of 1017,667 K in the thermodynamic analysis of the M601 B and for the experimental engine is equal to 1 023,15 K, and thus the difference between the values of the total temperature behind the gas turbine is only 5,483 K. The same significant temperature values drop can be seen behind the free gas turbine T_{5c} and in the outlet nozzle section T_{6c} with identical total temperature differences 111,663 K.

The values for the total pressure vary considerably in respect of calculated power unit. However, the total pressure in the "0-0" section is identical for the engines being compared, and thus the total pressure in the free atmosphere before entering the engine p_{0c} is equal to the value of 101 325,6 Pa (Fig 5). The total pressure before the compressor p_{1c} in the "1-1" section for the M601 B value of 100 312,34 Pa, while for the experimental engine the calculated value of 99 299,088 Pa. The difference between the total pressures upstream of the compressor is 1 013,26 Pa. Rapid increase in pressure, but with relatively large different values (up to 55%), are achieved by engines in section “3-3”. Overall, we can observe the largest difference in pressure values in the “4-4” section, which reaches a value of up to 57%. The main purpose of the gas turbine as well as the exhaust nozzle is to convert thermal and pressure energy into kinetic energy, which purpose is to drive the propeller through the reducer. As the pressure values in the sections behind the gas turbine decrease, the percentage pressure differences in the sections of the M601B engine and the experimental engine also decrease, to the value of Δp in section "4-4" 42%, in the section "5-5" the difference in pressure values is only 1,22% and the last section “6-6” is the total pressure difference only 1,013%

Table 2

Comparison of Works and Total Works of Compressor, Turbine and Free Turbine Engine

Parameter	**M601**	**Experimental engine**	**Difference [J.kg^{-1}]**	**Difference %**
Compressor work W_{Kc} [J.kg^{-1}]	280 591,35	184 271,20	96 320,15	34,33
Total work of the gas turbine W_{TKc} [J.kg^{-1}]	240 265,16	150 076,55	90 188,61	37,54
Heat cycle work W_{Pc} [J.kg^{-1}]	259 780,37	126 133,22	133 647,15	51,45
Free turbine work $W_{VPT'}$ [J.kg^{-1}]	96 042,56	96 042,56	-	0,00
Total free turbine work W_{VPT}[J.kg-1]	218 997,94	96 042,56	122 955,38	56,14

From the Table 2 it is possible to see the percentage differences between the M601 B and the experimental engine for the mentioned parameters, which range from 34,33% in the case of the compressor work, up to a percentage difference of 56,14% in the total free gas turbine work parameters. This significant difference is due to the fact that the less powerful auxiliary power unit AI-9, which is part of the experimental engine was connected to a free gas turbine of the same type as the in the case of the M601 B engine.

The specific thrust $F_{m,\Sigma}$ of the experimental engine is 56,15% lower than the M601 B engine. The specific thrust of the experimental engine is 286 687,04 N.kg.s^{-1}.

The specific consumption of the experimental engine c_m differs by 132,93% % from the power unit M601 B.

The largest difference in parameters between the compared engines is in the case of equivalent power P_{ekv}. The percentage difference is up to 83, 81% which represents a difference of 596 492.24 W.kg^{-1}.s. The calculated parameters for the M601 B engine of equivalent power are 711 743,315 W.kg^{-1}.s, while this parameter in the calculations for the experimental engine is only 115 251,07 W.kg^{-1}.s. The greatest influence on this parameter is the airflow rate Q_v, which in the case of the experimental engine does not reach a sufficient value.

4. Discussion

The first to be mentioned as significant factors in the calculations that influenced the differences in the results were the parameters for the airflow rate Q_v, which has for the M601 B engine has a value of 3.25 and for the experimental engine - for the APU AI-9 - a value of slightly lower, exactly 1.2. The second important parameter is the total compression ratio of the compressor π_{Kc}, which has a value of 6.4 for M601 B and for the experimental engine - APU AI-9 a value of 2.9, which is only 45.31% of the total compressor compression in the M601 B.

A detailed description of the comparison of the obtained thermodynamic analysis parameters of the two engines studied revealed the shortcomings or weaknesses of the proposed of the experimental engine. The first significant decrease in the total pressure was observed in the section behind the compressor. There is the first space for possible improvement of the design, since the total degree of the compressor compression ratio of the experimental engine is only 45.31% of the π_{Kc} of the compared M601 B engine and thus the difference in compressor work as already mentioned, up to 96 320,15 J.kg^{-1}(34,33%). With respect to W_{Kc} value it is obvious, that the experimental engine will not have the performance of the compared M601 B engine, but its size should also be smaller. Due to the difficulty of the technological modification, no change will be made in the compressor of the experimental engine.

In the section behind the combustion chamber or before the gas turbine - "3-3", a significantly lower pressure differential was observed. This phenomenon shows that the energy that the combustion chamber of the auxiliary power unit AI-9, and thus the experimental engine, is producing is sufficient. Therefore, the combustion chamber is not proposed to be changed.

Behind the gas turbine, a decrease in the resulting total pressure difference between the observed units is also observed. The difference in the total work of gas turbines is 17.76%. The difference is not so significant and therefore no changes are proposed on the gas turbine.

Behind the "4-4" cut, behind the gas turbine, there is the biggest breakthrough in the technical construction for the experimental engine. In the mentioned section, the auxiliary power unit AI-9 becomes the experimental engine designed by us. At this point, a free gas turbine from an M601 B turboprop engine is connected to the original APU. The proposal is thus to add a stage of guide vanes in front of the free gas turbine, with the number and shape of the blades suitable for the changed parameters of the flowing gases in the experimental engine.

5. Conclusions

The aim of the article was to describe and characterize in detail the properties of the Ivchenko AI-9 auxiliary power unit and the turboprop aircraft engine Walter M601 B. Subsequently, to perform calculations for the thermodynamic analysis of the M601 B engine and also for the experimental engine, which is a rebuild of the auxiliary AI-9 auxiliary power unit into a turboprop engine with the addition of a free gas turbine and a reducer from the M601 B engine. The results of the thermodynamic analyses were necessary to compare, evaluate and propose modifications for the experimental engine, which could increase its performance. During the detailed description of the AI-9 auxiliary power unit and the M601 B engine, the basic components and their properties were described, based on which were drawn upon in designing the modifications. On the basis of thermodynamic calculations, both engine systems were analysed. Subsequent comparison of the analyses of the thermodynamic results led us to the conclusion to propose possible modifications to the experimental engine, thanks to that would make the engine even more efficient. The proposed modifications were in the "4-4" section by adding a stage of distribution blades in front of the free gas turbine.

We think we can conclude that the work is a contribution to the possible potential use of an experimental engine composed of auxiliary power AI-9 auxiliary power unit in conjunction with a free gas turbine and a reducer from an aircraft engine M601 B. This work can serve as a theoretical basis for the practical construction of the aforementioned experimental propulsion unit, which can be used in the future for experimental measurements and purposes.

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Progress of Optimization in Rail-Based Multimodal Transport Chains

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Abstract

Multimodal transport chains are the backbone of daily supply. In view of the challenges related to climate-friendly mobility, it is required to reduce CO_2 emissions. For this purpose, it is necessary on the one hand to simplify the shift to low-emission modes of transport, but on the other hand also to increase the efficiency of existing forms of transport and to optimise their processes. In the context of this paper, a structured literature review is used to determine the state of the art of optimisation along rail-based multimodal transport chains. In addition to an in-depth search of the related scientific literature, an exploration of relevant sector-related content is carried out. Thematically, the study is divided into optimization approaches at terminals, or transfer points on both sides of the main transport chain to pre- and on-carriage, and the rail transport section itself. This allows the collected data to be categorised according to sections as well as processes of the transport chain. Furthermore, the structured literature review can give also insights in different optimization technologies applied, for example hardware or software solutions. This elaboration serves as a basis for identifying areas along multimodal rail-based transport chains where research on further starting points for optimization is required.

KEY WORDS: *modal shift; multimodal transport; rail optimization*

1. Introduction

Freight transport is a fundamental requirement for the daily supply. Various modes of transport are used, which can be applied alone or in combination along the transport route. Transport chains can be single- and multi-link, whereby multi-link transport chains can be unimodal, using one mode of transport, or multimodal, using several modes of transport. A typical multimodal transport chain can, for example, be carried out with trucks in the pre-carriage and onward carriage and by rail in the main carriage. These different means of transport have different degrees of efficiency. Especially in the area of CO_2 emissions, there is a clear difference between road transport and rail transport. While a ton-kilometre on road carried out by a diesel truck causes on average 85.1g CO_2-equivalent, rail freight transport emits only 5g CO_2-equivalent per ton-kilometre[1] [1]. A modal shift to rail is therefore a goal to be striven for in order to achieve the climate targets. However, this requires optimisation of this mode of transport and the corresponding interfaces in order to increase efficiency and make rail transport more attractive for freight forwarders.

An initial state of the art overview showed that various research projects are already being carried out in the field of optimisation with regard to transport chains including rail, but a lack of implementation can be recognized. Therefore, the NITOB[2] project is launched to determine the current state of research in the field of transport chain optimisation and where research is still needed to make rail-based freight transport chains applicable. The first stage of the project, containing a systematically analysis of the status quo of existing processes and an identification of missing parts, is described in this paper. The applied methods for addressing this objective are described in the following chapter. Basis for our consideration is a multimodal transport chain, where for example products are transported by road transport to a hub and then by rail to another central hub, where the goods are transferred to road transport again.

2. Methods

To get a comprehensive and high-quality overview of existing literature concerning optimization of intermodal transport systems, several online databases were scanned. These included ScienceDirect, SpringerLink, Google scholar, informs and assessment of cross references in further sources. The research was conducted in March and April 2022 and due to the internationality of the research subject, primarily English terms were used. To obtain an insight in the current state of the art, research papers published since 2012 were considered for further analysis.

Previous to the review, a subclassification of optimization areas in intermodal transport was developed and in the course of research, this structure was adapted to its current version, which is shown in Fig. 1 .Subsequently for each category search terms and combinations of them were defined and applied in the databases. Commonly used notations in the investigated research fields were also considered. In general, basic terms as train, freight, road, port and intermodal/multimodal transport were used to narrow the results in the first stage. Further, these searches were enhanced

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[1] Data for Austria

[2] NITOB - Nachhaltige intermodale Transportketten durch Optimierung von Bahnabläufen / Sustainable Intermodal Transport Chains through Optimisation of Rail Operations

and combined with more specific notions, which are shown in Table 1.

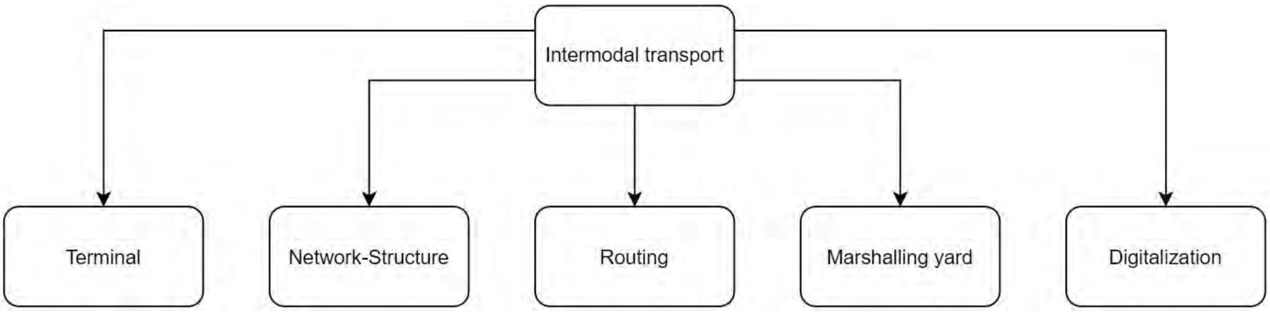

Fig. 1 Literature review structure

Table 1

Specific keywords

	Terminal	Network-structure	Routing	Marshalling yard	Digitalization
Specific search terms	Terminal	Terminal location	Routing	Marshalling yard	Automatic coupling
	Intermodal terminal	Hub	Graph theory	Hump yard	Automation
	Three mode terminal	Network structure	Ad hoc routing/timetabling	Classification yard	
			Rerouting		

The research papers were evaluated regarding their relevance for either intermodal transport in general or at least subareas of this subject and further classified into the subcategories shown in Fig. 1. In the first stage of the evaluation the research papers were reviewed and further sorted out based on the relevance of the title and keywords. Following the abstract and conclusion of the remaining papers were rated. Papers with high relevance after these steps were subjected for a detailed review. Each research paper was ranked regarding its relevance on an ascending scale from zero (no relevance) to five (high relevance). In this paper, research with an assessment of three or higher was considered. Table 2 presents the number of detailed reviewed and relevant papers. For reasons of comparability, the review mainly focussed on papers considering European intermodal and railway systems. However, in exceptional cases studies from non-European countries were included. This was justified with scalable models and general approaches as well as comparable circumstances of the discussed systems.

Table 2

Number of reviewed/ relevant papers

	Terminal	Network-Structure	Routing	Marshalling yard	Digitalization
Reviewed papers (investigated in detail)	34	10	22	11	7
Highly relevant papers	14	4	13	5	5

3. Results

NITOB is an ongoing project and therefore the following chapters present the current status and results of the project. Further information including the progress of the project will be introduced at the 26th international scientific conference Transport Means 2022. Intermodal transport is a complex system and includes various components and transhipments points. In order to provide a structured literature review in this chapter, the fields of intermodal transport networks are addressed based on the subclassification presented in Fig. 1.

3.1. Terminals

With respect to terminals in intermodal transport, several research papers discussing different aspects have been published over the previous years. Ricci et al. [2] provide forecasts of potential innovative technologies and operational improvements to increase container terminal performance by 2050. Furthermore, these potential improvements are compared with actual common standard technologies and operational handlings using various key performance indicators (total transit time, handling time etc, ...).

Schulz et al. [3] and Bruck et al. [4] introduce mixed integer models and heuristic approaches to optimize track allocation of inbound trains in large terminals to ensure an efficient usage of resources (cranes). Discussing optimized train loading in container terminals, Ambrosino & Caballini [5] and Dotoli et al. [6] use similar approaches as mentioned above to address the following objectives. On the one hand the target is to maximize the total priority and commercial value of the train and on the other hand the number of container rehandling should be minimized.

The research papers mentioned so far cover terminals in general, whereas further research has been published specifically considering intermodal port terminals. Heuristic methods are used for the port of Sevilla to optimize track allocation and simultaneous handling of multiple trains in large port terminals [7]. Discussing optimization of inter-terminal container transport in large ports, Hu et al. [8] introduce a Tabu Search algorithm based on a time-space graph problem formulation.

Contrary to the operational approaches of the research papers above, Wieslaw et al. [9] establish a technological innovation. A prototype of a special wagon with rotatable loading platforms for semitrailers is developed, which should save time and money in loading as no cranes are required.

3.2. Network Structure

Network structure covers aspects of terminal location and terminal types (rail-road, rail-rail, ports, trimodal terminals) and has partial correlations to the routing of commodities in a network.

Mostert et al. [10] investigate the economic and ecological consequences of different terminal location strategies in a three-mode (road, road-rail and inland waterway) intermodal network. As basis a bi-objective mathematical formulation is developed to achieve the environmental and economic objectives. Concluding, this formulation is applied in a case study in Belgium.

Kreutzberger & Konings [11] propose a restructuring of intermodal transport networks in Europe to increase the performance of the intermodal system. This objective is achieved by introducing hub-and-spoke (HS) bundling of freight trains. After describing different HS-networks, the most efficient network is pointed out, which contains of 'real hub terminals' and shuttle trains. Kreutzberger & Konings [11] define a 'real hub terminal' as a terminal, whose main function is rail-rail transhipment.

To identify the optimal terminal locations, both exact and heuristic approaches are used to achieve multiple objectives. The majority of research papers in this field focuses on multi-stage algorithms. Sörensen et al. [12] develop a two-stage algorithm trying to solve the terminal location problem. To use the strengths of both techniques, the combination of an exact algorithm (branch and bound) and heuristics (linear programming relaxation/lagrangian relaxation) are potential solutions to tackle a wide-area location problem [13].

3.3. Routing

Routing either characterizes the path, commodities take through an intermodal network, more specifically, which transport modes and transhipment terminals are used, or the routes of wagons or trains in a train service network.

Considering routing of freight trains and wagons in particular, a wide range of research has been published. A tool called GüterSIM is introduced to optimize the routing of single wagon load traffic [14]. GüterSIM is based on an agent-based simulation using the open-source software MATSim. The scalable model is applied to a case study in the Swiss cargo network with real-world data. Contributing to a more flexible rail freight transport, Ljunggren et al. [15] and Bożejko et al.[16] tackle the objective of ad-hoc train pathing and timetabling by introducing a Dijkstra-based algorithm. Respecting constraints as passenger train timetables and safety time buffers, this technique can be used to identify the fastest route of an ad-hoc train in an existing timetable [16].

Other approaches include the complete intermodal transport chain and focus especially on optimization algorithms. With the main objective of minimizing total transport costs, Bożejko et al. [17] introduce a Tabu Search algorithm for road and road-rail intermodal networks. Aiming at a similar target, two-stage algorithms based on GRASP/attributed hill climber and local search are developed in Sörensen et al. [12].

Baykasoğlu & Subulan [18] and Zhu et al. [19] address routing as part of a holistic approach in intermodal service network designs. Baykasoğlu & Subulan [18] provide a mixed integer programming model to solve a multi-objective load and transport planning problem. Main objectives of this model are the minimization of overall transport costs and total transit times as well as taking CO_2 emission into account. Zhu et al. [19] introduce a mathematical solution for optimizing the service network design. The proposed solution contains slope scaling, long-term memory-based perturbation strategies and ellipsoidal search.

3.4. Marshalling Yard

The research in the field of marshalling/hump yards mainly focuses on the optimization of humping procedures and train assembly.

Heuristic and exact approaches are used to handle train make-up problems, more precisely how inbound trains are split efficiently and following the humping sequence of railcars to subsequently form a new outbound train [20]–[22]. Correlations between inbound and outbound trains concerning tardiness are investigated in Jaehn et al. [21]. This research paper is enhanced with heuristic and exact (branch and bound) algorithms as well as Tabu Search algorithms for optimizing the humping sequence of incoming trains to minimize the weighted retardation of the outgoing train.

Maximizing total priority of an outbound train, which results out of the priority value of each railcar, can be tackled with exact and heuristic approaches [20]. A different approach is using branch and bound algorithms to minimize the sum of weighted holding time of an outgoing train, which is defined by a priority value of a railcar multiplied by its waiting time in the marshalling yard [22].

3.5. Digitalization

Including information exchange and automatization, digitalization can contribute to the improvement in nearly all areas considering intermodal transport.

Automatic information exchange between participants in an intermodal transport chain provides potential for optimization, e.g., reducing the turnaround times in terminals [23]. Addressing this objective, Jacobsson et al. [23] introduce an interoperable information exchange system for involved parties, which are specified as road hauliers, rail operators and seaport operators. Recommended information attributes for communication are, e.g., intermodal transport unit ID, estimated arrival time and goods priority.

Another issue is tackled by the project ‘ITS Italy 2020’ by developing a prototype software to monitor and manage freight transport in an intermodal network [24]. By collecting data of devices and sensors integrated in the network, the software allows users to track their commodities as well as to get specific information, e.g., the temperature of a refrigerated wagon.

Technical innovations, e.g., digital automatic coupling, also contain potential to increase the capacity in logistic systems and to reduce transport times. Automated coupling systems are particularly relevant for rail infrastructure managers on heavily utilized lines due to the potential of forming longer trains. Therefore, the need for integrating these systems is mainly pushed by infrastructure operators and not the shippers themselves [25, p. 160]. Stuhr [25] describes different types of innovative coupling, from semi-automated to full-automated with information exchange. The valuation of these variations regarding their overall benefit for the whole system is heavily depending on the weighting factors for the rated attributes. Hence, a reliable and validated assessment of the improvements is only possible to a limited extent [25, p. 208].

4. Conclusion

Reaching the climate targets is an omnipresent subject in various fields, also concerning the freight transport sector. To address the necessity of a shift in the modal split towards environmentally friendly means of transport, transport chains need to be more efficient. The NITOB project aims at contributing to this objective, in particular at optimizing intermodal transport networks. Therefore, a literature review was conducted in order to get an overview of the state of the art in research.

The results of the review were classified into predefined subcategories, hence conclusions about the current state of research concerning various fields of intermodal transport could be drawn. It became apparent that aspects as terminal processes, network structure and marshalling yards were intensively investigated by recently published research papers. Other points with high relevance were underrepresented e.g., routing and technical developments considering digital inventions.

Therefore, within the framework of this first consideration, a need for further research in these points can be identified. On the one hand, timetabling and routing is a possible approach, but also the technical innovations such as digital automatic coupling contain potential for improvement.

However, there are several limitations which need to be considered for this research paper. Due to the ongoing process of the NITOB project, the presented results should be seen as preliminary, which will be enhanced and adapted in the further proceeding of the project. The next stages of the research will be a further discussion and interpretation of the literature review, followed by interviews with specialists in various fields of railway systems and intermodal freight transport. Under consideration of the results of this paper and the assessment of experts, specific fields with potential for improvement will be pointed out and subsequently recommended for future research projects.

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Determination of the Stress State of the Body of a Hopper Car Transported by Sea

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Abstract

The work deals with the special features of the loading on the body of a hopper car transported by a train ferry. It has been found that the maximum stresses in the body of a hopper car exceed the normative values in the standard lashing diagram. This can endanger the stability of a vehicle on the train ferry and the stability of the sea vessel.
The safe transportation of a hopper car by sea can be ensured by means of improvements in its structure, i.e. fastening units for the chain binders. The rigidity of the bolster beam in the fixing points of these fastening units can be ensured with reinforcing diaphragms. The effectiveness of the proposed constructive improvement is confirmed by theoretical calculations. The results of the research will be of value for those who are concerned with the safe transportation of rail cars by sea.
KEY WORDS: *hopper car, inertial loading, strength of the body, stress state of the body, rail-ferry service*

1. Introduction

One of the criteria of good economic performance in European countries is the coordinated operation of the whole transportation system. And so far the railway transport has played the leading role and provided the transportation process both independently and collaboratively with other types of transport, thus forming combined transportation systems. Therefore the countries with an access to sea are developing train ferry transportation.

Apart from considerable advantages this type of transport has an important disadvantage, i.e. poor technical adjustment of rail vehicles to sea transportation. Due to a lack of special structural elements, rail cars are secured on the deck with the structural elements that are not designed for it. This can cause damage to the components of the rail cars, break their stability on the deck and pose a risk to the stability of the train ferry. Therefore, there is a need to research into customization of the construction of rail vehicles for transportation by sea.

2. Analysis of Publications

The issues of the loading and the strength of transport vehicles transported by sea have been studied by many specialists. The effect of the center of gravity of a transport vehicle on the equilibrium of a vessel is considered in [1]. The authors presented the methodology for estimation of the effect of the center of gravity of a vehicle on the vessel equilibrium. The research was made by the example of a modular vehicle placed on the container carrier. However, the researchers did not use this algorithm for a rail car.

The designing of advanced car construction are described in [2, 3]. The authors presented the spatial models of the construction of rail cars and the results of the stress state calculation. However, the designing of these rail car structures did not include forces occurring during transportation by a sea.

Study [4] details the special features of designing the body of a new-generation rail vehicle. One of the special structural features is the use of innovative materials, particularly, extruded aluminium panels. The body structure proposed is lower by mass and keeps the required strength.

The methodology of the multi-scale designing and optimization of innovative lightweight structures of hopper cars are described in [5]. It is based on the North American Standards. The design proposed was proved through comparison the results of computer modelling and those obtained from accurate analytical equations. In [4, 5] the authors did not research the issue of customization of the rail car structures proposed to the transportation by train ferries.

Study [6] describes the results of research of the loads on the construction of a rail car. But the authors used only the normative values of loading on the rail car in operation. The study also presents the results of stress state modelling for the construction of a rail car. However, the designing of these rail car structures did not include forces occurring during transportation by a train ferry.

The inertial loading of an open car placed on a deck is considered in [7]. The study presents the results of stress state calculation for the car frame during new fastening. The authors believe that the strength of a car can be improved by means of viscous binders used for securing it on the deck.

The designing of the bearing structures of rail cars used for operation on main lines and for train ferry transportation is substantiated in [8]. The research was made for the body of a flat car. However, the authors of studies [7, 8] did not give attention to the technical customization of the bearing structures of some types of rail cars to transportation by sea.

3. Purpose and Main Objectives of the Article

The objective of the research is to determine the strength and propose some improvements in the body of a freight car that will ensure its safe transportation by a sea. The research was made for a hopper car. To do this, the following tasks are allocated:

- to determine the strength of the standard body of a hopper car transported by a train ferry;
- to propose the measures for improvements in the body of a hopper car.

4. The Main Material of the Article

The stress state of the standard body of a hopper car transported by a sea was determined on the prototype of a hopper car Model 20-9749 (Ukraine). This type of a rail car was chosen because it has not yet been studied in terms of determination of the loads when transported by a train ferry.

During train ferry transportation (Fig. 1, a) hopper cars are most frequently secured to the towing shackles (Fig. 1, b). And reusable lashing devices are used.

a

b

Fig. 1 Hopper cars transported by a sea vessel: a – rail cars on the sea vessel; b – attaching the hook to the towing shackle

The inertial loads on the body of a hopper car were calculated with the mathematical model that described the rolling motion of a train ferry [9, 10]:

$$I_x \cdot \ddot{q} + \left(\Lambda_\theta \cdot \frac{B}{2} \right) \dot{q} = p' \cdot \frac{h}{2} + \Lambda_\theta \cdot \frac{B}{2} \cdot \dot{Y}(t), \tag{1}$$

where I_x – the inertia moment of a train ferry; Λ_θ – the roll damping coefficient; B – the train ferry breadth; p' – the wind load; h – the train ferry depth; $Y(t)$ – the law of motion of the sea wave.

Hence,

$$I_x = \frac{D}{12 \cdot g} \left(B^2 + 4 z_g{}^2 \right), \tag{2}$$

where D – the weight displacement; z_g – the coordinate of the gravity center of a train ferry.

The mathematical model included that the car traveled by the trajectory of a train ferry. The research was based on the characteristics of the vessel Geroi Plevny, which serviced the route from Chornomorsk (Ukraine) to Varna (Bulgaria) and from Chornomorsk to Poti/Batumi (Georgia).

The parameters of the disturbing action were taken from reference literature, and for the Black Sea they are as follows: wave height – 8 m, period – 9 s, wind pressure – 1.47 kPa [11].

The mathematical model was solved with the variation method for arbitrary constants [12] at the initial conditions equaling zero [13-15]. It was found that the total value of acceleration to a car placed on the sea vessel was

0.24g.

The acceleration value obtained was included in the stress state determining for body of a hopper car. The graphic model of a hopper car was built in SolidWorks according to its album of drawings.

The strength calculation of the construction of a hopper car was made with the finite element model in CosmosWorks [16-18].

The FEM consisted of tetrahedrons [19, 20]. The model has 376670 elements and 126221 units. The design diagram of the hopper car body (Fig. 2) included the following loads: the vertical static load P_v^{st}, the pressure from the cargo P_p, the wind load P_w, and the loads to the car body through the fastening P_{ch}. Steel 09C2Cu with the linear isotropic properties was used as the structural material.

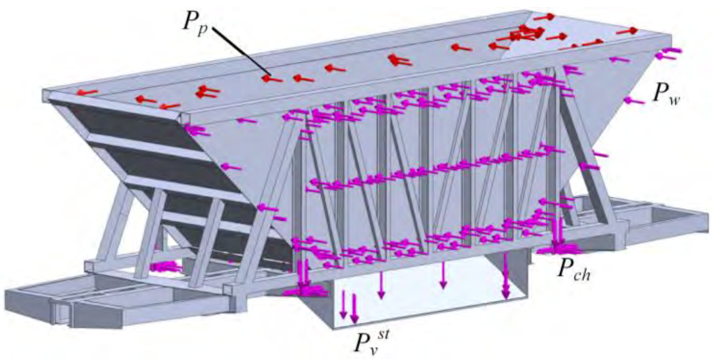


Fig. 2 Design diagram of the body of a hopper car

The stress state of the body of a hopper car are given in Figs. 3 and 4.

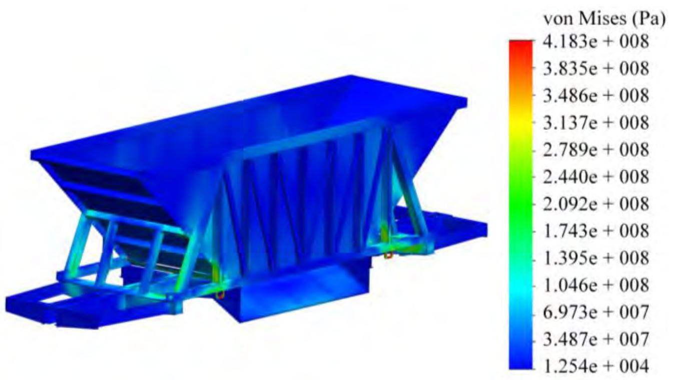


Fig. 3 Stress state of the bearing structure of a hopper car

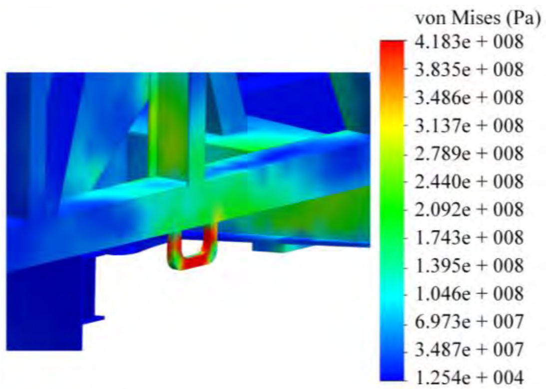
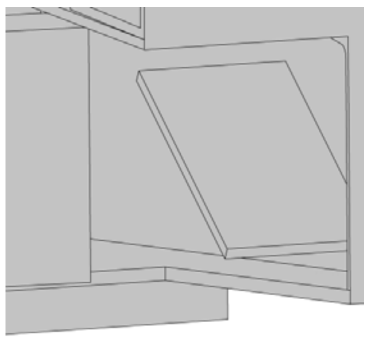


Fig. 4 Stress state of the bearing structure of a hopper car near the towing shackle

The maximum stresses in the body of a hopper car were about 420 MPa and were concentrated in the towing shackle. Thus, in the typical lashing diagram for a hopper car on the deck the maximum stresses in the body above normative values. The normative values included the yield limit of the material equaling 345 MPa [21, 22].

The authors believe that the reliable fastening of the body of a hopper car on the deck can be fulfilled by means of fastening units mounted on the bolster beams (Fig. 5, a); the required rigidity of the bolster beam in the fixing areas of these fastening units can be ensured with inclined reinforcing diaphragms (Fig. 5, b).

a



b

Fig. 5 Improvements in the body of a hopper car: a – fastening unit; b – reinforcing diaphragm

The thickness of the diaphragm should be equal to the thickness of the vertical sheet of the bolster beam. The parameters of the fastening unit were calculated with consideration of the dimensions of the bolster beam of a car and those of the hook of a fastening.

The stress state calculation of the construction of the car included the improvements proposed. And the design model (Fig. 6) included the loads identical to those taken in the research of the typical hopper car.

The FEM of the body of a hopper car consisted of 420212 elements and 13787 units.

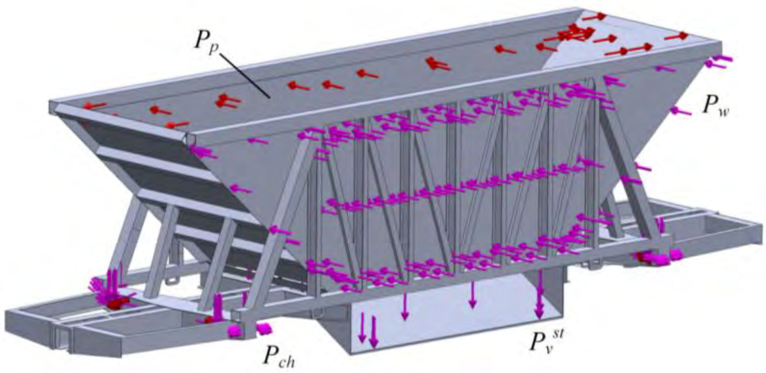


Fig. 6 Design diagram of the bearing structure of a hopper car

The stress state of the body of a hopper car are given in Figs. 7 and 8. The calculation demonstrated that the maximum stresses in the body of a hopper car were about 330 MPa and were observed in the radial part of the unit. Thus, with consideration of the improvements for a car the maximum stresses in its structural elements are within the normative values [21, 22].

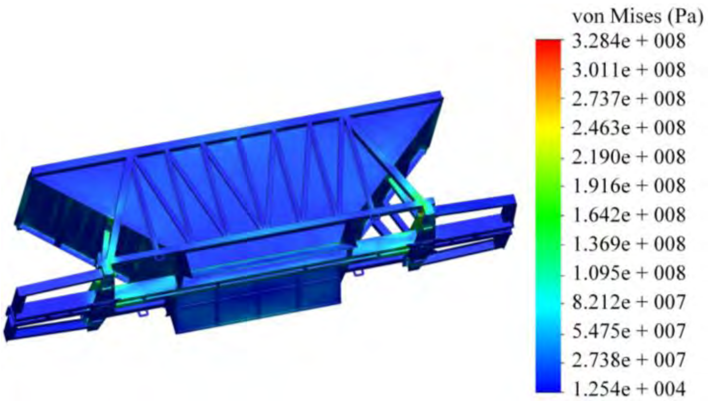


Fig. 7 Stress state of the improved body of a hopper car

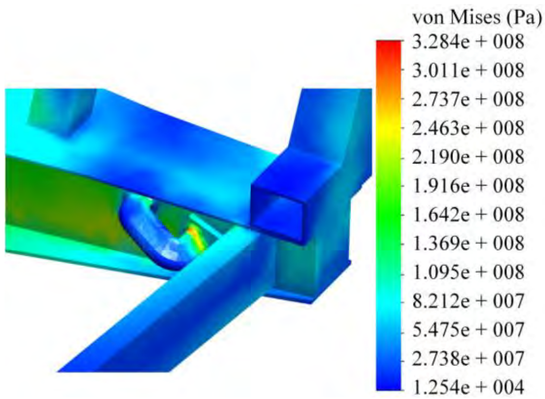


Fig. 8 Stress state of the improved body of a hopper car in the fastening unit

5. Conclusions

The research deals with the determination of the stress state of the body of a hopper car transported by a train ferry. The maximum stresses in the construction of a hopper car were about 420 MPa and were observed in the towing shackle. Thus, in the typical lashing diagram for a hopper car on the sea vessel deck the maximum stresses in the components of the construction exceed the normative values.

The authors have proposed the measures for improvements of the body of a hopper car for its safe transportation by sea. It has been found that the maximum stresses in the construction of a hopper car were about 330 MPa and they were observed in the radial part of the unit. The results of the research will be of value for those who are concerned with the safe transportation of rail cars by sea.

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Increasing the Energy and Environmental Efficiency of Rolling Stock by Increasing the Resource of the Contact Surfaces of the “Block-Wheel-Rail: System

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Abstract

The article proposes a method of increasing the energy and environmental efficiency of rolling stock by increasing the resource of contacting surfaces due to arc pulse surface strengthening of friction elements of rolling stock, which was performed by an advanced installation of arc pulse surface strengthening of metals Tesla Weld MSH 500.
According to the results of the experimental studies on the strengthening of the microsand of the 40X steel sample, it was established that the strengthening of its surface by the Tesla Weld MSH 500 arc pulsed surface hardening of metals made it possible to increase the surface hardness by 145%, while the steel core has a ferrite-pearlite structure, and the strengthened layer consists of hardened structures.
When studying the microstructure of the strengthened layer, the depth of the strengthened layer was measured, it was about 186 μm deep into the base metal, and the maximum depth of the strengthened layer was about 207 μm deep into the base metal at the maximum point.
KEY WORDS: *railway transport, wheel, rail, brake pad, wear, strengthening, hardness, microstructure.*

1. Introduction

In order to increase the effectiveness of the introduction of new equipment and technologies, which ensure a significant reduction of resources consumed in the industry, concentration of efforts on developments that have energy and environmental significance, the planned introduction of new technical means and advanced technologies aimed at increasing the technical level of railway enterprises is considered the most important task transport Therefore, research created to solve these problems is relevant.

One of the technological methods of solving these problems is to reduce the intensity of surface wear by increasing their properties with effective strengthening methods, and after wear with appropriate restoration methods. This direction is especially promising for parts that limit the service life of rolling stock, which primarily include the wheel and rail.

In addition, the safety of operation of rolling stock of railway transport largely depends on the reliable operation of brakes. In this direction, important questions remain unsolved and, in particular, the interaction of the brake pad, wheel and rail is insufficiently researched.

During the operation of the rolling stock, braking directly depends on the processes occurring in the friction pairs of pad-wheel and wheel-rail. At the same time, the block and the rail are structurally unrelated, however, they interact in the process of work with one and the same element - the wheel, and are interconnected due to the load and physical and chemical properties of the materials.

Therefore, an urgent task is to determine ways to increase durability based on the establishment and comprehensive study of the regularity of the processes of thermal dynamics of friction that occur in the «pad-wheel» and “wheel-rail» friction pairs in operation.

Thus, the purpose of the article is to increase the energy and environmental efficiency of rolling stock by increasing the resource of contacting surfaces by reducing the intensity of their wear, increasing their properties by an effective strengthening method.

The tasks of the research are:

– study of the effect of metal hardness on increasing the resource of contacting surfaces;
– description of Tesla Weld MSH 500 arc impulse surface strengthening of metals installation;
– experimental studies of surface strengthening of metal samples;
– conducting metallographic studies of the metal microstructure after hardening. Carrying out hardness tests.

2. Research Results

The increase in the volume of railway transport in recent decades has complicated the conditions of track and rolling stock operation, led to faster wear of rails, wheelsets and braking equipment. If previously intensive wear of rails and wheelsets was observed on sections with long ascents and descents, in recent years it has become common on flat railways as well. The intensity of wear of rails and wheels of rolling stock is influenced by many factors: imperfect spring suspension; the difference in the diameters of the tire rolling surfaces of one wheel pair; asymmetry of wheel pairs when placing them in the cart frame; static suspension of wheel pairs and increasing the weight of the train. This leads to increased wear of not only the traction part of the tire, but also the ridges of the wheels of the rolling stock, as well as the frictional elements of the braking equipment.

Today, it was possible to reduce the intensity of wear and tear to the level where the mileage of rolling stock between tire replacements is 500-700 thousand km. In 85% of cases, tire ridge wear is more intense than rolling surface wear [1, 2, 3]. Surface strengthening, optimization of the turning profile and tribotechnical materials are used to increase the service life of wheel pairs of rolling stock.

The resource of rolling stock wheels determines the periodicity of maintenance, in the process of which refinishing is carried out to restore the profiles of the rolling surfaces, or the replacement of completely worn wheels. The speed and safety of movement depends on the technical condition of the wheels of locomotives and wagons. Important technical and economic operating indicators of rolling stock work depend significantly on the permissible values of such wear indicators as ridge thickness, ridge steepness parameter, and tire thickness, namely: mileage of wheel pairs between tire turns, total number of tire turns during their operational life cycle, total resource of bandages. Therefore, the scientific community faces the task of ensuring the reduction of costs for maintenance, repair and extension of the operational life cycle of wheel rims of locomotives and wagons.

In order to increase the energy and environmental efficiency of the rolling stock, the main task of almost all known studies on the wear of wheel rims was to increase the mileage of wheel pairs between fairings - inter-repair mileage, as well as the total mileage of wheel pairs during the life cycle of tires by reducing the intensity of wear [4, 5]. When at least one of the profile parameters (ridge thickness, ridge steepness parameter) of one of the wheels of the wheelset reaches its minimum permissible value, the wheel is turned [6-8]. At the same time, the profile is completely restored and acquires the geometry of a new repair profile [9, 10]. Most of the existing methods of optimizing the profile of railway wheels are aimed at reducing wear, taking into account wear indicators [10].

A reduction in wear can be ensured by reducing the coefficient of friction in the contact zone of the comb with the rail (lubrication) and/or changing the mechanical properties of the wheel material. A comprehensive approach is assumed to be the most effective. And here, research in the field of tribotechnical materials science, as well as experiments that can reveal and find ways to reduce friction losses and increase wear resistance, are of exceptional importance [11].

Three main technologies have been developed and used to strengthen the ridges of wheel pairs of rolling stock: laser, plasma and electric contact. The application of the first two actually boils down to the hardening of the metal, as it is first heated on the surface by a constantly operating heat source (plasma jet or laser beam), and then quickly cooled by heat removal into the depths of the metal. As for laser technology, it is based on the passage of a light stream that is absorbed by free electrons in the near-surface layer (thickness of 0.1-1 μm), which leads to an increase in their energy and intensification of collisions between themselves. The use of a laser complex requires highly qualified service personnel, additional costs associated with the formation of absorbent coatings on the surface of the part to be strengthened (a decrease in reflectivity increases the efficiency of the laser), special climatic and sanitary conditions in production premises. Plasma technology is the most widespread on the roads of the CIS.

The process of metal strengthening was carried out on the Tesla Weld MSH 500 arc impulse surface hardening of metals installation, which is designed to increase the hardness of metal surfaces that are subjected to significant mechanical loads and friction: wheels, rails, brake discs and linings (pads), shaft seats, gear teeth, thrust plates, etc. It can also be effectively used to increase the strength of surfaces previously machined - bored or welded to give the restored surface the required degree of hardness.

The principle of arc pulse strengthening consists in heating the surface with an arc column, in which heat input into the part is limited due to the reverse polarity of the current, as well as pulse modulation of the arc. The increase in hardness at the same time occurs in the form of natural heat removal into the body of the part. Due to the pulsed nature of the current, the hardening process is more efficient, the risk of melting the surface is reduced.

The Tesla Weld MSH 500 impulse arc surface strengthening of metals consists of an MSH 500 power source, a WC 10 cooling unit, and an H 200 burner (Fig. 1). The main technical characteristics of the installation are presented in Table. 1.

Important features and advantages of the installation are cost-effectiveness and the possibility of use in an operational production environment. For example, strengthening the seat of a shaft or gear can be carried out at the installation site and does not require bulky and expensive equipment, as well as dismantling the part.

Fig. 1 General view of the installation Tesla Weld MSH 500

Table 1

The main technical characteristics of the installation Tesla Weld MSH 500

Technical parameter		Value
Power supply MSH 500		
1	Supply voltages of the plasma arc source, V	3x380±10%
2	Network frequency, Hz	50/60
3	Permissible ambient temperature, °C	(-5)...(+40)
4	Relative humidity, %, no more than	80
5	Nominal power consumption, kVA	13
6	The consumed phase current through the network is 380 V, A	20
7	Method of cooling	air forced
8	Operating current, A	60-500
9	No-load voltage, V	68
10	Working voltage of the arc, V	20-32
11	Duty cycle at a current of 160 A, %	100
12	The method of plasma excitation	HF contactless
13	Efficiency, %	85
14	Insulation class	H
15	Gas supply delay after cycle completion, p	1
Block WC 10		
16	Supply voltage of the liquid cooling unit, V	2x380±10%
17	Power consumption, W	370
18	The maximum output pressure, bar	4.7
19	Tank capacity, l	9
20	Productivity, l/min	5.8
21	Pressure sensor sensitivity, no more than bar	1.5
22	Protection class	IP21
23	Weight, kg	13.8
Torch H 200		
24	Burner cooling method	liquid forced
25	Recommended type of coolant	BTC-15
26	Width of the strengthening zone, mm	10-17
27	Depth of strengthening, mm	from 0.1-1.5
28	Maximum working current of the burner H 200, A	200
29	The maximum operating current of the HM 240 burner, A	240
30	Burner control mode	2T
31	Insulation class	H

In order to study the influence of the strengthening process with the Tesla Weld MSH 500 installation on the microstructure and hardness of the metal, we will conduct experimental studies of the operation of the installation on several metal samples: steel 3, steel 40X, steel 45. We will monitor the effectiveness with a dynamic hardness tester NOVOTEST T-D2.

The NOVOTEST T-D2 dynamic hardness tester uses the dynamic hardness measurement method (the Lieb method), standardized according to ASTM A596, and is ideal for measuring the hardness of massive parts, materials with a coarse-grained structure, cast iron and non-ferrous metals, and products with surfaces that are poorly prepared for measurement. The device calculates data according to the Rockwell, Brinell, and Vickers scales and has adjustable user parameters, and is also suitable for working with insufficiently processed parts surfaces.

The prepared metal samples (steel 3, steel 40X, steel 45) in all technical parameters met the requirements for the object of control for hardness measurement with the NOVOTEST T-D2 dynamic hardness tester (Table 2).

Table 2

Requirements for the object of control

Technical parameter	For a dynamic sensor
Roughness is not more than, Ra	3.2
The radius of curvature is not less than, mm	10
Mass, not less than, kg	5
Thickness not less, mm	10

Measurements of roughness on the surface of the samples were performed using the Hommel Tester type T1000 device (passport error 0.002 mm). A measuring transducer with an inductive probe system was installed and fixed on the cleaned, degreased surface of the samples. The action of the device is based on the principle of passing through the irregularities of the examined surface with a diamond probe needle and transforming the resulting mechanical oscillations of the probe into voltage changes proportional to these oscillations, which are amplified and converted by the electronic unit. The measurement results are displayed on the liquid crystal display of the control unit and stored in the device's memory [12, 13].

The methodology for conducting experimental studies of the operation of the Tesla Weld MSH 500 installation was as follows:

1. A sample of steel 3 was selected as the research object, and its surface was cleaned and degreased. The surface was divided into two halves - the original surface of the main material and the surface for the strengthening process.
2. The surface roughness of the sample was measured.
3. The process of strengthening the sample was carried out with the help of the H 200 torch, which the operator moves along one half of the surface of the metal sample at the required speed and at the same distance of the nozzle from the surface.
4. The NOVOTEST T-D2 dynamic hardness tester was used to measure the hardness at ten points on the surface of the base metal.
5. The NOVOTEST T-D2 dynamic hardness tester was used to measure the hardness at ten points on the surface of the hardened layer.
6. The received data were entered into the table for further processing.
7. Similar actions were performed for a 40X steel sample and a 45 steel sample.

The results of the mathematical processing of the experimental data obtained from the results of the strengthening studies of metal samples (steel 3, steel 40X, steel 45) are presented in Table 3.

Table 3

Results of experimental studies of strengthening of metal samples

Steel brand	The average hardness of the sample before hardening HV_a	The average hardness of the sample after hardening HV_a	Increase in hardness, %
Steel 3	126.5	334.6	165
Steel 40X	180.3	481.1	167
Steel 45	134.2	350.4	161

On the basis of the conducted experimental studies of the strengthening of metal samples (steel 3, steel 40X, steel 45) it was established that strengthening their surface using the Tesla Weld MSH 500 pulsed arc metal surface hardening unit made it possible to increase the surface hardness by more than 160%.

The roughness of the samples before hardening was Ra = 3 μm, and after hardening Ra = 3.2 μm. After the process of arc strengthening, the samples fully preserved their geometric dimensions, ready for tests and loads, they do not require additional mechanical processing.

In order to confirm the obtained patterns of hardening of the surfaces of the samples using the Tesla Weld MSH 500 arc impulse surface hardening of metals, a study of the microstructure of the metal after hardening and its hardness test was carried out at the Center for Independent Research of the Ukrintech LLC, test protocol № 0771-20 from 26.10.2020 (Table 4).

Table 4

Initial data for conducting research

Sample	A sample of steel 40X, with traces of thermal hardening after pulsed arc hardening with a current of 160A
Type of research	Metallographic studies Measurement of micro-Vickers hardness
Purpose	Study of the metal microstructure after hardening Hardness test
Regulatory documents	DSTU ISO 6507-1:2007 National Standard of Ukraine. «Metal materials. Determination of Vickers hardness. Part 1. Test method»
Sampling	Performed by the laboratory
Control equipment	Metallographic inverted microscope XDS-3 MET chief № S-N:421626. FTP-1M grinding and polishing machine with a set of consumables. Stationary hardness tester Micro-Vickers UIT HVmicro-1, chief № 130105, calibration certificate UA01 № 7501 dated December 11, 2019.

From the provided sample of rolled steel, a micro-grind was made for metallographic analysis in the specified zone. (Fig. 2).

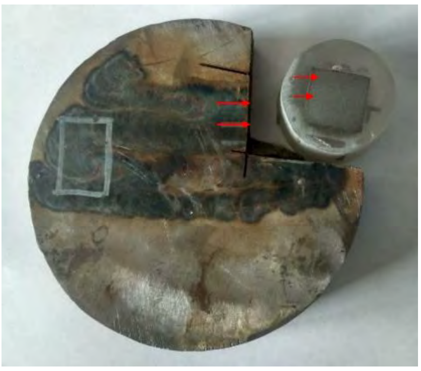

Fig. 2 Micro-grind «rolled steel sample», with an indication of the cutout zone

From the steel sample of rolled steel provided for analysis, with traces of heat treatment on one of the front surfaces, a transverse micro-grind was prepared. The place of selection of the grinding material is shown in Fig. 2.

After etching the grind in the «4% alcoholic solution of nitric acid» reagent, the microstructure of the steel was revealed (Fig. 3-4):

– the steel core consists of a ferrite-pearlite structure;
– the reinforced layer consists of hardened steel structures.

Fig. 3 Photo of the microstructure of the base metal core, x500

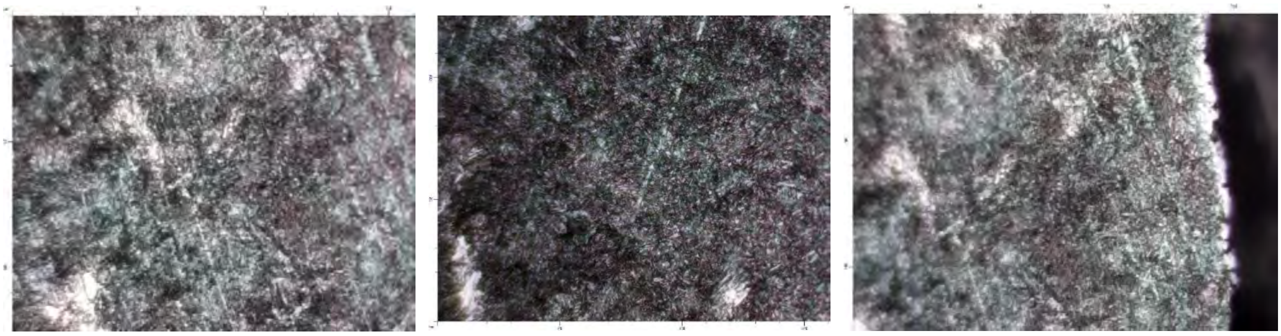

Fig. 4 Photo of the microstructure of the strengthened layer, x500

Fig. 5 Photo of the etched cut, panorama x100

Fig. 6 Photo of the microstructure of the strengthened layer, panorama x100

Fig. 7 Photo of the microstructure of the reinforced layer with an indication of the layer thickness

During this study the microstructure of the strengthened layer, the depth of the strengthened layer was measured, it was about 186 μm deep into the base metal (Fig. 5-7). The maximum depth of the strengthened layer was established, which was about 207 µm deep into the base metal at the maximum point (Fig. 8).

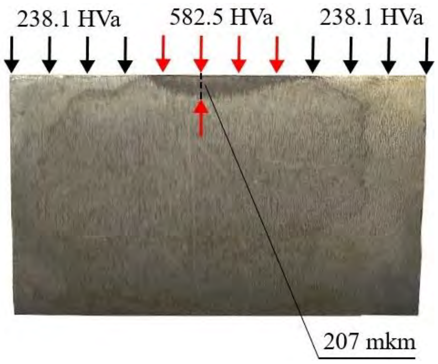

Fig. 8 The maximum depth of the reinforced layer

Measurement of the Vickers hardness of the base metal

The hardness of the base metal was measured in the cross-section of the sample, having previously prepared a microgrind, the hardness was measured with a stationary UIT HVmicro-1 hardness tester.

UIT HVmicro-1 measurement conditions:

Identification load – 500 g.

The exposure time is 10 seconds.

Ambient temperature + 22℃.

Hardness was measured linearly.

Table 5

Measurement of the Vickers hardness of the base metal

Scale designation	Total effort, kgf	Endurance, c	Temperature, ℃	Measurement results, $HV_{0.5}$	Average value, $HV_{0.5}$
$HV_{0.5}$	0.5	10	22	267.5	238.1
				227.7	
				226.4	
				230.4	
				238.3	

Vickers hardness measurement of the hardened layer

UIT HVmicro-1 measurement conditions:

Identification load – 500 g.

The exposure time is 10 seconds.

Ambient temperature + 22℃.

Hardness was measured linearly.

Table 6

Vickers hardness measurement of the hardened layer

Scale designation	Total effort, kgf	Endurance, c	Temperature, ℃	Measurement results, $HV_{0.5}$	Average value, $HV_{0.5}$
$HV_{0.5}$	0.5	10	22	598.0	582.5
				637.9	
				619.5	
				565.3	
				556.6	
				522.5	
				577.7	

Vickers hardness measurement from the edge of the hardened layer

UIT HVmicro-1 measurement conditions:

Identification load – 500 g.

The exposure time is 10 seconds.

Ambient temperature + 22℃.

Hardness was measured from the edge of the hardened layer.

Table 7

Vickers hardness measurement from the edge of the hardened layer

Scale designation	Total effort, kgf	Endurance, c	Temperature, °C	Measurement results, $HV_{0.5}$	Distance from the edge of the reinforced layer, mm
$HV_{0.5}$	0.5	10	22	510.3	0
				403.5	0.1
				392.1	0.2
				238.3	0.3
				226.4	0.45
				230.4	0.60

Table 8

Results of experimental studies of Vickers hardness measurement of base metal and hardened layer

Steel brand	Base metal measurement results, $HV_{0,5}$	The results of the measurement of the reinforced layer, $HV_{0,5}$	Increase in hardness, %
Steel 40X	238.1	582.5	245

The hardness of the base metal was measured in the cross section of the sample and was 238.1 $HV_{0.5}$ at ten points of the base metal, while the hardness of the hardened layer was 582.5 $HV_{0.5}$ at ten points of the hardened layer.

Thus, on the basis of the conducted experimental studies of the strengthening of the microsand of steel 40X, it was established that the strengthening of its surface using the Tesla Weld MSH 500 arc pulse surface hardening of metals allowed to increase the surface hardness by 145%, which practically coincides with the results of earlier studies using the NOVOTEST dynamic hardness tester T-D2. At the same time, the steel core has a ferrite-pearlite structure, and the reinforced layer consists of hardened structures.

3. Conclusions

The article proposes a method of increasing the energy and environmental efficiency of rolling stock by increasing the resource of contacting surfaces due to arc pulse surface strengthening of friction elements of rolling stock, which was performed by an advanced installation of arc pulse surface strengthening of metals Tesla Weld MSH 500.

According to the results of experimental studies of the strengthening of the microsand of the 40X steel sample, it was established that the strengthening of its surface by the Tesla Weld MSH 500 arc impulse surface hardening of metals allowed to increase the surface hardness by 145%, while the core of the steel has a ferrite-pearlite structure, and the strengthened layer consists of hardened structures.

When studying the microstructure of the strengthened layer, the depth of the strengthened layer was measured, it was about 186 μm deep into the base metal, and the maximum depth of the strengthened layer was about 207 μm deep into the base metal at the maximum point

Acknowledgement

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The Role of Road Hierarchization in Development of Transport Infrastructure in Urban Areas and Its Links to Urbanism

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Abstract

The hierarchization of roads plays a crucial role in the development of transport infrastructure in urban areas. Roads in urban areas can be described in a dualistic manner: as conductors of traffic (transport-engineering aspect) and as structures mirroring functions of the city (urbanistic aspect). However, few methods explore this dualistic characteristic, and so the hierarchization of roads is usually based solely (mainly) on the transport-engineering aspect. This paper discusses the importance of the dualistic characteristic and introduces a hierarchization method based on both aspects. The results of this study could contribute to our practical and intuitive understanding of the effects of transport on the development of cities and on other topics related to transport/urbanism.
KEY WORDS: *transport-engineering aspect, urbanistic aspect, hierarchization methods, transport infrastructure*

1. Introduction

Roads and, by extension, road networks are crucial elements of a city infrastructure. They play a key role in the transport accessibility of a city, and as such, roads are often described regarding their ability to conduct traffic (both passenger and freight). This traffic-oriented description of the road infrastructure can be labelled as a transport-engineering aspect. However, the transport-engineering aspect defines roads only partially, as the roads are dualistic in function. The second aspect of the definition of roads can be labelled an urbanistic aspect. The urbanistic aspect mirrors the functions of a city and projects them into the structure of the road itself. For example, a road in an attractive tourist area with many restaurants, cafes, etc. can incorporate this principle by creating space for outdoor seating areas, small plazas, parklets, and other pedestrian areas where people can stay (the road mirrors the commercial and tourist function of the city). Another example would be a road in a traffic calming zone. The structure of the road can mirror the residential function of the city by promoting the importance of pedestrians and allowing children's play activities in the area of the road. In some cases, the urbanistic aspect can be dominant. For example, pedestrian zones should connect important urban districts and areas and should be planned according to pedestrian routes (transport-engineering aspect of pedestrian transport). However, this is not always the case, and the urbanistic aspect may dominate the street in favour of an urban expression of the public space.

It is important to note that in this paper the terms road and street are used interchangeably. The authors of the paper argue that this is necessary to fully describe the relationship between road infrastructure and urbanism. The entire street profile should be evaluated when incorporating changes in the road structure or during the application of a road hierarchization process.

Road hierarchization is an important part of the road network analysis, as it enables one to assess the current state of the network and to propose adequate transport measures. Hierarchization methods are usually based primarily on the transport-engineering aspect, and the urbanistic aspect plays only a secondary role. The authors of the paper suggest that the urbanistic aspect should not be omitted or mitigated. On the contrary, it should be treated as an equivalent factor, and the road hierarchization process should be run in two separate instances. Thus, creating a conflict between the transport-engineering and urbanistic aspect. This conflict can be used to further deepen the road hierarchization process and can lead to a more accurately described road network.

The paper is based on the master's thesis of the first author [1]. Because of this, the paper delves mainly into the hierarchization methods used in the Czech Republic. However, the use of the new method presented in this paper is not limited to the Czech Republic. Some degree of adjustment may be necessary, but the main principle is universally applicable.

2. Analysis of the Current State

The basis for the transport-urbanistic assessment of roads in urban areas in the Czech Republic is currently the Czech technical standard CSN 73 6110 Design of urban roads [2]. The standard deals extensively with the issue of urban roads and, among other things, defines an approach that serves to divide urban roads into four functional groups:

- Arterial urban roads with mobility function (A);

- Collector urban roads with mobility and accessibility function (B);
- Local urban roads with accessibility function (C);
- Urban roads with mixed traffic (D1);
- Urban roads that are inaccessible to motor vehicles (D2).

Urban roads are grouped according to their attributes. These attributes include the extent of the transport functions (mobility and accessibility function) and non-transport functions (especially residential function), the traffic behaviour of the traffic participants, and the profile/structure of the street. In general, it can be stated that function groups categorize urban roads by their transport-urbanistic role in a specific road network. Therefore, they can be treated as hierarchical groups that determine the importance of a defined set of urban roads.

The method of CSN 73 6110 [2] defines the characteristic application of functional groups and the characteristic features of the urban roads included in the individual functional groups. The boundaries of functional groups partially overlap and, therefore, the method leaves enough room for intuitive assessment, which is based on perception of characteristics, knowledge of a specific road network, and the ability to provide expert evaluation. The functional groups serve as a baseline for the proposition of structural elements of urban roads. In relation to functional groups, traffic quality levels are also defined, which are directly related to a road capacity and determine whether a traffic flow is free, saturated, or supersaturated.

Alternatively, the method contained in the technical requirements TP 131 [3] can be used. This method does not operate with function groups but introduces the index of transport importance. The index of transport importance can theoretically take values in the interval <0,2; 62> [3], where the upper limit signals the most important roads, and the lower limit means roads of limited importance. For example, a highway could take a value of approximately 55, while an arterial road value of 15 and a local road value of 2. The importance of roads based on this index can be understood as a quantified hierarchization. This approach makes it possible to perceive the importance of individual roads at a lower level of distinction without the need to introduce a significant number of hierarchical groups. The index of transport importance is expressed as the product of individual subindices. The description of these subindices is given in detail directly in TP 131 [3].

- Subindex of road class (I_t);
- Subindex of transport significance (I_D);
- Subindex of current traffic intensity (I_{SDI});
- Subindex of prospective traffic intensity (I_{VDI});
- Subindex of importance of the mobility function (I_{VDF});
- Subindex of function conflict (I_{SF}).

3. Construction of the New Method

The method proposed in this paper is based on two principles:

1. The duality of roads in urban areas is an essential concept of the proposed method and is crucial at all levels.
2. The proposed method can be divided into two processes. The first is a quantified hierarchization similar to the approach of TP 131 [3] and the second is group assignment similar to the method of CSN 73 6110 [3].

However, this approach creates two problems that make the proposed method not easily applicable. These problems need to be addressed.

3.1. Problem 1 – Conflict Between the Urbanistic and Transport-Engineering Aspect

Both of the mentioned methods incorporate the idea of the urbanistic aspect, but the role of this aspect in the process of hierarchization is ultimately diminished in favour of the transport-engineering aspect.

The method of TP 131 [3] incorporates the urbanistic aspect in the form of the subindex of function conflict (I_{SF}). However, the index of transport importance, which is crucial for the hierarchization process, is the result of the product of its subindices, which means that the urbanistic aspect is no longer distinguishable from the transport-engineering aspect and vice versa. The result of this merger may be called an universal aspect of transport importance. The universal aspect is more manageable, as there is no need to evaluate the road network two times. On the other hand, it completely removes the concept of duality from the hierarchization process. It is important to note that the structure of the subindex of function conflict itself is not adequate for road hierarchization in urban areas (see Problem 2 – Subindices of TP 131). The character of the subindices implies that the method is more inclined towards the transport-engineering aspect. Traffic intensity, road class, transport significance, and mobility function are all transport-engineering oriented attributes. It can be argued that the subindex of importance of the mobility function could also indicate the importance of other functions, as the mobility function with low importance could indicate accessibility or residential function with high importance. However, the method does not operate on this principle and a low value of the subindex of importance of the mobility function simply lowers the overall transport importance.

The urbanistic aspect is also reflected in the method of CSN 73 6110 [2]. However, the method of CSN 73 6110 is deliberately ambivalent. This is due to the functional groups and their characterization. The method implies that the functional groups C, D1, and D2 have some degree of importance in terms of the urbanistic aspect, but it is never clearly stated. Due to the ambivalence mentioned, the method functions more as an intuitive tool and gives more freedom to urban planners and their expert evaluation. On the other hand, the ambivalence makes the distinction between the transport-engineering aspect and the urbanistic aspect impossible. It can be noted that the ambivalence causes a similar result as in the case of TP 131 – the traffic-engineering and urbanistic aspects are merged and the hierarchization process is run according to the universal aspect.

Neither of the mentioned methods distinguish between the transport-engineering and urbanistic aspect. However, the proposed method, which is based on the methods of CSN 73 6110 0and TP 131, is related to the duality of roads. This incompatibility can be rectified by separating the subindex of function conflict from the index of transport importance. Separated subindex of function conflict is called index of urbanistic importance (I_{UV}) and the original index of transport importance without the subindex of function conflict is called index of transport-engineering importance (I_{DV}). This separation not only creates a foundation for the dualistic hierarchization process, but also creates the second problem.

3.2. Problem 2 – Subindices of TP 131

In the case of the second problem, it is necessary to mention that the primary use of the TP 131 [3] method is the assessment of the transport importance of roads in nonurban areas (this is also evident from the structure of the subindices). Within the urban area, the method is limited to the roads that start and exit in a nonurban area and only transit through the urban area (transit parts of roads). Of course, the method can also be used for a general assessment of roads in urban areas, but in such a case there is a rather significant risk of biased results. Therefore, individual subindices must be adjusted to the situation in an urban area. This is, of course, also true for the index of urban importance.

Subindex of road class – According to the TP 131 method [3], roads can be classified into one of the ten defined classes - see Table 1.

Table 1
Road classes and values of subindex according to the TP 131 [3]

Road Class	Index I_t [-]
I. class highways	1,5
II. class highways	1,3
I. class roads	1,0
Transit parts of I. class roads	0,9
Urban roads incorporated into the BRS	0,8
II. class roads	0,7
Transit parts of II: class roads	0,6
III. class roads	0,5
Transit parts of III: class roads	0,5
Other urban roads	0,4

The influence of the road class is recommended to be maintained within the proposed method. However, the categorisation contemplated by TP 131 (2) is inadequate for urban roads hierarchization. The category of urban roads incorporated into the Basic Road System (BRS) is especially problematic. It is not appropriate for the BRS to be an input to the hierarchization process but should instead be one of the potential outputs. Furthermore, it is not necessary to assess roads in a nonurban area, therefore, it is required to assess only the transit parts of the roads in question. The existing assessment also lacks the category of arterial urban roads, which play a specific role in the urban road system. For these reasons, the authors of the article propose a modification along the lines of Table 2.

Table 2
Road classes and values of subindex according to the proposed method

Road Class	Index I_t [-]
Arterial urban roads	1,2
Transit parts of I. class roads	1,0
Transit parts of II. class roads	0,8
Transit parts of III. class roads	0,6
Other urban roads	0,5

Subindex of road significance – except for omitting the category of other selected road network (the range of this road network is no longer monitored – a specific category for the Czech Republic), this subindex can be used without modifications.

Subindex of current/prospective intensity – the subindex of current/prospective intensity is based on the annual average traffic intensities measured in the national traffic count [3] and divides roads into nine categories (see Table 3). The TP 131 method [3] assumes the use of only one lane with the highest intensity; to avoid causing too much distortion of the results, when comparing two-lane and multi-lane roads, it is preferable to consider the highest intensity of one of the entire directions [4]. The same values are used for both current and prospective intensities. In other regards, the subindex is valid as is, but it could be theoretically transformed into more intuitive measurement based on qualitative assessment of current traffic flow.

Table 3
Categorization of traffic intensity according to the TP 131 [3]

Category and Intensity	Index $I_{SDI/VDI}$ [-]
I. more than 30 000 vehicles/24 h/lane	5,0
II. more than 20 000 vehicles/24 h/lane	4,0
III. more than 15 000 vehicles/24 h/lane	3,4
IV. more than 10 000 vehicles/24 h/lane	2,8
V. more than 5 000 vehicles/24 h/lane	2,0
VI. more than 2 500 vehicles/24 h/lane	1,5
VII. more than 1 500 vehicles/24 h/lane	1,3
VIII. more than 500 vehicles/24 h/lane	1,1
IX. 0-500 vehicles/24 h/lane	1,0

Subindex of importance of the mobility function – the subindex divides roads into five category groups labelled *a-e* according to the importance of the mobility function. The category groups have the following subindex values:

- Category group *a* – value of 1;
- Category group *b* – value of 0,9;
- Category group *c* – value of 0,8;
- Category group *d* – value of 0,6;
- Category group *e* – value of 0,4.

The definition of the subindex according to TP 131 [3] creates two problems when using this method in urban areas. First, the entire spectrum of categorization cannot be used, as the category group *a* is defined only for roads in nonurban areas (and without transit parts of those roads). Second, a holistic assessment of the road network in urban areas requires a lower level of distinction. Due to the mentioned problems, the authors of the article propose a scale assessment (see Fig. 1). In this approach, the value of 0,4 signals a high importance of the residential function, and value of 1 signals a high importance of the mobility function. The value of 0,6 is interpreted mainly as an accessibility function with residential function potential.

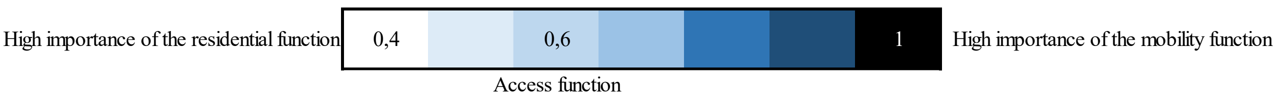

Fig. 1 Scale assessment of the index of importance of the mobility function

Index of urbanistic importance – method of TP 131 [3] describes the index as a representation of the conflict between the mobility function and one other function that is defined by the method (see Table 4).

Table 4
Function conflict and index values according to the TP 131 [3]

Conflict of the mobility function with	Index I_{SF} [-]
Direct accessibility function (nonurban areas)	1,05
Direct accessibility function (urban areas)	1,1
Public transport stops	1,15
Pedestrians or bicyclist's routs	1,2
Busy commercial street	1,25
Residential function, tourist function, etc.	1,3
No conflict	1,0

Function conflict limited to only two functions is appropriate for nonurban areas, where functions can be identified and separated [4]. However, the merging of two and more functions is characteristic for urban areas, and so this principle fails in implementation. The categorization itself is adequate for use in urban areas, nevertheless, the authors of the article propose a modified categorization which is more linked to city functions (see Table 5). Some of the categories should be assessed with a range that allows one to define the intensity of the parameter. In the proposed method, the index of urbanistic importance is a result of the sum of its subindices:

- Transport function with parameter of motor transport (FD_{IAD}) – motor transport and especially private transport is dominant, routes of public transport and/or bicycle and pedestrian transport are non-existent or insignificant (in case this is the only function that was applied). Can be combined with the function FD_{HD} and/or $FD_{C/P}$.
- Transport function with parameter of public transport (FD_{HD}) – road is important from the point of view of public transport – routes, stops, preferential measures, etc. are part of the street. Can be combined with the FD_{IAD} and/or $FD_{C/P}$.
- Transport function with parameter of bicycle and pedestrian transport ($FD_{C/P}$) – road is important from the point of view of bicycle and pedestrian routes; there may be a significant volume of pedestrians and cyclists that interact with motor traffic.
- Transport and access function towards industrial facilities (*FP*)
- Residential function (*FO*) – street is characterized by residential and accessibility function and may be part of a traffic calming zone.
- Transport and accessibility function towards civil amenity facilities (*FOV*) – schools, libraries, administrative facilities, hospitals, theatres, etc. are vital parts of a city infrastructure and create specific transport demand. Civil amenity facilities are also an important part of city space and, as such, are valuable from an urbanistic point of view.
- Transport and accessibility function towards recreational and tourist targets (*FR*) – important function near parks, plazas, squares, etc. The road itself should be also considered as a potential recreational/touristic target.

Table 5

Function conflict and index values according to the proposed method

<table>
<tr><th>Urbanistic function type</th><th colspan="3">Index [-]</th></tr>
<tr><td>Transport function with parameter of motor transport</td><td>FD_{IAD}</td><td>1</td><td rowspan="7">Or 0 in the case of non-existent function</td></tr>
<tr><td>Transport function with parameter of public transport</td><td>FD_{HD}</td><td>1,15-1,3</td></tr>
<tr><td>Transport function with parameter of bicycle and pedestrian transport</td><td>$FD_{C/P}$</td><td>1,15-1,3</td></tr>
<tr><td>Transport and access function towards industrial facilities</td><td>FP</td><td>1,1</td></tr>
<tr><td>Residential function</td><td>FO</td><td>1,2-1,3</td></tr>
<tr><td>Transport and access function towards civil amenity facilities</td><td>FOV</td><td>1-1,2</td></tr>
<tr><td>Transport and access function towards recreational and tourist targets</td><td>FR</td><td>1,2</td></tr>
</table>

3.3. Creating Hierarchical Groups Within the Proposed Method

The quantified nature of the modified TP 131 method is suitable for the specific assessment of individual roads and for the detailed analysis of the observed network. However, this "fluid" hierarchy lacks clarity and is time consuming when creating outputs. Adequate measures would have to be defined for each discrete value that can potentially be achieved in the interval of the modified TP 131 method. It is more time saving to group roads into similar hierarchical groups based on their transport-engineering/urbanistic importance. This part of the proposed method is inspired by the functional groups of CSN 73 6110 [2]. In the proposed method, a set of hierarchical groups is defined for both the transport-engineering and urbanistic aspect. Individual roads are grouped according to the value assigned to them by the modified TP 131 method: For each hierarchical group, an interval is defined that decides whether a particular road will/will not fall into a particular hierarchical group. For example, hierarchical groups may be defined as follows:

- I. transport-engineering hierarchical group $<1.5; \infty)$;
- II. transport-engineering hierarchical group $<0,8; 1,5)$;
- III. transport-engineering hierarchical group $<0,4; 0,8)$;
- IV. transport-engineering hierarchical group $<0; 0,4)$;

In general, it is not possible to determine how to set the intervals for each hierarchical group. This needs to be assessed individually for each network under consideration, as the proportional range of each hierarchical group will be different for different cities.

The number of hierarchical groups should be the same for both aspects. This will also make it possible to determine the dominance of one aspect over the other and the strength of this dominance. If, for example, a road is classified in the highest hierarchical group in terms of transport-engineering aspect and in the lowest hierarchical group in terms of urbanistic aspect, it can be concluded that the transport-engineering aspect strongly dominates the urbanistic aspect. The dominance does not imply that the dominated aspect should be suppressed, but only establishes its lower priority. It may also be the case that a road is ranked in equally important hierarchical groups in both aspects. In such a case, it is necessary to balance the two aspects, as they are in direct contradiction, and neither is a priority.

4. Discussion

The perception of transport infrastructure solely on its ability to conduct traffic may not be holistic and conceptualized, as transport infrastructure should also be perceived as an urban element. The transport infrastructure in urban areas is a substantial part of public spaces, and transport itself is intertwined with a city structure and its other functions. The definition of transport infrastructure should consider not only the transport engineering aspect but should be broad enough to describe the infrastructure as a part of a sociologically and urbanistically complex issue of public space design. The links between transport infrastructure and urbanism allow for the close interaction of infrastructure and public space.

This definition should be reflected in the road hierarchization process, as road hierarchization is a basic assessment of the use and character of roads in urban areas. The proposed method is based on this principle. By separating the transport-engineering and urbanistic aspect both roles of roads are assessed. The proposed method may be one of the ways to stabilize the links between urbanism and transport infrastructure and offer more specific transport and urbanistic measures. The transport infrastructure is inherently connected to a modal split, as the transport infrastructure affects the modal split and vice versa. This modal split – transport infrastructure feedback is not only defined by a current state but is also significantly influenced by a forward-oriented state. Accurate assessment of roads can lead to a better understanding of individual road functions and roles and to a more accurate design of road structures that are connected to a public space expression. This is also directly related to the concepts of traffic behaviour and sustainable mobility as these concepts are significantly influenced by a modal split, state and hierarchy of the road network and the structure of individual roads. This implies that detailed knowledge of the mentioned functions and roles may lead to specific measures that influence traffic behaviour in a more sustainable manner.

5. Conclusions

In this paper, the authors presented a new method for road hierarchization which is based on methods currently used in the Czech Republic. However, the proposed method is principally different as it is defined by the dualism of roads in urban areas. Both currently used methods, TP 131 and CSN 73 6110, combine transport-engineering and urbanistic aspects into one universal aspect of transport importance. This approach is appropriate to assess roads in nonurban areas but may be too inaccurate if applied in urban areas. This can lead to imprecisely designed transport-engineering measures and/or suppress one of the aspects.

The proposed method strictly separates the transport-engineering and urbanistic aspects and conceptualizes the urban road network according to both aspects. The proposed approach offers more flexibility, accuracy, and detail. On the other hand, it is more time consuming as it requires one to assess a road network twice (from the transport-engineering aspect and from the urbanistic aspect).

Further research is needed to determine whether the proposed approach has its merits or if more adjustments are needed (especially compared to current methods and their effectiveness). However, the authors believe that current methods are not adequate since transport infrastructure and other urban infrastructure are increasingly more intertwined and require stable links to urbanism. For smaller cities, the separation of aspects may be an advantage in development, but for larger cities, the separation may become a necessity for a holistic assessment of a whole road network.

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Joint Undertakings for Research and Development of Railway

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Abstract

In Horizon 2020, R&I funding for the rail industry was done through the Shift2Rail Joint Undertaking (Shift2Rail). Shift2Rail is a public-private partnership between the EU and the rail industry established in 2014 under Horizon 2020 to coordinate and manage research and investment in the Union in the rail sector. Europe's Rail Joint Undertaking is the successor to Shift2Rail in the current Horizon Europe financial perspective. Europe's Rail Joint Undertaking will build on the successful results of Shift2Rail's work to speed up the development and deployment of innovative technologies. It will focus on digital innovation and automation to achieve the radical transformation of the rail system needed to deliver on the European Green Deal objectives.

In 2017 in Poland, the National Centre for Research and Development (NCBR) and PKP Polish Railway Lines (PLK S.A.) set up Joint Undertaking "Research and Development in Railway Infrastructure" - BRIK. The programme supports research and development work in the area of railway infrastructure and aims at increasing the Polish railway potential. The competition was announced in the following five thematic groups: digitisation and processing of rail traffic parameters, reduction of the negative impact of rail transport on the environment, increasing accessibility and durability of facilities related to passenger services, increasing the railway infrastructure resilience to climatic factors and third parties' interference, improvement of railway infrastructure maintenance and modernisation.

The article presents selected joint undertakings at both European and national levels. The creation of modern rail transport system is only possible using the latest solutions and technologies, thus joint research and development work by scientists and entrepreneurs aims to contribute to it.

KEY WORDS: *Shift2Rail Joint Undertaking, Europe's Rail Joint Undertaking, BRIK Research and Development in Rail Infrastructure Joint Undertaking, research funds, railway*

1. Introduction

The main tool for funding research and innovation in the European Union (EU) is the Framework Programmes - FPs. In the mid-1980s, the EU started crreating the Framework Programmes, which initially covered collaborative research and exchange of researchers in selected research areas. Then a network of a European nature was attempted, consequently, the integration of national research programmes and the development of thousands of concerted research consortia with strong business involvement, leading to establishing the Framework Programmes. Since FP7, which ran from 2007 to 2013, there has been a surge in EU research funding (Fig. 1).

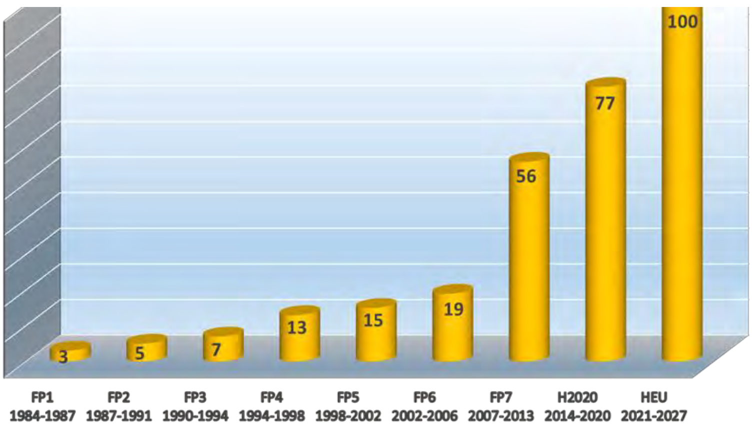

Fig. 1 Evolution of research and innovation investments in billion € under the EU Framework Programmes (the authors' own elaboration based on source material [1])

Funding for research and development (R&D) in the area of rail transport is provided by both EU and national funds and serves to improve the level of rail services. In the past financial perspective - Horizon 2020 – the funding for research and innovation for the rail industry was carried out through the Shift2Rail Joint Undertaking, which is a public-private partnership between the EU and the rail industry [2]. In the current Framework Programme, research for rail transport will be funded by the Europe's Rail Joint Undertaking (EU-Rail), which is intended to be a continuation of the existing Shift2Rail in Horizon Europe [3]. The national offer of research support in the area of railway infrastructure, delivered by the Joint Undertaking of the National Centre for Research and Development (NCBR) and the infrastructure manager - PKP PLK S.A., is called BRIK - Research and Development in Railway Infrastructure [4]. The next railway research programmes are to deliver innovative solutions within the defined thematic areas.

2. Shift2Rail Joint Undertaking

In 2014, the first European and institutionalised railway partnership called Shift2Rail Joint Undertaking was established under the 8th Framework Programme Horizon 2020 [5, 6]. Shift2Rail pursues the following objectives: to significantly increase or improve the capacity of the rail network to enable railways to compete effectively and handle a significantly higher proportion of passenger and freight traffic volume, improve the quality of rail services by responding to the needs of passengers and shippers, remove technical obstacles that limit the sector's interoperability capabilities, and reduce negative externalities associated with rail transport [7, 8]. Shift2Rail operates on the basis of a public-private partnership. The Founder on the public side is the European Union (EU) represented by the European Commission (EC), while on the private side are the Founding Members other than the EU: Alstom Transport, Ansaldo STS, Bombardier Transportation, Construcciones Y Auxiliar De Ferrocarriles, Network Rail, Siemens Aktiengesellschaft, Thales and Trafikverket. In addition, Shift2Rail members include those who were granted associate member status through an open, two-stage competition (Fig. 2). The participation in the initiative was not restricted to its members only, but it was possible for all stakeholders through open calls for project proposals [9].

Fig. 2 Direct members of Shift2Rail other than UE

The Shift2Rail budget amounts EUR 920 million, of which EUR 450 million is covered by the EU funding, EUR 270 million comes from the Founding Members and EUR 200 million is from the Associate Members.

The Shift2Rail Programme focuses R&I on demonstration activities and the dissemination of relevant market entry results, promoting the competitiveness of the European rail industry while creating a multiplier effect of the EU funds.

Taking into account the ageing of the railway infrastructure in Europe, the backlog of repairs in many countries, and the growing expectations of users, the Shift2Rail focuses on providing innovative solutions in five main thematic areas called "Innovation Programmes" (IP) covering all different structural (technical) and functional (process) subsystems of the rail system (Fig. 3) [9, 12]:

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.

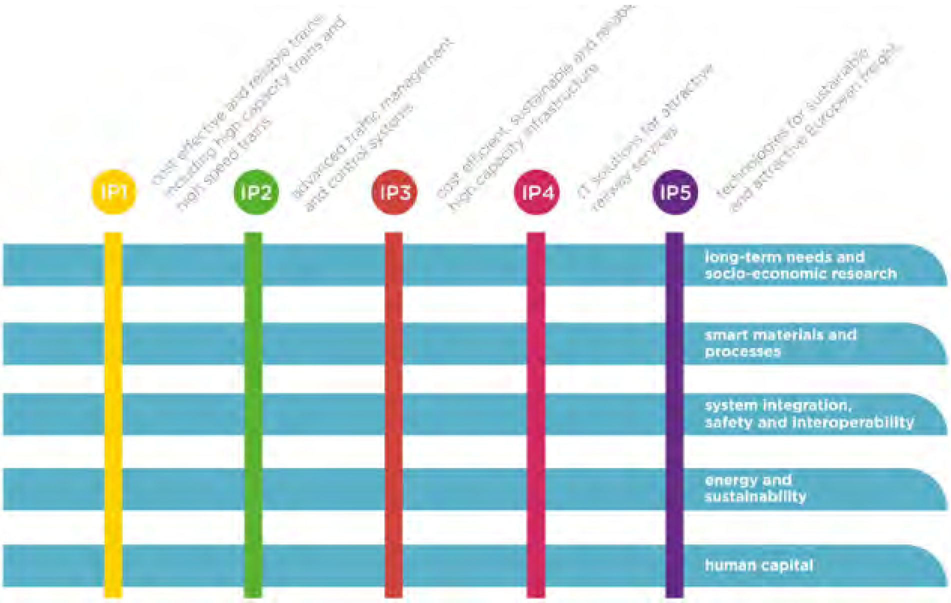

Fig. 3 Shift2Rail structure per IP and CCA activities [10]

The mentioned above IPs are accompanied by additional areas and topics that address in a cross-cutting way the issues relevant for each project and take into account the interactions between the IPs. The following cross-cutting activities (CCA) have been identified: long term needs and socio-economic research, smart materials and processes, system integration, safety and interoperability, human capital, and energy and sustainable development.

Each of the IP identifies the challenges, objectives and research activities to be implemented through the research and innovation projects. Since 2019, the Shift2Rail programme has attracted 412 participants from 29 countries, including 109 SMEs and 113 universities and research institutes [12].

3. Europe’s Rail Joint Undertaking

Europe's Rail Joint Undertaking is the follow-up of the Shift2Rail Initiative implemented in Horizon 2020. The objective of the new rail partnership is to enable the European rail network to be a crucial part of the Green Deal policy towards an environmentally friendly and energy-efficient mobility. Dependability, resilience and service quality will be key objectives to fulfil the goal of being a core part of a competitive and resource-efficient multi-modal European transport network. Europe's Rail was established by Council Regulation (EU) 2021/2085 of 19 November 2021 [11]. The current Europe's Rail Partnership is based on a long-term commitment by the European Union and its private members to deliver system-oriented solutions ready for industrialisation, implementation and operation.

Europe’s Rail JU is one of 10 European Partnerships under the Horizon Europe research initiative between the European Union and industry with an objective to accelerate the green and digital transition. The other partnerships approved by the council include:

- Global Health EDCTP3;
- Innovative Health Initiative;
- Key Digital Technologies;
- Circular Bio-based Europe;
- Clean Hydrogen;
- Clean Aviation;
- Single European Sky ATM Research 3;
- Smart Networks and Services;
- Metrology.

Europe’s Rail has been approved alongside nine other joint undertakings through which the EU will partner with member states and industries to deliver innovative solutions in Europe for global health, technology and climate challenges. The EU will provide nearly €10bn of funding from Horizon Europe that the partners will match with at least an equivalent amount of investment.

With a significant increase comparing to Shift2Rail’s budget, estimated at almost 50%, EU-Rail started officially on 30 November 2021, for a period of ten years, with a total amount of activities of EUR 1.2 billion to be delivered by its Members and other stakeholders under Open Calls, funded by EU-Rail with the resources provided by Horizon Europe up to EUR 600 million. The objective of Europe’s Rail is to deliver a high-capacity integrated European railway network by eliminating barriers to interoperability and providing solutions for full integration, covering traffic management, vehicles, infrastructure and services, aiming at faster uptake and deployment of projects and innovations. This should exploit the huge potential for digitalisation and automation to reduce rail’s costs, increase capacity, and enhance its flexibility and reliability, based on a solid reference functional system architecture shared by the sector, in coordination with the European Union Agency for Railways (ERA). By improving competitiveness, it will support Europe’s technological leadership in rail, with a leverage effect of each 1EUR invested by the Union, creating more than 2EUR of Research and Innovation added value.

In addition to the European Union, represented by the European Commission, the new partnership consists of 25 industry Members, selected through a transparent process started by the European Commission in August 2020, ensuring a balanced representation of the rail sector, including the operating community, rail and infrastructure managers, the supply industry, research centres and small medium enterprises, creating an opportunity for the sector to join forces and work together. The members of Europe’s Rail are the following: the European Union, ADIF, ALSTOM, MER MEC, AZD Praha, CAF, CEIT, CD, DB, DLR, European Smart Green Rail Joint Venture (eSGR JV), represented by Centro de Estudios de Materiales y Control de Obra S.A (CEMOSA), Faiveley Transport SAS, Ferrovie dello Stato Italiane S.p.A. (FS), Hitachi Rail STS S.p.A., INDRA SISTEMAS S.A & PATENTES TALGO S.L.U., Jernbanedirektorate (Norwegian Rail Directorate), Knorr-Bremse Systems, OBB, PKP SA, ProRail, SIEMENS, SNCF, Strukton Rail Nederland B.V., Thales, Trafikverket, Voestalpine Railway Systems GmbH [3].

Research and Innovation activities are structured around 7 key Flagship Areas (FA) and cross-cutting activities:

FA1 Network management planning and control, and mobility management in a multimodal environment

FA2 Digital and automated up to autonomous train operations

FA3 Intelligent and integrated asset management

FA4 Sustainable and green rail system

FA5 Sustainable competitive digital green freight services

FA6 Regional rail services / innovative rail services to revitalise capillary lines

FA7 New or emerging technologies for land transport

Cross Cutting Activities: digital data and activators

The first calls were announced in the first quarter of this year. Europe's Rail JU may award only one project per topic within the project duration period of 4 years. The call for proposals ends on 23.06.2022 and is open to all stakeholders.

4. Research and Development in Rail Infrastructure – BRIK (Poland)

In Poland, the National Centre for Research and Development (NCBR) is a state executive agency of the Minister of Education and Science. The Centre's activity is financed from state resources and European Union funds. The Centre's tasks include supporting Polish scientific entities and enterprises in developing their capabilities to create and use solutions based on scientific research results. The main objective of NCBR is to manage and implement strategic scientific research and development programmes which directly translate into the development of innovativeness. The tasks of NCBR also include supporting the commercialization and other forms of transfer of scientific research results to the economy, management of applied research programmes and implementation of projects in the area of national defence and security. The framework of national programmes conducted by the NCBR also cover the implementation of joint undertakings i.e. undertakings carried out in cooperation with an external entity which is obliged to make a contribution of at least 50% of the funds allocated for co-financing the project selected in the competition [14]. As mentioned in the introduction, since 2017 the NCBR and PKP PLK have been implementing the Joint Research and Development Undertaking with the acronym BRIK. PKP Polskie Linie Kolejowe S.A. is the manager of the national railway lines network. The company manages railway traffic operations and is also responsible for developing and updating the train timetable on a national scale. PKP PLK's priority is investment activity, which involves construction, modernisation and restoration of railway infrastructure. The aim of the conducted projects is to increase the availability of infrastructure and to improve the rail transport quality, as well as to adapt the railway network to EU standards and to create an integrated system of rail transport within the European Union [15].

The main objective of the Joint Undertaking is to increase innovation and competitiveness of rail transport. The implementation of the programme is to contribute to the increase in R&D activity in the field of railway infrastructure, rise in the number of innovative solutions in this area, improve the effectiveness of operation and management of railway infrastructure and reduce the negative impact of rail transport on the environment. The programme is dedicated to scientific units and companies from the railway sector. Within the framework of the Joint Undertaking BRIK - Research and Development in Railway Infrastructure, PKP Polskie Linie Kolejowe S.A. and the National Centre for Research and Development will allocate a total of PLN 100 million (PLN 50 million from each partner) for the development of innovations in the railway industry until 2033. The BRIK I competition from the National Centre for Research and Development is financed from the Intelligent Development Operational Programme. Financing of the BRIK II competition is planned entirely from national funds. In the first competition, 30 applications were submitted. Ten innovative projects were selected for co-financing, including five, in which the Railway Research Institute is involved as a leader or consortium member. The implementation period of the projects covers the period of 2017 - 2022. Due to the pandemic, some of them were extended until 2023 [Fig. 4].

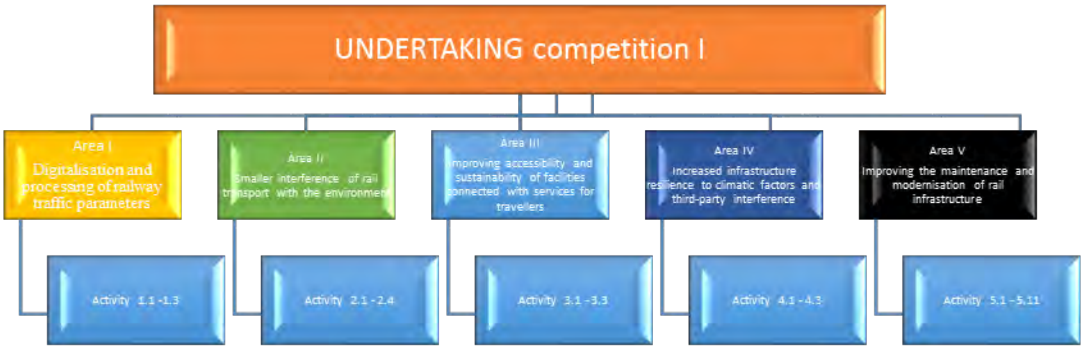

Fig. 4 Levels of the BRIK I Undertaking (the authors' own elaboration based on source material [4])

Below are listed projects the Railway Research Institute participates in together with scientific and industrial partners, in the first four of which the Institute is a consortium leader:

- Development and implementation of elements of an anti-theft system for the overhead contact line (OCL) in rail transport;
- Development of an innovative management system for the lighting infrastructure on the network managed by PLK S.A.;
- Standardisation of selected computer interfaces of railway traffic command control and signalling devices and systems (srk);
- Optimisation of ultrasonic transducers system for detection of internal rail defects according to catalogue of defects binding in PLK S.A.;
- Innovative solutions for protection of people and buildings from vibrations caused by railway traffic (IK as a consortium member) [13].

In December 2021, NCBR announced the second BRIK competition. A total of PLN 50 million was allocated to support projects in the competition (PLN 25 million from each partner). Only consortia may join the competition. The consortium may consist of at least one scientific unit and at least one enterprise or at least two scientific units, but no more than 5 entities. Only a scientific unit may become a consortium leader. The competition cannot be entered by entities related or partner companies in relation to PKP PLK S.A.

The thematic scope in the second stage of BRIK included the following research topics:

- Thematic area I - Railway traffic safety
  Activity 1.1 - Development of an innovative Rail Vehicle Warning System - SOPK
  Activity 1.2 - Development of a line dispatcher support system
  Activity 1.3 - Development of a method to manage environmental risks affecting rail traffic safety
- Thematic area II - Development of energy efficiency
  Activity 2.1 - Implementation of bi-directional traction substations and energy storage to increase network receptivity and improve energy efficiency and reliability on the railway
  Activity 2.2 - Improvement of energy efficiency of Electric Points Heating (EOR) devices
- Thematic area III - Development of pro-ecological solutions
  Activity 3.1 - Innovative solutions enabling the use of photocatalytic concrete on infrastructure managed by PKP PLK S.A.
  Activity 3.2 - Developing a system for precise monitoring of railway lines network managed by PKP PLK S.A. in terms of railway traffic impact on the environment and for processing information on traffic operations, technical and environmental data occurring on this network.
  Activity 3.3 - Development of innovative and pro-ecological solutions for vegetation control on railway lines managed by PKP PLK S.A.
- Thematic area IV - Improvement of diagnostics process
  Activity 4.1 - Concept of using Point Cloud from scanning measurements, for modelling of spatial objects located near the railway track for the needs of a railway manager (in scope of e.g. assets management, oversize transports, maintenance needs etc.).
  Activity 4.2 - Innovative solutions for rail flow detection testing at speeds from 60 km/h to 120 km/h.
  Activity 4.3 - Innovative solutions for radiological testing of rails with R60E1 or E2 profile
  Activity 4.4 - Development of an innovative Rail Infrastructure Condition Monitoring System (SMSIK).

As a result of the competition, 45 applications were submitted for the total amount of PLN 266,788,784.02. Currently the substantive assessment of projects is in progress. In the second stage, the Railway Research Institute submitted 6 project applications covering the subject areas 1.3, 2.2, 3.1, 3.3, 4.2, 4.3. The BRIK Joint Undertaking was included in the 18-year perspective, which is related to the time needed to produce, test and implement the tools that are the results of funded research work carried out under more than one competition [4]. The level of funding depends on the status of the company and the activities it undertakes.

5. Conclusions

The problem of funding research and development work in the field of rail transport by the European Union and the Member States remains a complex and multi-faceted topic. Projects involving scientific and industrial partners play the greatest role. Cooperation between the business sector and scientific institutions is an opportunity for joint innovation generation. A joint undertaking is a mechanism for funding research and development work, carried out in cooperation with an external entity. The aim of the project is to direct the activity of scientific entities to the implementation of R&D works on technological solutions whose need was defined by particular entrepreneurs or other public institutions. To sum up, the cooperation of the enterprise sector with scientific institutions is a chance for generation innovations jointly within the EU.

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Energy System Analysis for Greener Passenger Transportation in İstanbul Strait

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Abstract

Istanbul is one of the most crowded cities in the world, located at the crossroads of two continents, Europe and Asia. The city has high passenger mobility, however getting from one side of the city to the other is difficult, especially during working hours. Maritime transportation, which is done from various ports, is one of the modes of transportation used for passenger transit. To conduct the analysis, a liner passenger transit route in İstanbul Strait was chosen. Transportation operations in the Strait have an impact on both the environment and human health that living around. The International Maritime Organization, in particular, has established limits on CO2, NOx, SOx, and PM emissions within the scope of the Paris Agreement Objectives, which are emitted by ships. In addition to the Initial IMO Strategy on the reduction of GHG emissions from ships, the European Union has also published a series of measures via the European Green Deal, including waterborne transport, to make Europe the world's first climate-neutral continent by 2050.
Electrification, or the use of electricity as a power source, is an efficient technique for lowering shipping emissions and allowing cleaner transportation. In this sense, maritime travel between two nearby terminals has been investigated in this study since short-sea transportation is well-suited to electrification. Furthermore, a reference energy system for the vessel operating on this route has been built, and it has been analysed and simulated in terms of technical, economic, and environmental aspects using the Low Emissions Analysis Platform (LEAP). On the other side, an alternative scenario has been designed and implemented to demonstrate the potential consequences of electricity in the Istanbul Strait.
KEY WORDS: *Maritime transportation; energy system analysis, passenger transportation; energy efficiency; LEAP; maritime emissions*

1. Introduction

The maritime sector poses a severe environmental concern due to its reliance on fossil fuels and the fact that ship operations are typically carried out near coastal areas. The IPCC has given the IMO authority to minimize and prevent sea-borne emissions. With the yearly MEPC meetings, IMO keeps the prevention of harmful emissions up to date, particularly the MARPOL 73/78 Convention, and establishes new regulations in response to changing situations. The International Marine Organization (IMO) defines "green maritime shipping" holistically as terms such as green ship, green port, and green shipyard, which are among the world's binding choices. The primary goal of green shipping is to minimize emissions. Furthermore, the IMO defines forward-thinking, comparable, and classifiable high requirements for green shipbuilding and operation to boost maritime environment and atmosphere protection. In this context, the current study supports the United Nations Sustainable Development Goals, as well as the IMO's 2022 green marine theme in the maritime area.

The United Nations Environment Program (UNEP) was established in 1972 as the first worldwide application to analyse and control environmental concerns. Under UNEP, the United Nations organized the Intergovernmental Panel on Climate Change (IPCC) in 1988. In the Special Emissions Scenarios (SRES) booklet, published by the IPCC in 2000, information obtained from six different sources, namely population, economy, technology, energy, land use, and agricultural activities, estimated economic development between 1990 and 2050 in light of economic, social, and technological developments, and four different future scenarios were determined. Monitoring and reducing ship-sourced emissions has become necessary due to the consequences of emissions on global climate change and air pollution.

The IPCC has given the IMO authority to minimize and prevent ship-borne emissions. With the yearly MEPC meetings, IMO keeps the prevention of harmful emissions including CO_2, NO_x, SO_x, CO, PM, and black carbon up to date, particularly the MARPOL 73/78 Convention, and establishes new regulations in response to changing situations. are examples (BC). The International Marine Organization's Second IMO Greenhouse Gas Study, released in July 2009, analysed the greenhouse gas values resulting from international maritime transit, and it was determined to implement technical and operational steps for all ships, independent of flag or ownership. Gas emissions from international marine operations were estimated using several methodologies in the IMO's 2014 report for the years 2007-2012. Additionally, projections for the years 2012-2050 were developed.

Ekmekçiolu et al. (2020) calculated emission and spread for two prominent Turkish ports based on ship arrival [1]. Bilgili and Celebi (2018) investigated the development of various equations to predict the probable airborne emissions of a bulk carrier during pre-design based on two primary features (DWT and CB) [2]. Ekinci et al. (2011) used Computational Intelligent Techniques instead of experimental methods to forecast primary design parameters and main engine power for ships outside of the current data cluster [3]. Besides, Bilgili and Celebi (2020) concentrated on assessing emissions during operation and lodging, establishing emission factors, and optimizing routes [4]. In another study by Ekmekçioğlu et al. [5], they calculated emissions from ships arriving at Turkey's 4 largest ports using two bottom-up methods, ENTEC [6] and EPA [7]. Emission estimation equations have been developed for cruising, manoeuvring and port operation modes depending on the ship GRT for the container ship type. Moreover, Ekmekçioğlu et al. [8] estimated NOx, NMVOC, PM, SOx, CO and CO_2 emissions from a container ship during a 37-day voyage. Top-down and bottom-up methods [9] were used to make the estimations and the two methods were compared with each other. Bilgili and Çelebi [10] estimated the emissions from 9 bulk carriers using 3 years of data from 3 different methods in the literature. Emission estimation equations based on DWT and CB dimensions have been developed to predict emissions during the preliminary design of ships.

The 30-kilometer-long Istanbul Strait connects not only the Black Sea and the Sea of Marmara but also the continents of Europe and Asia. The Istanbul Strait, an international waterway, separates Istanbul into two parts: European and Asian. Throughout history, the Istanbul Strait has served as a trade gateway to the waters from the Mediterranean and the Mediterranean for the nations that border the Black Sea [11].

The rising population density of Istanbul produces various environmental issues. The water and air pollution affecting the Istanbul Strait may be studied from a variety of perspectives. Aside from the pollution created by the neighbouring communities and the oceans to which it is connected, ships travelling through the Istanbul Strait pose environmental threats. The environmental contamination induced by marine transportation can be classified as "Air Pollution" and "Marine Pollution" [11].

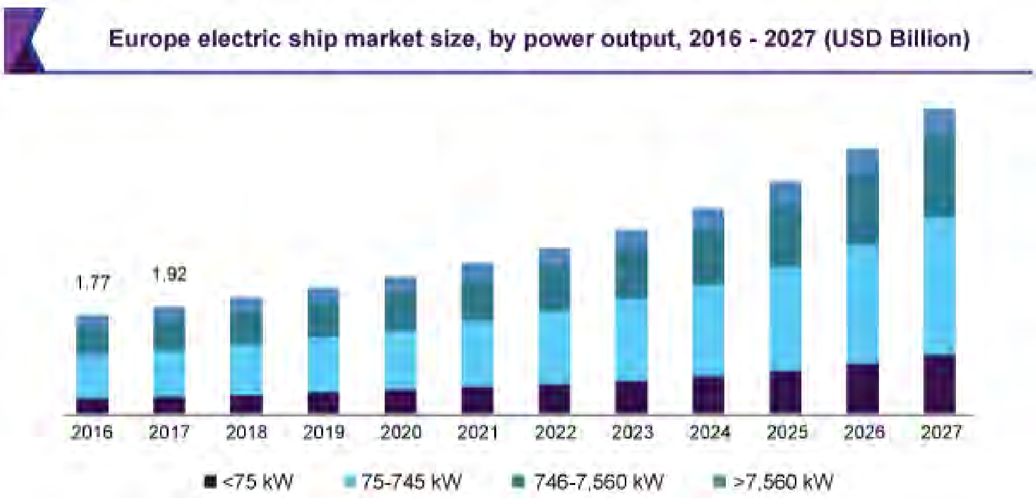

Fig. 1 Europe e-ship market size 2016-2027 [12]

When the population density and industrial diversity of Istanbul are examined, the magnitude of the risks in the Istanbul Strait becomes significant. In addition to strait accidents, another important risk factor is ship emissions. When MARPOL ANNEX 6 is examined, it has gained importance in recent years how much the strait crossing and port areas close to the living areas will be affected by these emissions. Many actions and measures have been taken in recent years since transportation is a very important source of pollution worldwide. Electrification, or the use of electricity as a power source, is an efficient technique for lowering shipping emissions and allowing cleaner transportation. In particular, over the last decade, the number of ships built with electric drive systems has significantly increased and this type of drive system is considered for the majority of new ships. This is because a diesel-electric drive system for most types of vessels is superior to a traditional diesel system in its technical, operational and economic aspects. In this sense, maritime travel between two nearby terminals in Istanbul has been investigated in this study since short-sea transportation is well-suited to electrification. Electric drive systems are now a proven and recognized solution in the global marine as seen in Figure 1. According to Fig. 1, it is expected to increase Europe's electric ship market size annually.

2. Reference Energy System and Decision Support Tools

Taking into consideration variables such as combatting global climate change, growing energy demands, regional conflicts between nations, and the Covid 19 pandemic, it is vital to assess how energy demands will be fulfilled in the future and what requirements will develop, and to take appropriate actions. To define the starting point and assess the essential measures and their outcomes, we must first examine and analyse the existing situation [13]. The energy elements indicate the current condition of the energy system, current energy applications, and previous performance against legal and other standards. In other words, the system used to picture the energy system in terms of energy consumption is referred to as the Reference Energy System (RES) [14].

RES is a diagram that depicts the demand technologies that are utilized to fulfil demand as well as all of the processes that the energies used in these demand technologies go through from the source [15]. RES is a flow chart that allows us to perceive and analyse the current situation, leads us in evaluating future situations, and aids decision-makers in benefit-harm analysis (Fig. 2 shows a simple example of RES preparation) [16]. It can also be applied to large energy systems with several regions on a global scale since the Reference Energy System may be used for the smallest energy system with a single area, [17].

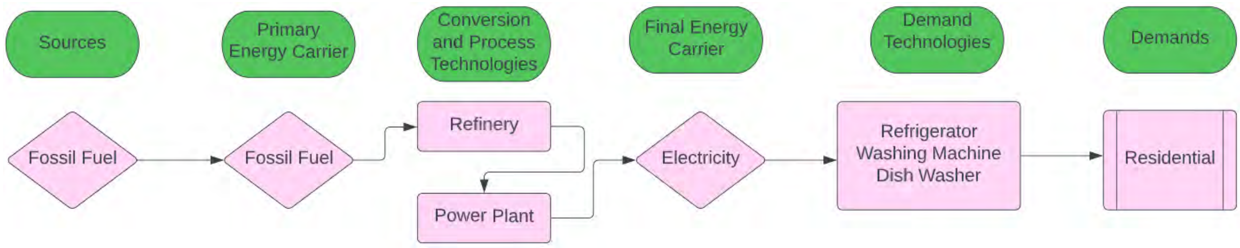

Fig. 2 Reference energy system diagram

According to Fig. 2, the source and main energy carriers are energy sources that have not been transformed or processed and exist in nature. Fossil fuels, biomass, the solar, wind, and hydraulic energies are the most extensively used primary energy carriers [18]. Conversion and process technologies, on the other hand, change main energy carriers into final (secondary) energy carriers, which are required and utilised in-demand technologies. Refineries, internal combustion engines, and power plants are the most common conversion and process technologies. Demand varies depending on the energy or sub-energy category under consideration [15]. The technologies we employ to satisfy the needs are referred to as demand technologies, and the energies utilised by these demand technologies are referred to as final energy carriers. For example, heat and electricity are the most common final energy carriers.

Using the Reference Energy System Concept [19], energy modelling and decision support technologies can be referred to as analysis, optimization, and modelling tools. Almost all energy analysis modelling tools employ the Reference Energy System Concept [20]. Energy modelling tools have been around since the 1970s. With the oil crisis of the early 1970s, various energy modelling techniques for analysing energy or sub-energy system appeared [21].

Due to limited storage options, sustainable and renewable energy alternatives, and the technological limitations of the time, decision-makers could not provide many energy consumption patterns. However, with the rise of the global climate problem and the expansion of storage possibilities and capacities based on evolving technology, there are now approximately forty energy modelling and decision support tools produced worldwide by various non-governmental organizations, international organizations, states, universities, and unions [22].

When energy modelling and decision support tools are reviewed, it is discovered that one or more of the following methodologies are employed together: Optimization, System Dynamics, Accounting, Geospatial Systems Dynamics Modelling, Simulation, Database, and Data Visualization. At least one of the long-, medium-, and short-term energy, economy, environment, and engineering studies of an energy system may be performed using energy modelling and decision support tools [23]. It should be noted that energy decision support technologies do not supply the answers we require; instead, they provide insight into the energy system [24].

Energy decision support tools serve many purposes, including improving understanding of current and future needs; supply, demand, and prices; facilitating the better design of energy supply systems in the short, medium, and long term; ensuring the sustainable use of energy resources; and understanding of current and future interactions between energy and the rest of the economy. On the other hand, understanding the potential consequences of environmental pollution is simple when using energy decision assistance tools [25]. The most extensively used energy decision support tools in the world are Times/MARKAL, WASP, EnergyPLAN, RETScreen, ENPEP-Balance, and LEAP.

In this study, we chose to utilize the Low Emission Analysis Platform (LEAP), because it is a scenario-based integrated energy-environment modelling tool which is extensively used by developing nations throughout the World.

The Stockholm Environment Institute created LEAP, which shows how energy is used, transformed, and generated in a certain energy system given a set of different assumptions.

2.1. Low Emission Analysis Platform (LEAP)

The LEAP energy model was developed and first utilized in the early 1980s. It was a technology called at the time LDC (Least Developed Nations) Energy Alternatives Planning (LEAP), and it was utilized as a computerized energy information management system designed specifically for energy planning in developing countries [26]. In 1980, the Beijer Institute's Kenya Fuelwood Project adopted the LEAP energy model [27]. It was a tool called LDC (Least Developed Nations) Energy Alternatives Planning (LEAP) at the time, and it was utilized as a computerized energy information management system designed specifically for energy planning in underdeveloped countries.

Due to concerns about the environmental consequences of energy in the early 1990s, the Environmental Database (EDB) was included and the name was changed to Long-term Energy Alternatives Planning, and LEAP was used under this name until 2020 [28]. LEAP, which was transformed into a windows-based software tool at the end of the 1990s by incorporating greenhouse gas emission reduction due to the advancement of technology and software tools, as well as the growing concern about the effects of increasing climate change, was presented to users in 2001 [29].

In the following years, with the updates of LEAP, multi-region modelling capabilities, least-cost optimization modelling, and the OSeMOSYS energy modelling system, LEAP to be linked to SEI's WEAP model to support energy-water "nexus" modelling analysis and data display, which makes more effective added Sankey Diagram shown in Fig. 3 [28].

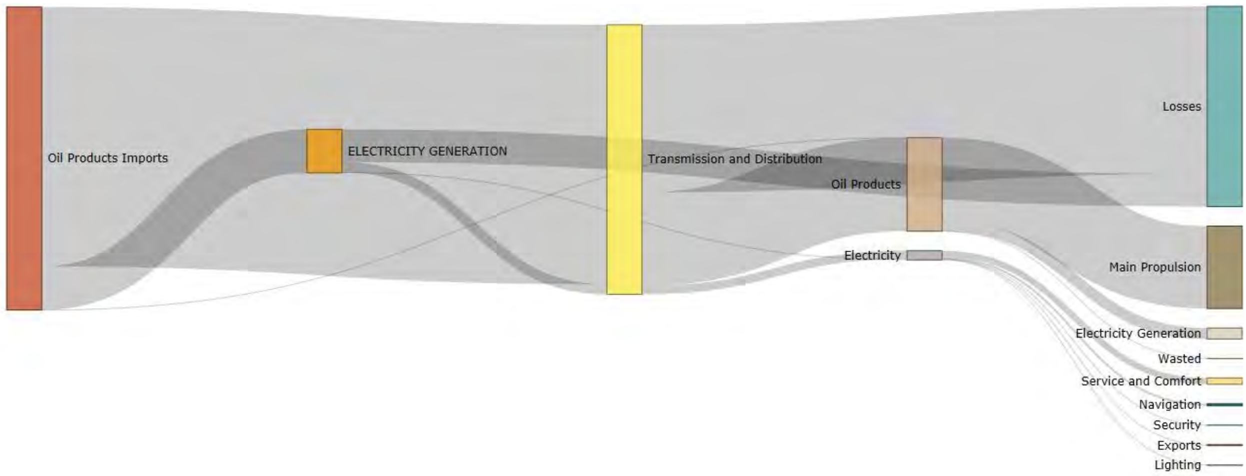

Fig. 3 Sankey diagram of a ferry

LEAP's latest version in 2020 introduced several advances, including the Next Energy Modelling System for Optimization (NEMO) framework for optimization modelling. LEAP did not change its acronym in 2020, but it did change its long name from Long-range Energy Alternatives Planning to Low Emissions Analysis Platform to emphasize the importance of finding new pathways to reduce greenhouse gas emissions and to demonstrate the evolution it has undergone over time [30].

LEAP is now a scenario-based modelling tool that investigates how emissions may vary in the future under various policy scenarios (e.g. baseline and low emission development scenarios). It is frequently applied on a national basis, but it may also be applied to city, region, and multi-region investigations [31]. It is largely concerned with the energy sector and GHG emissions in the energy sector, but it may also be used for non-energy industries. Furthermore, it not only allows modelling but also data management and documentation, result visualization, and stakeholder communication. The Integrated Benefits Calculator (IBC) [30] allows LEAP to assess the consequences of air pollution on health and climate.

In this work, we used the RES concept and the LEAP decision support tool to do an energy analysis and modelling of a private ferry employed in marine transit in Istanbul, Turkey's most populous city.

2.2. Reference Energy System of a Ferry

Fig. 4 shows developed RES for usage in the LEAP decision support model in which fossil fuel was utilized in the great majority of maritime transport. It was also employed as the source and principle energy carrier in the ferryboat which was designed to convey passengers between Kadıköy and Eminönü in Istanbul. Two main engines and two diesel-engine generator sets turn these basic energy sources into final energy carriers. The rectifier is utilized as the process technology to convert the power generated by the diesel generator into 24 VDC electricity. The ferry's final energy carrier is heat and electricity (220 VAC and 24 VDC). Thirty-three demand technologies employ these three final energy carriers to fulfil six major demands.

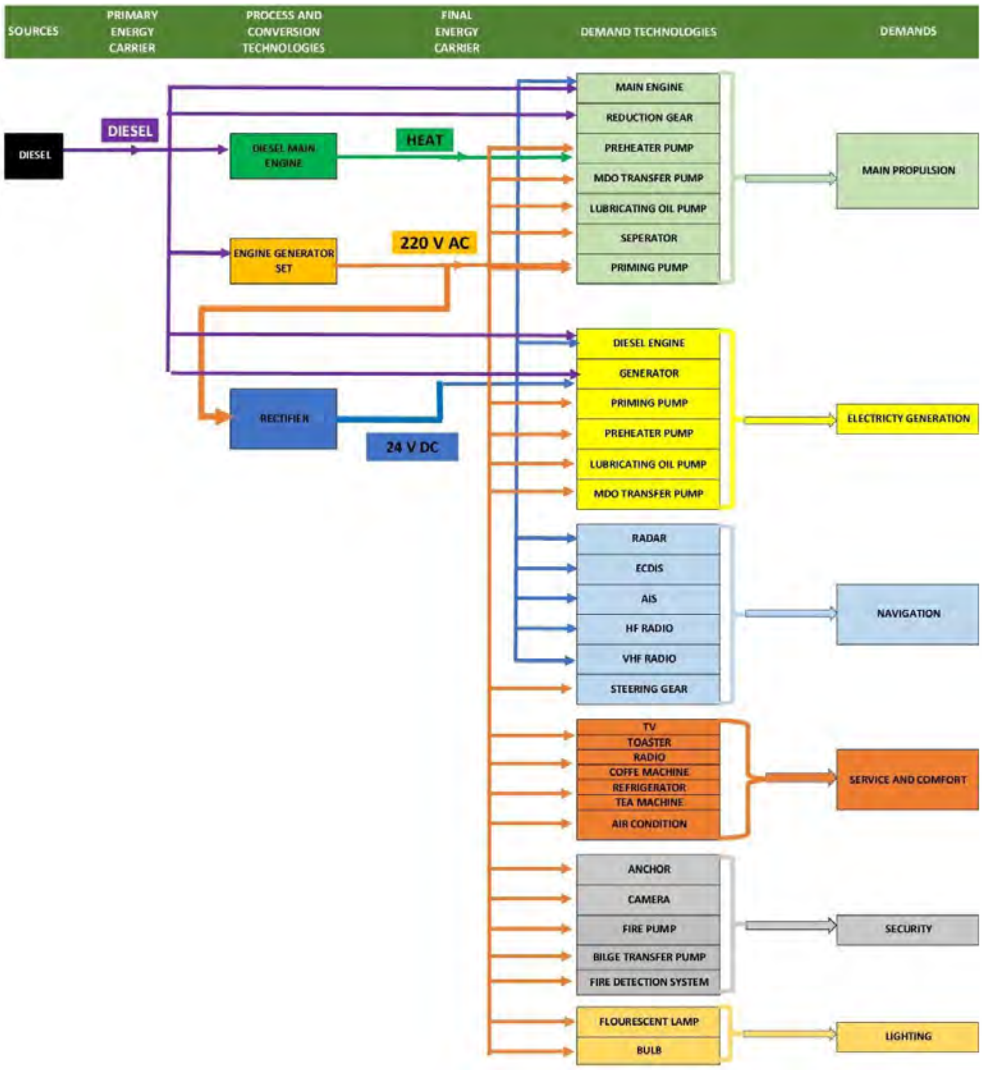

Fig. 4 Reference energy system of a ferry

These major demands are main propulsion, electricity generation, navigation, service and comfort, security, and lighting.

3. Energy System Analysis of a Ferry via LEAP

Within this study, RES was initially modelled in the LEAP decision support tool. The reference year was assumed as 2021, and energy analysis of a specific ferry was utilized in the Istanbul Strait. This ferry is employed on domestic lines and transports people between Kadiköy and Eminönü. This research conducted three scenario evaluations based on the Business-as-Usual (BAU) scenario, as well as the constraints imposed by the European Union Green Deal and the IMO. According to the research done with 2021 data, our ferry operates five days a week. In addition, it operates for an average of seven to eight hours per day during the summer and operates for an average of six to seven hours per day during the winter. According to the collected data from Turyol and the developed parameters, the energy balance of a ferry operating between Kadıköy and Eminönü in 2021 is shown in Table 1. The whole energy requirement of the ferry is covered by fossil fuels and powered by Marine Diesel Oil (MDO). The energy intake required to satisfy all of the ferry's demands is 6793.8 Gigatonnes. However, 4693.5 Gigatonnes of energy are wasted in the conversion and processing technologies used to satisfy the ferry's energy demands. The majority of these energy losses occur in internal combustion engines. When we look at the demands that the ferry has, we can see that the primary propulsion is the most in-demand, as shown in Fig. 3 and Table 1.

After main propulsion, the biggest energy requirements are electricity generation, service, and comfort. According to Table 1, the majority of the power generated by the ferry is used for service and comfort. Moreover, three further scenario assessments are constructed regarding this data in this study.

Table 1

Energy balance for Kadıköy-Eminönü ferry

Energy Balance for Area "KADIKOY EMINONU FERRY"			
Scenario: BAU, Year: 2021, Units: Gigajoule			
	Electricity	**Diesel**	**Total**
Production	-	-	-
Imports	-	6793.8	6793.8
Exports	-	-	-
Total Primary Supply	-	6793.8	6793.8
ELECTRICITY GENERATION	244.4	-959.8	-733.2
Transmission and Distribution	-34.0	-3733.8	-3767.8
Total Transformation	210.4	-4693.5	-4500.9
Main Propulsion	-	1852.2	1,852.2
Electricity Generation	-	248.0	248.0
Navigation	45.0	-	45.0
Service and Comfort	141.2	-	141.2
Security	0.3	-	0.3
Lighting	6.1	-	6.1
Total Demand	192.6	2100.2	2292.9
Unmet Requirements	-	-	-

3.1. BAU Scenario

With Istanbul's growing population and the relocation of manufacturing and commercial centres, transportation has become even more important. Maritime transportation is one of the most essential solutions to overcoming traffic density, which has been one of Istanbul's major challenges for years. In this context, energy and environmental analysis were conducted between 2021 and 2050, with the United Nations forecasting that the usage of seaway in passenger transportation in Istanbul will grow by 2.5 percent as of 2021 [32]. Figure 5 and Table 2 from the BAU scenario demonstrate that energy demand will more than double in 2050 compared to 2021.

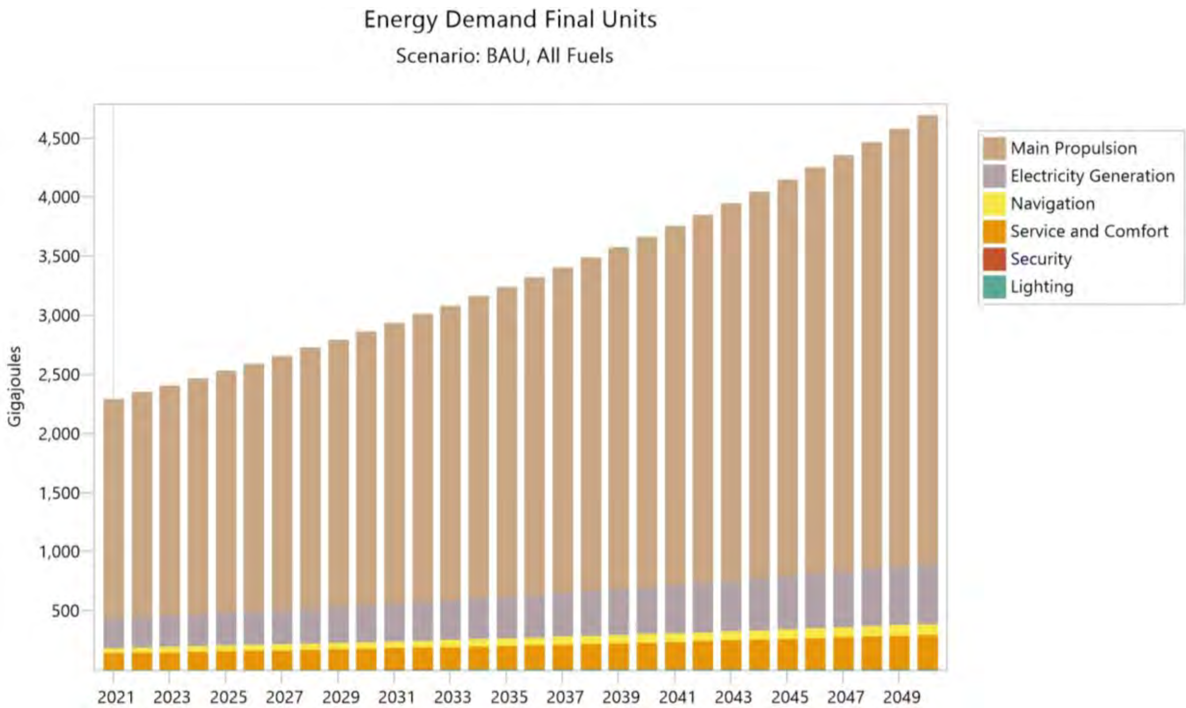

Fig. 5 Business as usual scenario energy demand

Table 2 clearly shows that only the primary propulsion demand will be larger than the overall demand in 2021 as of 2030 in this scenario.

Table 2

Energy demand final units for BAU scenario

Energy Demand Final Units							
Scenario: BAU, All Fuels							
Branch: Demand							
Units: Gigajoules							
Branch	**2021**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Main Propulsion	1852.2	2044.5	2313.1	2617.1	2961.0	3350.1	3790.4
Electricity Generation	248.0	273.8	309.8	350.5	396.5	448.6	507.6
Navigation	45.0	49.7	56.3	63.6	72.0	81.5	92.2
Service and Comfort	141.2	155.8	176.3	199.5	225.7	255.4	288.9
Security	0.3	0.3	0.3	0.4	0.4	0.5	0.6
Lighting	6.1	6.7	7.6	8.6	9.8	11.1	12.5
Total	**2292.9**	**2530.9**	**2863.5**	**3239.7**	**3665.5**	**4147.1**	**4692.1**

When we examine the environmental implications of the BAU scenario, we can see in Fig. 6 and Table 3 that if no actions are implemented, the demand for passenger transportation by seaway would grow from 410.03 metric tons of CO2 equivalent in 2021 to 839.08 metric tons of CO_2 equivalent in 2050.

Table 3

Acquired emissions for BAU scenario

Direct (At Point of Emissions)							
Scenario: BAU, All Fuels, All GHGs							
Branch: Demand							
Units: Metric Tonnes CO_2 Equivalent							
Branch	**2021**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Main Propulsion	361.60351	399.14261	451.59323	510.93629	578.07751	654.04164	739.98809
Electricity Generation	48.42465	53.45175	60.47575	68.42276	77.41407	87.58692	99.09656
Total	410.02815	452.59436	512.06898	579.35905	655.49158	741.62856	839.08465

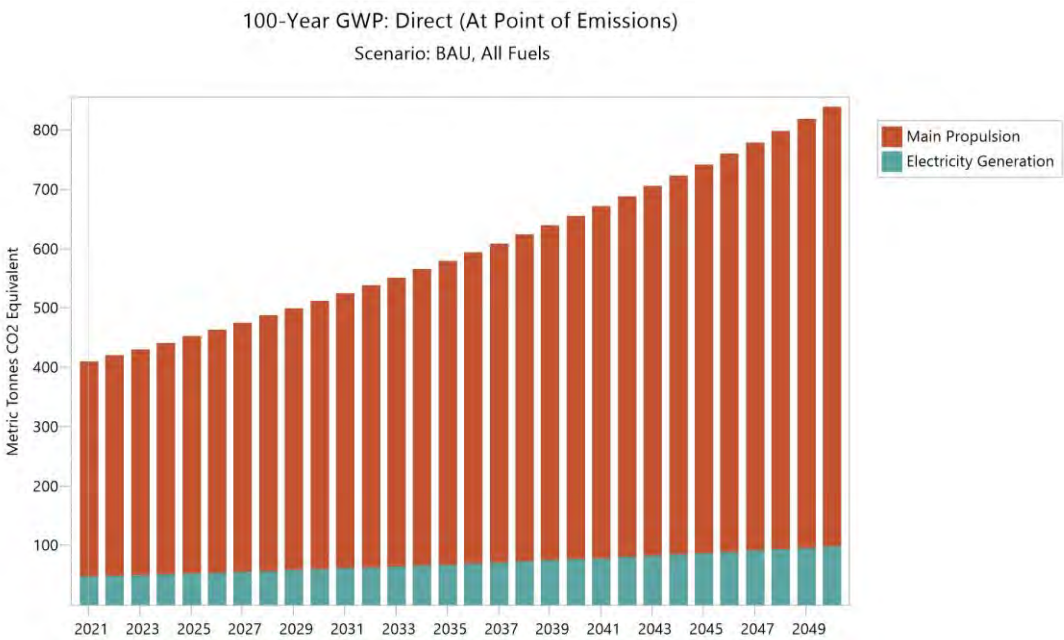

Fig. 6 Emission analysis of BAU scenario

According to the scenario, the emission from the main engine in 2049 will be more than the total amount of emissions in 2021.

3.2. EU Green Deal Scenario

The European Green Deal (Carbon Footprint) is a combination of European Commission policy measures intended to make Europe the first climate-neutral continent by 2050. An impact-assessed strategy is being developed to boost the EU's aim of reducing greenhouse gas emissions by 2030 to at least 50% and 55% below 1990 levels [33]. Climate change, biodiversity loss, ozone depletion, water pollution, urban stress, waste generation, and other environmental challenges are motivating the plan's development. The European Green Deal intends to boost resource efficiency by transitioning to a clean, sustainable economy, preventing climate change, reversing biodiversity loss, and lowering pollution.

In this respect, in accordance with the EU Green Deal objectives, the necessary CO_2 values have been studied to lower the emission value by 55% in 2030 compared to 2021 in the case of a 2.5 percent growth in passenger transportation demand as a scenario and to reach zero in 2050.

Table 4

Emissions for EU Green Deal scenario

Direct (At Point of Emissions)								
Scenario: EU GREEN DEAL, All Fuels, All GHGs								
Branch: Demand								
Units: Metric Tonnes CO2 Equivalent								
Branch	**2021**	**2025**	**2030**	**2035**	**2040**	**2045**	**2049**	**2050**
Main Propulsion	361.60	301.57	203.22	172.44	130.07	73.58	16.24	-
Electricity Generation	48.42	40.39	27.21	23.09	17.42	9.85	2.18	-
Total	**410.03**	**341.96**	**230.43**	**195.53**	**147.49**	**83.43**	**18.42**	**-**

To reduce emissions by 55% in 2030 compared to 2021 data, severe steps must be implemented in 8 years. As shown in Fig. 7 and Table 4, maximum of 230.43 metric tons of CO_2 equivalent GHG emissions should be released in 2030 in order to reach the lowest emission of 18.42 tons in 2049.

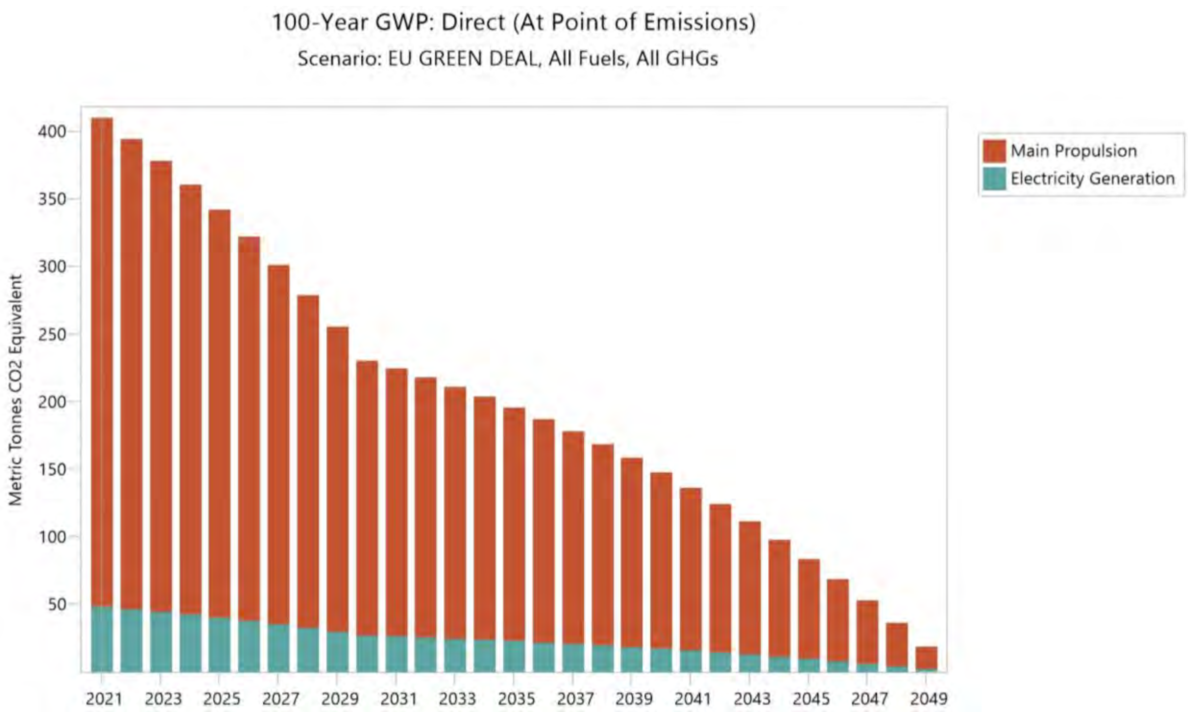

Fig. 7 Emission analysis of EU Green Deal scenario

According to the emission analysis of the EU Green Deal scenario, the emission reduction rate will be slightly slower in the twenty years following 2030 since there is more time to achieve the zero-emission objective (see Fig. 7).

3.3. IMO Scenario

The Marine Environment Protection Committee (MEPC, 72) assembled in London in 2018 intending to decrease greenhouse gas emissions from shipping and established the first plan to minimize greenhouse gas emissions from ships. According to 2008 data, the first approach aims to reduce the carbon intensity produced by worldwide maritime transport by 40% until 2030 and 70% until 2050. Global shipping's annual total greenhouse gas emissions will be cut in half by 2050 compared to 2008, and emissions will be eradicated in the long run [34]. MEPC, which meets twice a year, is scheduled to adopt more stringent measures by updating the initial plan in the future, but no decision has been reached.

Although the demands rise by 2.5 percent yearly in this scenario following the IMO's first plan, situations where GHG emissions decline by 40% in 2030 compared to 2021. Therefore, the data of 70% in 2050 compared to 2021 were examined.

Table 5

At the point of emissions for the IMO scenario

Direct (At Point of Emissions)							
Scenario: IMO, All Fuels, All GHGs							
Branch: Demand							
Units: Metric Tonnes CO2 Equivalent							
Branch	**2021**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Main Propulsion	361.60	328.18	270.96	268.24	260.13	245.27	222.00
Electricity Generation	48.42	43.95	36.29	35.92	34.84	32.85	29.73
Total	**410.03**	**372.13**	**307.24**	**304.16**	**294.97**	**278.11**	**251.73**

According to Fig. 8 and Table 5, if a 40% reduction is obtained in 9 years by 2030 compared to 2021 data, the quantity of GHG emissions would fall from 410.03 metric tons of CO_2 equivalents in 2021 to 372.13 metric tons of CO2 equivalents in 2030. It was determined that by 2050, the total amount of GHG released shall be reduced to the equivalent of 251.73 metric tons of CO_2.

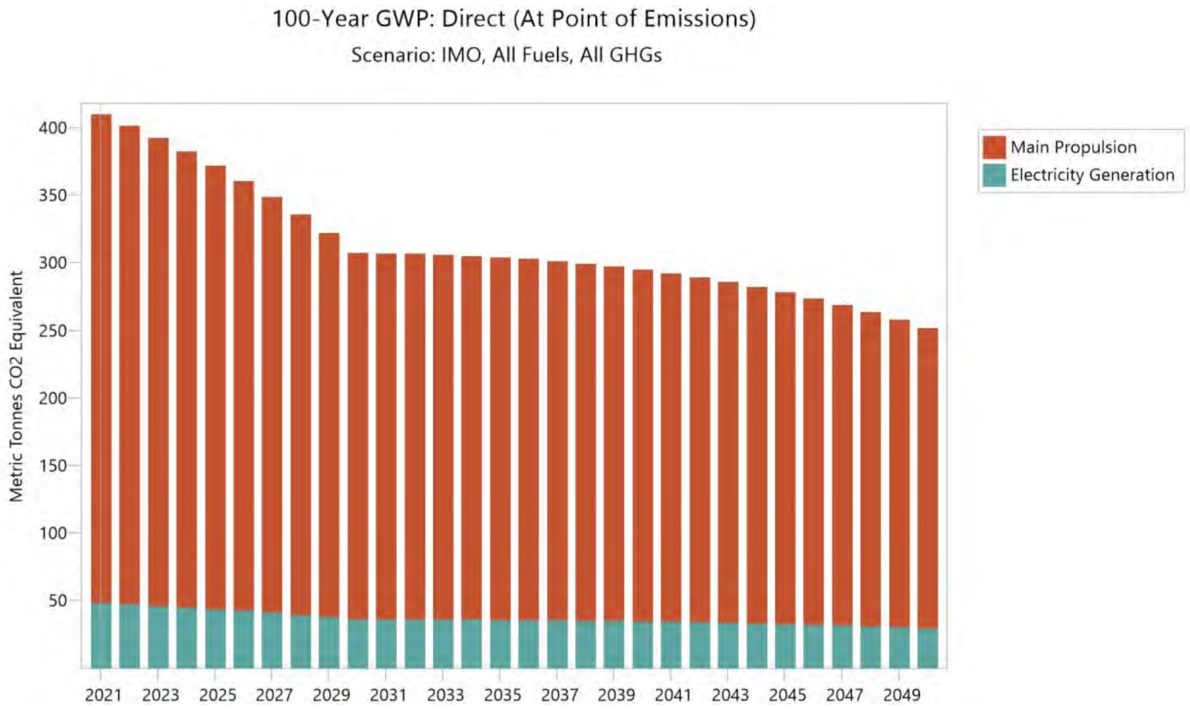

Fig. 8 Emission analysis of IMO scenario

4. Conclusions

The RES approach and the LEAP decision support tool are considered in this research to conduct an energy and environmental analysis of a ferry carrying people between Kadıköy and Eminönü, which is employed in urban transportation in the Istanbul Strait. Fig. 6 and Table 3 show that if no action is taken in the scenario analysis, environmental pollution will deepen day by day. When the EU Green Deal and IMO scenarios are compared, Tables 4 and 5 show that the EU measures are more rigorous; whereas the GHG emission level attained in 2030 in the EU Green Deal scenario is 230.43 metric tons of CO_2 in 2050, it is 251.73 metric tons of CO_2 in 2050 in the IMO scenario. As noted in the IMO scenario, because there is no zero-emission objective in 2050, it is assumed that emission targets can be met using alternate solutions such as the use of alternative fuels (LPG, LNG, etc.), scrubbers, and hybrid energy. However, alternative fuels, scrubbers, and hybrid energy are utilized for the transition until 2030 to reach the EU Green Deal objectives, but it is believed that the usage and storage of clean, renewable, and sustainable energy should be obtained in order to meet the carbon-neutral target in 2050.

From this perspective, it can be seen that strengthening the measures by amending the first plan at the IMO MEPC meetings is the correct option in terms of mitigating climate change. Since clean, renewable, and sustainable energy transit, storage, and use are challenging in the marine industry, which has a high energy demand, the IMO should clarify the tighter precautionary decision as soon as possible and allow sufficient time for implementation.

However, it is known that an important step in the fight against climate change can be taken by using clean, renewable, and sustainable energies in passenger transportation over short distances such as the Istanbul Strait; today's technologies are sufficient to achieve this, and there are numerous applications in many parts of the world, particularly in Norway, England, the United States, and Japan.

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Importance of Compatibility of Financial Statement Indicators in Calculating Financial Standing Indicators for Structural Units of Railway Transport

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Abstract

The prerequisite for a consistent economic analysis is a clearly determined sequence of measures that must be carried out when indicators of the financial state are calculated based on the company's reporting forms. Such a sequence should include the following stages: sorting data into a comparable form; specifying criteria and indicators of financial status assessment; calculating indicators for the period in question; analyzing changes in the calculated indicators over time; developing specific measures and management solutions. These are the crucial conditions to achieve the main goal of economic analysis, i.e., avoiding distortion of information in the support of management solutions at the micro- and macro-levels. Avoiding false conclusions becomes possible already at the first stage of the implementation of economic research – bringing the data into a comparative form. This publication discloses methodological approaches for ensuring the comparison of financial reporting indicators in order to calculate and analyze the indicators of the financial standing of railway infrastructure enterprises, provided that as much as possible data for the analyzed reporting periods is available. Unfortunately, no single methodology with the above focus area is available so far, which would take into account the specifics of the activity of structural divisions of railway company. The authors of the publication proved the universalized results of the development of conceptual methodological approaches to the evaluation of the comparison of financial reporting indicators (including those adapted to structural subdivisions of railway companies), and in case of urgent need, converting the indicators to a comparable form, for calculating the indicators of the financial standing.
KEY WORDS: *transport, railway transport, structural unit, reporting, comparability of indicators, methodology, comparability procedures, comprehensiveness of information, indicators of financial standing, change of indicators, conceptual approach.*

1. Introduction

Assessment of the financial condition of businesses includes calculating and studying a set of indicators that reflect various aspects of the enterprise's activities and affect the validity and effectiveness of managerial decisions at the micro and macro levels [1].

Depending on the results of the assessment of the financial standing, measures can be developed to improve the capital structure, restore solvency, increase profitability, determine the optimal amount of current assets needed by the enterprise, identify reserves for improving the efficiency of the enterprise and its development prospects, as well as avoid a financial crisis at the enterprise [2].

The calculation of financial standing indicators based on the financial reporting indicators of a business entity provides for certain procedures, the comprehensive implementation of which provides a qualitative analysis consisting of calculations of financial standing coefficients based on economically justified information on financial reporting indicators and the possibility of providing objective and unbiased conclusions about the actual condition and further development of the business entity [3].

Taking into account the specific activities of structural units of railway transport, it is necessary to develop conceptual methodological approaches have been developed to assess the comparability of financial reporting indicators and, if necessary, to bring its indicators to a comparable form for calculating financial standing indicators.

2. Analysis of Recent Publications on the Necessity of Implementation of Methods of Compatibility of Indicators Used in Calculations, Determination of the Purpose of the Study

Management of financial and business activities of enterprises should be based on the use of structured and reliable data on the financial standing of the enterprise, the main information source of which is the economic and other indicators of the business entity's activity, which today are accumulated in financial statements. In turn, the formation of indicators of financial statements is based on accounting data, as an integral part of Management Science [4, 5].

The variety of views on the methodology for assessing financial standing has led, on the one hand, to consolidated scientific justification of the author's approaches, and on the other hand, to desystematization of possibly estimated indicators. Still, all modern authors agree that these indicators should be calculated based on the indicators of financial reporting forms [3]. For example, in the selection of information for any analysis and in particular for the calculation of indicators of financial standing, there is an indisputable provision on the need to apply the procedure for assessing the comparability of input information from the point of view of the main methodological provisions for the selection of statistical data in research (Andrieieva G. I. [2], Mnykh E. V. [9]), the content of accounting data for analytical research is confirmed (Kalabukhova S. V. [6]), in order to ensure the comparability of accounting data in case of changes in accounting policy laws during the compared periods, the need to recalculate indicators is established through prospective/retrospective application [8], methodological approaches to assessing the financial condition of an enterprise (Masyuk Yu.V., Reznychenko A.V. [7]), the relevance of using financial reporting indicators in calculating financial standing Indicators with justification of the general methodology (Yatsukh A. A., Zakharova N. Yu. [12]) is revealed. Now, in addition to fundamental definitions in the legislation [8, 11], there are no scientific studies on the correctness of applying financial standing Indicators in calculations using financial reporting indicators of various indicators in their qualitative essence – at the reporting date and for the reporting period, despite their combination with one corresponding reporting period (quarter, half-year, year).

It should also be noted that none of the above developments take into account the specifics of the structural units of railway transport [13-17].

Purpose of the article is developing conceptual methodological approaches to assessing the comparability of financial reporting indicators and, if necessary, additional bringing its indicators to a comparable form for calculating financial standing indicators for structural units of railway transport.

3. Conceptual Approach of the Methodology for Preparing Reporting Data in a Comparative form to Calculate Financial Standing Indicators

Information about the financial and economic activities of the enterprise is accumulated in financial reporting indicators, the methodology for determining which is clearly regulated by the current legislation and is formed through the systematization of data on accounting accounts by applying the reporting methodology for the established NP(S)bu [8], P(S)bu [11] and other regulatory documents [12].

Meanwhile, the procedure for analyzing the financial condition of an enterprise under the current legislation is regulated by the Instructions on the Procedure for Analyzing the Financial Standing of Enterprises Subject to Privatization, approved by the Order of the Ministry of Finance of Ukraine and the State Property Fund of Ukraine dated 26.01.2001 No. 49/121 [18], which defines the financial standing of an enterprise as a set of indicators reflecting the availability, placement and use of enterprise resources, real and potential capabilities of the enterprise. At the same time, today the regulation [18] can be considered irrelevant, since the established methodology for calculating financial condition indicators on it was appropriate until changes were made to the current National Accounting Standards [8] and Accounting Regulations [11], as a result of which the indicators of financial statements were critically changed according to the formation and encryption procedure in the reporting according to the established codes of articles, as a result of which the calculation of financial standing indicators based on financial reporting indicators was desystematized.

Also, the regulatory basis for the implementation of relevant calculations is methodological recommendations for the analysis and assessment of the financial standing of enterprises, paragraph 3.4. of which reveals the general algorithm for the sequence of analysis [19]:

– preparation of reporting data for analysis (technical verification of the correctness of filling out financial statements, bringing the data into a comparative form, etc.);
– determination of criteria and indicators for assessing the financial standing (the few most important ones);
– calculation of indicators for the analyzed period;
– assessment of the financial standing by indicators in dynamics;
– development of specific measures and managerial decision-making.

Although this methodology [19] was developed later, today it still is relevant from the point of view of the content of the approach that is laid down in it regarding the basis for implementing economic analysis of financial standing indicators using certain algorithmic procedures. We are talking about the first stage of this methodology [19] (preparation of reporting data for analysis (technical verification of the correctness of filling out financial statements, bringing data into comparative form, etc.)), which, as a rule, is not always given due attention (and sometimes ignored by specialists), but it is the careful implementation of this stage that lays the foundation for qualitative analysis, which consists of calculations of indicators of financial standing based on financial statements and the possibility of providing objective and unbiased conclusions about the actual state and further development of the business entity.

Thus, already at the initial stage of implementing the methodology for assessing the financial standing of a business entity, it shoukd be determined what the approach will be used as the basis for analysis, because the vast majority of indicators of the financial condition of enterprises are calculated on the basis of data from Form No. 1 "Balance Sheet (statement of financial standing) as of ___20__" and Form No. 2 "Statement of financial results (statement of total income) as of ___20__", where according to the methodology for calculating the vast majority of indicators of financial condition, both indicators of Form No. 1 and indicators of Form No. 2 simultaneously participate, there is a methodological obstacle to the implementation of adequate calculations after all, the indicators of these forms are not comparable by period, despite their combination with one reporting period disclosure of information about the financial and economic activities of the business entity, since Form No. 1 provides data "on the date" (that is, at the end of the last day of the reporting period with simultaneous information notification of the state at the beginning of the reporting year as a whole), and Form No. 2 - "for the reporting period". There are indicators of financial standing that are calculated using other forms of financial statements (cash flow statement (Form No 3), equity statement (Form No. 4) and notes to financial statements (Form No. 5)), indicators for which also contain information "for the reporting period" [1, 3].

For the balanced implementation of the first stage of analysis and assessment of the financial condition-preparation of reporting data for analysis (technical verification of the correctness of filling in financial statements, bringing data to a comparative form, etc.) – we suggest that the purpose of analysis and information support of reporting data are the key factors, i.e., taking into account the state of comprehensiveness of information content of reporting data in time, in such possible ways [1]:

– using the data of Form No. 1 without bringing it to a comparable form – for conducting point-by-point (instantaneous) analysis. This allows, however, based on the data of one reporting period, to perform an analysis in dynamics – at the beginning and end of the reporting period;

– using data from Form No. 1 with bringing it to a comparable form (requires a special procedure for bringing data from Form No. 1 to a comparable form – transferring instantaneous data to a periodic one). Here, under a special procedure, we understand the additional calculation of indicators of Form No. 1 for the corresponding year as the arithmetic mean value for the corresponding indicators of columns 3 and columns 4, taking the result obtained as an indicator for the reporting year. This allows you to create a so-called "arithmetic mean balance sheet" for the reporting period, which conditionally translates balance sheet data from instantaneous indicators to period indicators. If there are data for two or more reporting periods, there is a prospect of performing an analysis in dynamics for the corresponding reporting periods.

Paragraph 4 of Section III "Qualitative characteristics of financial statements and principles of its preparation" of the Accounting Standard 1 "General requirements for financial statements" [8] approved the requirement to ensure the ability of users to provide comparability of financial statements of an enterprise for different periods and financial reports of different enterprises, which in turn sets the urgent task of ensuring the elimination of receiving incorrectly calculated indicators methodologically and technically in order to avoid information distortion and achieve and approve erroneous conclusions. At the same time, there is another problem, from what side – internal or external – the analysis is carried out, which means that the question arises of the comprehensiveness of initial data in terms of volume and dynamics, that is, the state of inclusiveness of information content of reporting data in time, taking into account the goal of achieving, regardless of the side of the implementation of the analytical process – the implementation of high-quality economic analysis, which is the key to unbiased conclusions about the actual state and further development of the business entity.

This means that each of the above methods should be considered from the point of view of providing information reporting data over time (annual or interim reporting) and its availability in dynamics, which together should ensure the preparation of reporting data for analysis (technical verification of the correctness of filling out financial statements, bringing data into comparative form, etc.).

So, this means that both the method of using the data of Form No. 1 without bringing it to a comparable form, and the method of using the data of Form No. 1 with bringing it to a comparable form in preparing reporting data for a comparative form can have a single informative basis for making calculations – annual or interim reporting.

Evidently, both annual and interim reports will have both limitations and opportunities for detailed analysis.

Implementation of the proposed methods of preparing reporting data for analysis to bring data into a comparative form for the possibility of analysis and calculations from a methodological point of view, we will give examples of the formal model "input – output" with a subsequent assessment of "prospects for the development of future results" by indicators of financial condition in dynamics, where [1]:

– "in" – a method with a specific choice of reporting in the reporting period (annual or interim);

– "out" – digital material brought to a comparable (comparative) form for calculating and analyzing financial condition indicators for the corresponding reporting periods;

– "perspective of future results" - assessment of the possibility of performing analysis in dynamics for reporting periods in conditions of limited reporting data for reporting periods, that is, taking into account the state of comprehensiveness of information content of reporting data over time.

As a result of modeling, we have developed the following conceptual methodological approaches for evaluating and, if necessary, bringing financial reporting indicators to a comparable form for calculating financial condition indicators (the idea has been improved according to the source [1]):

without previously bringing their indicators(in particular, those of F. No. 1) to a comparable form for annual reporting (Table 1, source: compiled by the authors based on the results of own research);

without first bringing their indicators (in particular, indicators of F. No. 2) to a comparable form for interim reporting (possible only in the case of analyzing interim reporting for the corresponding years, for example, the first (second, third, fourth) quarter of the reporting year is compared with the first (second, third, fourth) quarter of the previous year, respectively) (using Table 1 with certain assumptions for periods). Separately, similar calculations are possible for half-years;

with preliminary bringing of their indicators (in particular, indicators of F. No. 1) to a comparable form for annual reporting (Table 2, source: compiled by the authors based on the results of own research);

with preliminary bringing of their indicators (in particular, indicators of F. No. 2) to a comparable form for interim reporting (possible only in the case of analysis of Interim Reporting for quarters in the middle of the reporting year, for example, in the case of sequential analysis – the second with the first, third with the second, fourth with the third quarter of the reporting year, and in the case of basic analysis – the fourth with the first, fourth with the second, fourth with the third quarter of the reporting year) (using Table 2 with certain assumptions for periods). Separately, similar calculations are possible for half-years.

Table 1

Scheme for calculating financial condition indicators using financial reporting forms without first bringing their indicators to a comparable form /for annual reporting/ [20]

"Login" / a method with a specific choice of reporting in the reporting period/ → ↓		Method for preparing reporting data for analysis → ↓	"Exit" / indicators of reporting and analysis of Financial Condition Indicators for reporting periods have been brought to a comparable form/ → ↓		"Perspective of future results" / advantages (" + ") and disadvantages (" - ") for further analytical procedures/ ↓
Annual reporting → ↓		Research position: the indicators are comparable → ↓	Generated reporting periods for analysis ┌↓┐		«+»: Dynamics is achieved for the formed conditional reporting periods in conditions of limited comprehensiveness information content and reporting data over time; «-»: data from F. No. 2 for the same reporting period of the previous year are not used
			at the beginning of rep. per.	at the end of rep. per.	
Form No. 1 (annual) → ┌↓┐		without bringing the indicators to a comparable form ↓	set of calculated indicators of financial standing ┌↓┐		
at the beginning of rep. per.	at the end of rep. per.				
Form No. 2 (annual) → ┌↓┐		without bringing the indicators to a comparable form	{IFC}	{IFC}	
reporting period	prev. period		*source: {IFC} – indicators of financial condition*		

It should be noted that these models are not final and may have an alternative method of implementation, depending on the purpose of the study and other factors, for example, the state of comprehensiveness of information content of reporting data over time.

We will prove this thesis on the example of possible options for implementing the first model – the method of using the data of Form No. 1 without bringing them to a comparable form for annual reporting (determining the status of "Main" or "alternative" is taken by the researcher independently) [1]:

– option 1 (that we adopted conditionally as the main one): "in" – using data from Form No. 1 at the beginning and end of the reporting period talcum powder to data only from the reporting period Form No. 2 → "out" – getting indicators "at the beginning of the reporting period" and "at the end of the reporting period" → indicators "at the beginning of the reporting period" and "at the end of the reporting period";

– option 2 (adopted by US conditionally as an alternative): "in" – use the data of Form No. 1 at the beginning and end of the reporting period to the data of the previous reporting period and the reporting period of Form No. 2, respectively → "out" – get indicators "at the beginning of the reporting period" and "at the end of the reporting period" → indicators "at the beginning of the reporting period" (alternative name "for the previous reporting period") and "at the end of the reporting period" (alternative name "for the reporting period").

Thus, option 1 covers the use of reporting data of Form No. 2 only for the reporting period and in the absence of similar data from the previous reporting period does not allow for the implementation of analysis in dynamics, while Option 2 covers the reporting and previous periods, which provides an opportunity to analyze the Financial Condition Indicators calculated in the future in dynamics.

Similar procedures and conclusions should be applied to other areas identified by us-ways of using reporting forms when calculating and analyzing financial condition indicators using financial reporting forms, depending on the purpose of the study and the comprehensiveness of information content with reporting data over time.

Also, it should not be borne in mind that annual reporting forms are a priori comparable by year, provided that the accounting procedures for generating reporting indicators remain unchanged, while interim reporting forms are comparable both for the corresponding interim periods by year, and within the reporting year by quarters and half-years. So, if data is limited only to quarterly data within the reporting year, they require a special procedure for bringing Form No. 2 data to a comparable form by quarters, and if data is limited only to data for half a year within the reporting year, they also require a special procedure for bringing Form No. 2 data to a comparable form for half a year.

By a special procedure, we mean additional calculation of the indicators of Form No. 2 for the corresponding quarters (second, third, fourth) and half-year (second), because Form No. 2, starting from these reporting periods, contains data on an accrual basis. This is achieved by excluding the relevant data for the previous reporting period of interim reporting and drawing up the so-called "settlement" Form No. 2.

The indicators of Form No. 2 for the first quarter (for quarterly comparison) and for the first half of the year (for semi-annual comparison) do not need to be recalculated, since they have already been determined by the corresponding limits of the reporting period.

Table 2

Scheme for calculating financial statement indicators using financial reporting forms with preliminary bringing their indicators to a comparable form /for annual reporting/ [20]

"In" / a method with a specific choice of reporting in the reporting period/ → ↓	Method for preparing reporting data for analysis → ↓	"Out" / indicators of reporting and analysis of Financial Condition Indicators for reporting periods have been brought to a comparable form/ → ↓	"Perspective of future results" / advantages (" + ") and disadvantages (" - ") for further analytical procedures/ ↓
Annual reporting → ↓	Research position: the indicators are not consistent → ↓	Generated reporting periods for analysis ┌↓┐ prev. period | reporting period	«+»: Dynamics is achieved if the reporting data is comprehensive over time (2 or more reporting periods); «+»: transformation of F. No. 2 results in a comparable form with F. No. 1 for the corresponding reporting periods; «-»: in conditions of limited comprehensiveness of information content and reporting data over time
Form No. 1 (annual) → ┌↓┐ at the beginning of rep. per. | at the end of rep. per.	bringing indicators to a comparable form ↓ calculation of the"arithmetic mean balance" [[F. No. 1 (gr. 3+gr.4)]/2] ┌↓┐ prev. period | reporting period	set of calculated indicators of financial standing ┌↓┐	
Form No. 2 (annual) → ┌↓┐ reporting period | prev. period	Recommended procedure for preparing the reporting data of F. No. 2 to a comparable form of F. No. 1 for the corresponding reporting periods prev. period | reporting period	{IFC} | {IFC} *source:{IFC} – indicators of financial condition*	

It should be noted that the state of inclusiveness of information content of reporting data over time has a certain impact on determining the purpose of economic research and at the same time determines its sufficiency. For example, if there is data for only one reporting period, it is not possible to evaluate data for economic efficiency due to the absence of a comparison object, but only according to recommended or regulatory or industry indicators, and so on. If there is data for two or more periods, it is possible to adequately assess the indicators both in dynamics and in comparison with recommended or regulatory or industry indicators, and so on.

4. Conclusions

Calculation of financial standing indicators based on financial reporting forms (complete or simplified) contains a set of measures, a clear sequence of implementation of which (bringing data into comparative form; determining criteria and indicators for assessing financial condition; calculating indicators for the period that is analyzed; assessing financial standing by indicators in dynamics; developing specific measures and making managerial decisions) is the key to high-quality economic analysis.

Prevention of erroneous conclusions becomes possible already at the first stage of implementation of economic research – bringing data into a comparative form, which is extremely important in applying any methodology for assessing the financial standing based on the indicators of the financial statements of a business entity. For this purpose, methodological approaches to ensuring comparability of financial reporting indicators should be introduced in economic research to calculate and analyze financial standing Indicators in a certain state of inclusiveness of information content with reporting data over time.

The authors of the publication has developed conceptual methodological approaches for assessing the comparability of financial reporting indicators and, if necessary, bringing its indicators to a comparable form for calculating financial condition indicators.

The developed conceptual approaches are the basis for further alternative modeling, depending on the purpose of the study and other factors, for example, the state of inclusiveness of information content of reporting data over time and taking into account the specifics of the activities of structural units of railway transport.

As a result of the scientific development, the authors of the study has provided conceptual proof of the expediency of conducting annual reports and interim reports in the analysis, the methodological need to bring its indicators to a comparable form for calculating financial standing indicators using special procedures, such as calculating the "arithmetic mean balance sheet" and preparing a "settlement statement of financial standing", respectively, depending on the time parameter of reporting.

The relevance of the procedure for preparing reporting data for a comparable form before the fundamental analysis is proved.

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Design of a Steel-Steel Adapter for a Light Rail-Road Vehicle

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Abstract

Transportation is a quite complex system for the relocation of passengers and goods for longer or shorter distances. Nowadays, a combination of several types of transport is typical for most countries. Land transport includes road transport and railway transport. There is a number of types of vehicles used for these individual kinds of transport. Most of them are able to move only on a road or on a railway track. However, there is a quite narrow group of vehicles, which can move both on a road and on a railway track. There are called rail-road vehicles. In principle, there is derived from a road vehicles. They come from lorries and they include a special attachment allowing their running on railway tracks. The main objective of this contribution is the presentation of an engineering design of an adapter for a light lorry. It is a continuation of research activities in this field presented in the previous event. This technical solution is based on the transmission of driving and braking forces of the additional adapter of the rail-road vehicle by means of rolling of steel wheels on rails. Thus, it is an adapter, which works on the same principle as a standard rail vehicle. The work brings the main structural units of the rail-road vehicle and compares its properties with the previous engineering design (i.e. with a tyre-rail adapter). Despite, there being rail-road vehicles, this engineering design is characterized, that the adapter allowing setting of railway wheels to the main track gauge. It is contributing mainly to such regions, where railway tracks with various track gauges are built.
KEY WORDS: *light rail-road vehicle; steel-steel adapter; engineering design, transmission of forces*

1. Introduction

Railways are inseparable part of a transport network in many countries. In principle, every European country use railway for transportation of passengers and goods for both domestic as well as international transport. Daily use of railway infrastructure lead to necessary maintenance of railway tracks, i.e. rails and other components [1, 2]. For these activities, there are used special machines, which are equipped by various devices and allow to clean e.g. from snow, from grass, to repair broken devices and other. These machines are able to move either only on railway track, or they are also special vehicles, which are called as rail-road vehicles and they can move both on roads and railway tracks [3, 4].

This contribution is focused on the design of a modification of a particular light lorry, which will be equipped by a special chassis including railway wheels and it will be able to move on railway tracks. It is a continuation of the research presented in the previous event [5]. As it will be described below, there are more possibilities to modify a road vehicle to a rail-road vehicle. Whereas the modification presented in [5] has resulted to the tyre-rail adapter, the current paper presents a steel-steel adapter. They differ to each other by some key factors, which are described in following sections and these differences are obvious when one compares them to each other.

2. Types of Rail-Road Vehicles and the Way of Forces Transmission

The available sources of the literature offer more aspects, how rail-road vehicles are categorized. Categories according to Bado [6] can be supposed the most suitable for rail-road vehicles. This categorization takes into account the way of transmission of driving and braking forces from the drive-train of a vehicle to the railway track, or to the rails [6, 7]. Then, three different categories are recognized.

The vehicle belonging to the first category are equipped by such a system, where the tyres roll on rails heads and thus, they also drive the vehicle.

The second category includes rail-road vehicles, on which, tyres roll on wheels of a railway axle (or on railway axles in case of multi-axle vehicles). However, only railway wheels rotate on rails.

The last category consists of vehicles, which are equipped by the railway chassis with a special drive-train system and a vehicle moves by means of it. Only railway wheels are in a contact with rails. These systems usually use a hydrostatic drive-train, they are mounted on bigger and stronger lorries and they allow relatively accurate control of a rail-road vehicle during its movement on a track. These additional railway chassis are heavier and more expensive, however, they are able to transmit to a railway track much bigger weights and they are also safer.

2.1. A System of the Forces Transmission Steel-Steel

All system of transmission of driving and braking forces mentioned above have their advantages and disadvantages. Their application depends on the use and a type of a vehicle.

The research activities presented in this article are a part of wider works, which relate with the modification of a light vehicle Multicar M31 Hydrostat to a rail-road vehicle. This modification has taken into account two possible adapters to be used on the vehicle and namely they are the adapter of the type tyre-rail and the adapter of the type steel-steel. While the tyre-rail adapter has been the subject of the article presented in the previous event [5], this research is focused on the presentation of the engineering design of the steel-steel adapter.

The properties of the steel-steel transmission system come from its fundamentals. As the wheels of the steel-steel system are in the contact with rails [8-10], tyres are not so significantly worn and thus, they do not have to change that often [11-13]. The transmission of forces to road wheels is deactivated, which brings a significant advantage of this system, because the power-train of a vehicle is not loaded during an extreme load. Thanks hydrostatic chassis, a vehicle can move at the same speed both forward and backward. Further, the vehicle is powered only by a hydraulic pump and railway wheels roll on railway rails with much lower rolling resistance, the fuel consumption is lower. The main disadvantage of this system in comparison with the "tyre-steel" system are the costs. Examples of rail-road vehicles with the steel-steel adapter are shown in Fig. 1 and Fig. 2.

Fig. 1 A steel-steel rail-road vehicle – Mercedes-Benz Arocs [14]

Fig. 2 A steel-steel rail-road vehicle – Volvo FE [15]

As it can be seen on Fig. 1 and Fig. 2, in a case of application of "steel-steel" adapter to a lorry, the entire lorry, i.e. also the total weight of the vehicle rest on these adapters. Usually, these rail-road vehicles are equipped by two adapters, one is in the front part of the lorry and the other is in the rear part of its. When we consider the front adapter, it can be placed either behind the front axle, as it can be seen in Fig. 1. This mainly concerns vehicles of the heavier category and multi-axles vehicles. It is because the lorry has a larger space for it together with and in a case of multi-axles vehicles, the total weight is better distributed to adapters. In case of smaller lorries, the front adapter can be placed in front of the front axle (Fig. 2). This configuration has another advantage, which is, that the rail-road vehicle can be transferred from the road to the rail by means of both front and rear adapter. In principle, the rear "steel-steel" adapter is always located behind the last axle (in the driving direction). It is because of enough space and a favourable possibility to transfer from the road on a railway track.

3. A Modification of a Light Vehicle Multicar M31 Hydrostat to a Steel-Steel Rail-Road Vehicle

A light vehicle Multicar M31 Hydrostat (Fig. 3) is a versatile implement carrier and a powerful transporter, which combines multifunctionality, economic efficiency and manoeuvrability with a compact design [16].

Fig. 3 A modified light vehicle, the Multicar M31 Hydrostat brand [16]

This light lorry also provides sufficient safety and comfort for a crew (a driver and a possible passenger). The cabin frame is certified by the Dekra company. It has extra-large windows, which ensures a sufficient view from it onto traffic on a road and a track as well as to the attached working tools. Thanks these features, this vehicle can be used for a wide range of applications with about three hundred attachment combinations. Such a vehicle is able to work during all years' sessions on both roads and railways tracks. Just the designed steel-steel chassis adapter should ensure the safe and reliable operation on railway tracks with various track gauges. The vehicle's wheelgauge is of 1327 mm. However, with an adjustable steel-steel adapter, it should be able to move on railway tracks with the narrowest track gauge of 1000 mm and with the widest track gauge of 1520 mm.

The Multicar M31 Hydrostat vehicle offers various dimensions of tyres, namely 225/75 R16, 285/65 R16, 315/55 R16, 325/60 R15. Then, these tyres dimensions influence the wheel gauge of the vehicle. Using of wider tyres allows to move this vehicle on railway tracks with narrow track gauge (up to 1000 mm), on the normal track gauge (1435 mm) as well as on the wide track gauge (up to 1520 mm). Together, these three track gauges occur in the Slovak Republic and a map of the railway network in this country with marked tracks with different track gauges can be find in the previous contribution [5].

In a case of the steel-steel system, driving and braking forces are transmitted by means of a rail adapter. Thanks to the fact, that the vehicle is standardly equipped by a hydraulic system with a maximal flow rate of 110 litre per minute and with a maximal operational pressure of 30 MPa, it is not necessary to add other hydraulic pump. The vehicle will be able to generate driving and braking forces. The vehicle will meet all requirements regarding to the contours, because the rail adapter will lift the entire vehicle on a track.

In comparison with the designed tyre-rail system (or an adapter) [5], in the case of the steel-steel system, the driving and braking forces will be better transmitted to the rails, because railway wheels will be constantly in a contact with rails.

The steel-steel adapter is shown in Fig. 4. The railway adapter consists of five main parts. A grooved shaft is inserted on a main frame by means of bearings. A hydromotor is also mounted on the main frame. Two sliding adapters are mounted on a grooved shaft and adapters include a grove, which ensure their positions.

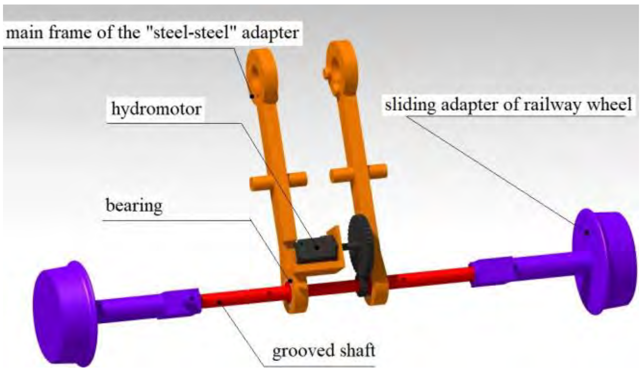

Fig. 4 The designed steel-steel adapter and its components

The main frame is sufficiently massive to carry the total weight of the vehicle, because tyres will not be in the contact with rails and thus, they will not carry any part of the vehicle weight. The one part of the main frame of the adapter is mounted to the main frame of the vehicle. The wheel gauge will be adjustable manually.

The vehicle with the steel-steel adapter can be transferred from a road to a rail in every place, where a road is in the same level as a rail head. It means, there are all railways crossings. The main condition is, that this place is large sufficiently that the vehicle is oriented perpendicularly to the road, i.e. parallel to the railway track. However, this is minimal problem regarding to the total dimensions of the modified vehicle. When the vehicle will be set in the railway track axis, an operator will set the wheel gauge on all four sliding adapters of railway wheels. Then, he will secure that positions by means of special grooves and a screw driver. The next step is, that an operator will release the adapter to the railway track by means of two double-acting hydraulic cylinders from a vehicle cabin. Then, the vehicle will be able to move forward and reverse on the railway track.

The front railway adapter (Fig. 5) hangs on a pivot placed on the vehicle frame and it rotates about it. The lifting movement of the adapter is controlled from the cabin by means of hydraulic cylinders mounted from the outside of the frame (Fig. 5, green components).

The rear railway adapter (Fig. 6) differs from the front adapter by the fact, that hydraulic cylinders act by the force from the inside of the adapter frame and cylinders are closer to each other (Fig. 6, green components).

Fig. 7 show the designed rail-road vehicle on the railway track with the track gauge of 1000 mm (Fig. 7 left) and on the track with the track gauge of 1520 mm (Fig. 7 right). It can be seen, that the tyres of the vehicle are not in the contact with the rails, when it is on the railway track.

It is assumed, that it will be appropriate to proceed in the presented research. Therefore, the future research activities should include analyses of designed adapters as well as analyses of the entire vehicle. There are mainly numerical analyses of individual components in term of a distribution of stresses and deformations in their structures [17-20] and dynamical analysis of the modified vehicle [21-23], when it will move on the road and the railway track.

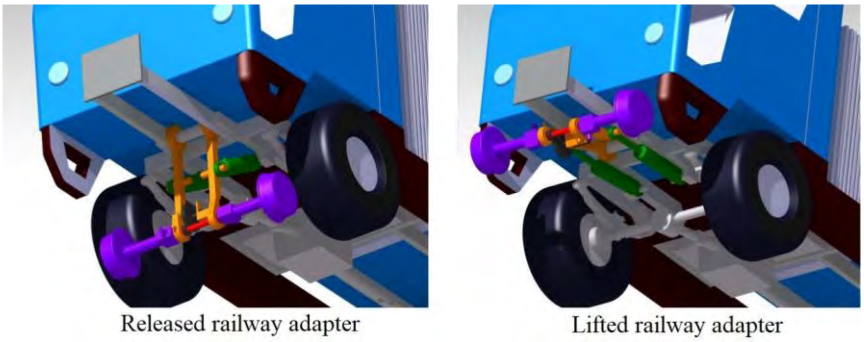

Fig. 5 A view of the vehicle with the designed steel-steel adapter in the front part of the vehicle

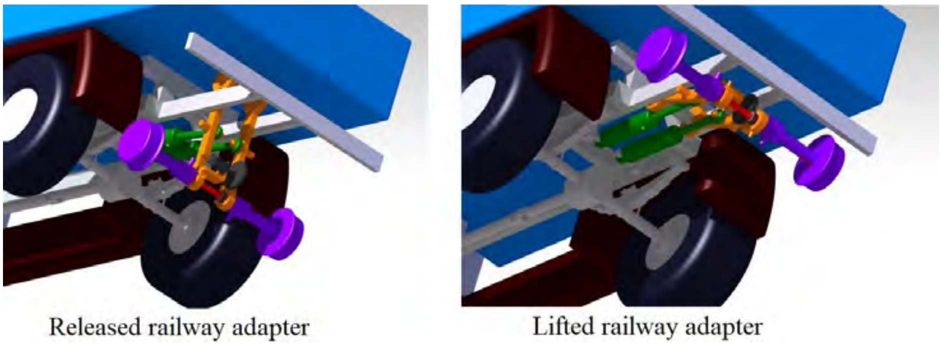

Fig. 6 A view of the vehicle with the designed steel-steel adapter in the rear part of the vehicle

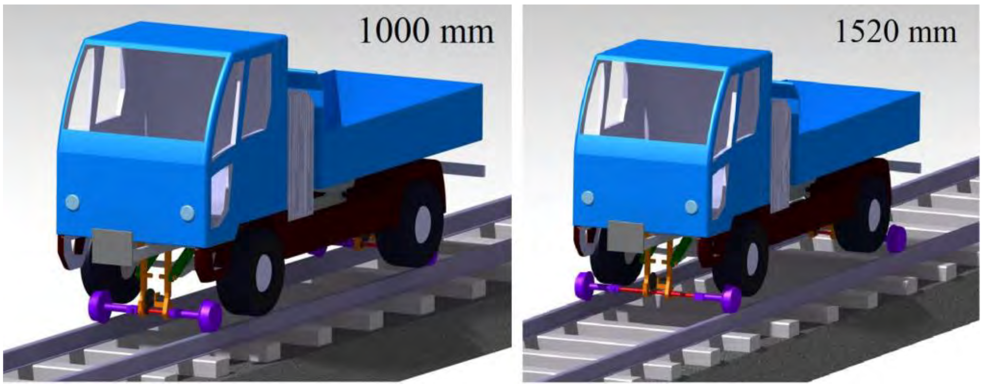

Fig. 7 A view of the vehicle with the steel-steel adapter on the railway track with the gauge of 1000 mm (left) and on the railway track with the gauge of 1520 mm (right)

4. Conclusions

The presented research aimed at the design of the adapter of the type steel-steel. This adapter is intended to be mounted on the light lorry type Multicar M31 Hydrostat. The main purpose of the designed modification of the vehicle is to spread its versatility that it will be able to move not only on roads, but also on railway tracks.

This modification has its own speciality, which consists in the fact, that the adapter includes railway wheels with an adjustable wheel gauge. This ensure a possibility of the use of this vehicle on railway with various track gauges from the narrow gauge of 1000 mm to the wide track gauge of 1520 mm. Another advantage of this modification is, that it does not require a significant change of the basic structure of the original light lorry. In principle, the designed steel-steel adapters can be mounted to the original supporting beams of the chassis. Despite of mounting additional hydraulic components to the vehicle, their actuating is solved in a quite elegant way, because they can be connected to the original hydraulic system of the vehicle. Minor disadvantage can be supposed a fact, that the setting of wheel gauge of the railway wheels is not possible automatically from a vehicle cabin, but a driver (or an operator) has to leave a cabin and to set a wheel gauge manually by means of a screw mechanism. Other operations, like releasing and lifting the adapters and the driving of a vehicle is performed from a vehicle comfort cabin.

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Selected Method for Evaluation of Vehicle′s Automated Driving Systems

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Abstract

The present trend of complex electronic systems implementation can be observed in various areas, especially in the automotive industry. Vehicle manufacturers introduce many kinds of automated assistance systems in real usage, trying to reach higher safety level, comfort and also easier vehicle operation. Automated systems are capable to participate in the driving process or even significantly changing decisive driving parameters by active intervention. Taking this fact into consideration, forensic experts require new support materials, equipment and procedures for traffic accident analysis to get reliable and trustworthy results. The article is dealing with a selected method for evaluation of vehicle′s automated systems which could be a reliable source of information for further analysis. Evaluation of automatized systems will be considered as determination of basic parameters related to the traffic situations in critical moments such as distance, acceleration, deceleration, speed and steering. As the main method for depth estimation will be described stereo vision system, which could be a useful and relatively low cost solution. It is strongly believed that automated vehicles will be massively spread soon and thus correct understanding of automated systems will be crucial for all concerned parties.
KEY WORDS: *automated system, evaluation, stereo vision, distance*

1. Introduction

Automated systems in vehicles are under rapid development and it is believed that soon are going to be massively applied in real life traffic. Currently many car manufacturers offer various driver assistance systems, which are supporting steps towards fully autonomous driving and increased safety levels. The benefit of an active safety system to prevent road accidents can be definitely achieved according to various real testing [1].

Innovations in this field are believed to change the car insurance industry by reducing accidents – a new report predicts that accidents will drop by 80% by 2040 [2].

Further research and improvement are also necessary, to enhance behavior of automated vehicles to case of pedestrian safety. As pedestrians are considered to be the most vulnerable participants of road transport, it will be absolutely crucial to set detecting algorithms to the highest possible level in order to predict, same as experienced human drivers do [3].

All assistance systems are using different kinds of sensors and devices, which provide important information for vehicle control units. As it is absolutely necessary to work with reliable data, there are applied some special processes which are improving inputs and thus increasing the safety level of driving. One of those is the Sensor fusion process. The article is dealing with the proposal of an external measuring device for the evaluation of automated vehicle intervention in driving, specifically the determination of the ego vehicle's distance from obstacles. This measuring device will be mobile and applicable for various types of vehicles. The key challenge will be gathering of information from cameras and accelerometers, consequently its synchronization and final evaluation. For this purpose, MATLAB software will be used as a numerical computing environment. A measuring device will be installed in the vehicle and afterward will be connected with a portable device, a laptop. Vehicle with such equipment is ready for simulation of critical traffic situation or traffic accident reconstruction. A special applications will provide parameters of automated system intervention. The key point will be a description of critical moments with details such as distances in time, speed, acceleration or deceleration. This device will provide exact details about automated system intervention in a critical situations, the distance in which the system was activated and also the level of influence on the actual driving situation.

2. Automated Systems in General

Automated systems are getting very complex using gradually more complicated algorithms. All systems use variety of sensors to understand the surroundings. In general, the automated system functional data procedure could be divided into 4 main steps:

a) Sense – this step is a sensing step, where data from environment of the vehicle are collected, basically it is connected to all available sensors, radars, lidars or camera outputs;

b) Perceive – in this step, all information from previous step are proceeded and transferred to the version, which could be understood by autonomous system. As an example, could be set of pixels detected by camera which represents the obstacle. Without further recognition, system would not be able to interpret it as a real danger for vehicle. Consequently, this information will be sent for next step;

c) Plan – information from previous step, are taken into consideration, system is looking for solution;
d) Act – last step of procedure, where system calculate how to execute the planned action [4].

3. Basic Hardware Used in Automatized Systems

Basic hardware devices which are most commonly used in ADAS – Advanced driver assistance systems - are radar, lidar, camera and various other sensors (Fig. 1). All devices have their advantages and also disadvantages, therefore usage more of them leading to optimization and improved result. Some car manufacturers using for their system all currently available devices but other like TESLA is not using for example Lidar at all.

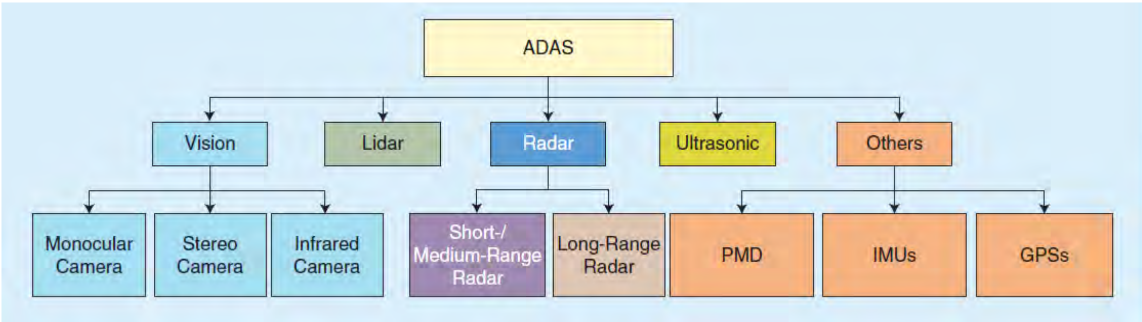

Fig. 1 Basic hardware review used in ADAS [5]

3.1. Radar

Radar – (Radio Detection and Ranging) is device which emits radio waves and receive the reflected waves from surrounding objects. Based on waves returned back and frequency shift is able to detect position, speed and direction of detected objects. This frequency shift of waves bounced from moving objects is called Doppler effect. The radar has been already in use in Second World War for location of the ships, aircrafts and other moving objects.
Regarding operation range of radar there is:

- SRR - Short range radar with range 0,2 – 30 m;
- MRR - Medium range radar with range 30 – 80 m;
- LRR - Long range radar with range 80 -200 m.

The remarkable advantage of radar is its operating reliability. It can work in various weather condition, heavy rain, snowing or in fog. Also, the reasonable price, low cost of production and compact size is benefit. As a disadvantage could be mentioned lower accuracy in comparison with lidar. Final output has lower resolution and it is problematic for detailed object classification [6].

3.2. Lidar

Lidar (Light Imaging Detection and Ranging) is a device working on similar principle as Radar with difference, that it emits laser light beams with wavelength of infrared electromagnetic radiation (typically 905nm), which is not visible by naked eye and not even harmful. Based on beams bounced back from objects, it creates point cloud, which is used for generating of detailed 3D picture of surrounding area. The Lidar principle has been connected with invention of laser technology back in 60th years. The most famous laser application was in mission Apollo 15, where it was used for Moon surface scanning.

The Lidar is generating precise 3D pictures, which is even able to recognize human gesture as pedestrian's head turning by the upcoming vehicle notification. This detailed reading of surrounding area could be helpful for prediction of pedestrian's behavior in real traffic situation. On the other hand, the disadvantage of Lidar is sensitivity for weather condition. It works in limited way under heavy rain or snowing and it is not able to generate detail output as it is supposed. That is reason, why it has to be combined with other sensors or devices such as radar. The other problem is high production costs, higher customer price and mechanical sensitivity due to its complex structure [7].

3.3. Camera

Camera belongs to older and widely used technology, which are implemented in various areas of industry. It is passive system, which have irreplaceable advantages over radar and lidar (Fig. 2). Although is sensitive for weather condition same as human eye, whereas it works in limited way, it can recognize as only device the texture, color and contrast. The ability of high resolution, details detecting makes camera a leader for objects classification. With low cost production is the main building stone for advanced assistance systems in automated vehicles [8].

Fig. 2 Basic components for ADAS. From Left: radar, lidar, camera

4. Current Possibilities for Evaluation of Automated System Intervention

Actual situation and possibilities regarding evaluation of automated system intervention is very limited. Forensic experts have not any kind of special device, which would evaluate participating of automated systems in driving situation. This special information would be very useful for traffic accidents investigation. Currently there are certain possibilities to retrieve some dynamic parameters, but their accuracy, scope and accessibility does not often meet required level. One of the devices for such information gathering is EDR – Event data recorder. Event data recorder records a range of vehicle data over a short timeframe before, during and after a triggering, usually by the deployment of an airbag, caused by a vehicle crash. The EDR stores critical crash-related information such as vehicle speed, state of restraints and braking systems as well as other relevant vehicle data at the time of the collision. This system, also called a "black box", was used in selected vehicles for the first time in 1974 by Generals Motors (GM) [9]. In the 1997 model year, Ford began the gradual introduction of EDR in vehicles, but for reasons of privacy and personal data protection, it did not allow data to be read from the EDR system using publicly available devices. Toyota has begun to gradually introduce the EDR system into its vehicles since 2001 and more carmakers have been gradually added. Currently, the EDR system serves most new vehicles and data can be read via a publicly available device [10].

For all necessary dynamic parameters gathering would be suitable to create measuring device with cameras, radar or lidar. All this hardware components could provide depth information of surrounding objects. Despite decreasing tendency of components production costs, they are still expensive, thus their usage in massive scale is very limited.

As an alternate solution could be considered set of two cameras called stereo vision system, which is able provide accurate depth coordinates and also 3D reconstruction of the scene.

5. Stereo Vision System

Cameras are one of the most important devices to capture surrounding of the vehicle. For some application has irreplaceable place in ADAS structure. Apart from standard purpose as it is for example traffic signs recognition, there is also another possibility of usage – depth estimation. However, there is also option to calculate objects depth with monocular camera system, the main subject of the article is stereo vision system – system with 2 independent cameras. This relatively simple but effective system has been used for long time, before radar was invented. In the past, main purpose of the stereo vision system was to estimate enemy ship's position. In the times, when camera was not invented yet, a set of mirrors was used instead of them. Received two images through mirrors were superimposed and then aligned. The result reflected on the special calibrated dial indicated the position of the enemy ship.

The fundamental principle of stereo system has not been changed since the beginning [11].

5.1. Details of Stereo Vision Operating

First of all, it is important to execute calibration of 2 cameras set. The most common method consists of preparing the calibration special checkboard, where we know size of squares and taking a series of photos for calibration. To get reliable and robust result from the system, it is important to keep correct calibration procedure and after it not to move with cameras with respect to each other – the distance between them must be fixed. If the distance would be changed, whole calibration must be repeated. The main purpose of the calibrated stereo vision set is to detect object and calculate its distance from camera. In this matter, calculating of the distance could be reformulated to find the disparity between 2 images captured by both cameras in the same moment. After rectification of the images, which is basically horizontal alignment of both pictures from the left and right image, the disparity is explained as number of the pixels which has particular point moved in the left camera picture compared to the right camera picture. To put it simply, disparity is distance or shift of the points in the images captured by both cameras at the same moment. This is basic principle used in stereo vision system to calculate distance of objects. In the Fig. 3 there is graphical explanation of the stereo vision system. The depth of a point is inversely proportional to the disparity of that point between the left and right cameras. It means, the closer an object is to the cameras, higher is the disparity. On the other hand, object in infinite distance from cameras has zero disparity [11].

5.2. Problematic Issues in Stereo Vision

The stereo vision system has certain limitations and it is problematic to calculate depth under all circumstances.

Some scenes are difficult for depth evaluation and a number of conditions must be kept. As an example:

- Surface must have texture – some features for stereo comparison;
- Surface must not be repetitive – repeating patterns would confuse stereo comparison;
- Foreshortening effect – matching of the pixels is due this effect more complicated;
- Suitable pixel size of the matching window – small pixel size causes high sensitivity for noise, on the other hand the large window results in poor localization. The solution could be multiple window sizes – adaptive window method.

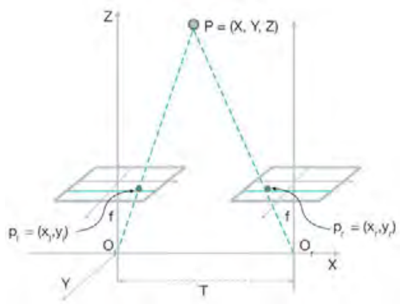

Fig. 3 Graphical explanation of stereo vision [11]

According the Fig. 3, there is point “P” which represents the position of object. The coordinates of the point “P”, especially coordinate “Z” which is wanted distance or depth of the object is calculated according Eq. (1).

“T” is baseline, “p_l” with position (x_l , y_l) is left camera plane optical intersection and “p_r” the same of right camera [11].

$$Z = \frac{f \cdot T}{x_l - x_r} \tag{1}$$

6. Proposal of Measuring Device Using Stereo Vision System

Proposal of the measuring device for evaluation of automated systems intervention into driving consists of 2 cameras installed on base bar with adjustable mutual distance. The base bar is attached to the windshield of the vehicle by 2 suction cups, which provide fixed position of the device even under various dynamic condition such as emergency braking. These 2 cameras are considered to be the stereo vision system. Isolated depth information of the objects or vehicles would not be enough for the purpose of the evaluation device, so it will be supplemented by accelerometer. As this device should be affordable for all forensics experts, general low costs for creating such device, is also an issue. For this reason, monitoring of the deceleration is solved by accelerometer in smart phone with android operating system. The mobile phone must be also fixed to the windshield with solid suction cup holder. As the software environment is used MATLAB, which is a multi-paradigm programming language and numeric computing environment developed by MathWorks. It contains several suitable tools for computer vision, image processing, automated driving systems, machine and deep learning. On the Fig. 4 is shown the measuring device attached to the windshield.

Fig. 4 Measuring device installed in the vehicle – two cameras with accelerometer in mobile phone

6.1. Calibration of the Stereo System

The initial step is calibration of the cameras, ideally directly in the vehicle, in order to ensure fixed mutual position of the cameras. Once the distance between cameras would be changed, calibrating of the cameras must be repeated. Software MATLAB contains also the application for stereo vision calibration. For this purpose, the special calibration checkboard (similar to chessboard) was prepared. This calibration checkboard is placed in front of the vehicle. Then several pictures are taken by stereo vision system in order to obtain calibration parameters of cameras. For correct process of calibration (Fig. 5), it is necessary to input to the application size of the checkboard square – here it was 50 mm.

Fig. 5 Calibration of the stereo vision with calibration checkboard in front of the vehicle

In order to receive accurate result, it is suitable to make at least 10 set of pictures, afterwards to remove those with higher final reprojection error and keep only those with overall Mean error below 1 pixel. In the Fig. 6 is example of calibration result with overall mean error = 0,08 pixel – acceptable level of accuracy.

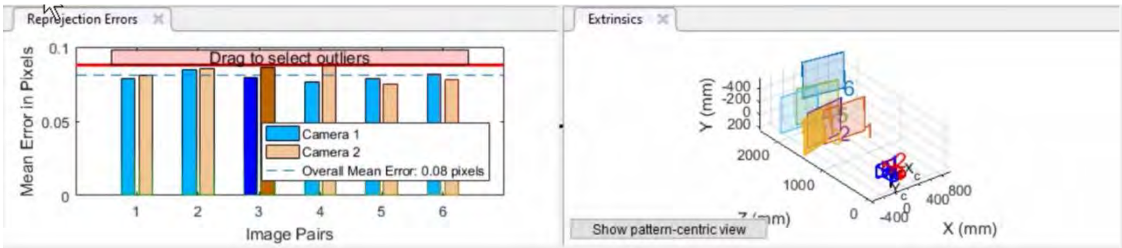

Fig. 6 Result of calibration [12]

6.2. Output of the Measuring Device

The purpose of the measuring device is to evaluate automated driving systems. However, there are several possibilities to construct the measuring device, this article deals with low cost version, with stereo vision system – 2 web cameras installed on adjustable bar and smart mobile phone with accelerometer. This composition could be relatively easy-accessible for forensics experts. The device proposed in actual version is capable to measure distances to the obstacles or other vehicles in front of ego vehicle in real time. For the purpose of forensic investigation and evaluation of the intervention, it will be crucial information. Regarding collecting of those information, the most important are decisive moments of driving scene. Decisive moments are considered to be the first detection of the obstacle – acoustic or visual sign, start point of the braking or steering of the system and end position of the vehicle, obstacle after intervention is finished. The key purpose of the measuring device is to get that information in real time and thus evaluate ability of automated system to safely stop the vehicle and avoid the collision or just mitigate the consequences, in case of late reaction. To obtain information about initial important moment of driving scene, the measuring device must be upgraded with third camera pointed to the cluster of the vehicle. This would be added information about timing of obstacle warning by system - either acoustic or visual sign displayed in the cluster.

To achieve the position coordinates, it is necessary to create disparity map from stereo pictures as it is in Fig. 7, which is used for advanced processing.

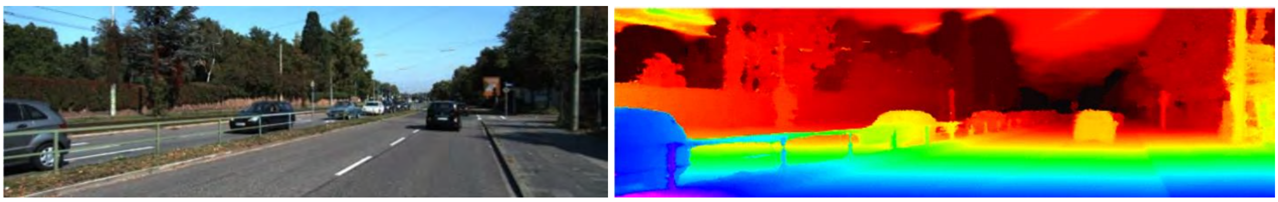

Fig. 7 Left: Picture from real traffic / Right: Disparity map of the real traffic picture [12]

The disparity map is helpful tool to simply visualize the distances of the objects in the picture. The color of the object defines the actual distance from the ego vehicle, e.g.: vehicle in blue is closer than further vehicle in yellow and furthest vehicle in red. This information without detailed position coordinates is not much valuable as general depth of the object is also easy to understand from simple picture. For better visualization of the exact position of any object, is more suitable the transformation of disparity map to the 3D point cloud, which is also possible in MATLAB software.

Fig. 8 Vehicles exact distance calculation in real time

For the purpose of automated systems evaluation, it will be sufficient to classify the vehicles and point out their distance in real time as it is shown in Fig. 8. The desired form of the MATLAB application will display simultaneously information about the distance of the obstacle or vehicle in real time in combination with development of acceleration - to monitor braking process or steering. An optional camera pointed to the dashboard will provide information regarding acoustic or visual warning signs displayed on a cluster of the vehicle. All it has to be synchronized in one sequence to obtain the correct analysis.

7. Conclusions

Modern assistance systems are becoming a common part of new vehicles and they are considered to be the path towards advanced autonomy. However, there is a long way to the full autonomy implemented in real life, the growing effort of the concerned parties are delivering promising results. This new trend requires also new knowledge fom all related experts in order to keep their professionality with correct and high-quality results. Also, forensic experts are expected to work with new advanced technologies. One of the toughest challenges will be to investigate the traffic accidents of automated vehicles. At present days, there is no an accessible device for evaluation of vehicles' automated driving systems. Despite the hardware simplicity of the proposed solution in this article, the measuring devices can be a useful and accurate tools for basic parameter determination and thus will help to improve the investigation of automated systems and their influence on the driving situations.

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Modelling of Structure of Public Transport Lines in the Agglomeration of Pardubice

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Abstract

The paper is focused on modelling of public transport lines in the comprehensive city agglomeration of Pardubice (in the Czech Republic). A deep analysis of all internal and external factors is combined with an assessment of geographic, economic, social, cultural, historic and future development specifications of the region. There is also presented proposed method for support of public transport line design in the paper. This method is based on the results of transport demand models. A set of indicators for the evaluation of the structure of public transport lines is also proposed.
KEY WORDS: *city agglomeration; line; model; public transport; simulation*

1. Introduction

Design of structure of public transport lines is one of the most complicated tasks of transport planners, because its mathematical solution is not too much easy. State-of-art methods supporting this are often heuristic or they have too many simplifications. Method presented in this paper combines results of four-step transport demand modelling, Monte Carlo simulation and multicriteria point of view on assessment of (temporary) solution. This leads to integration of socio-economical point of view, reduction of computing demands and possibility to find line structure according to different criteria, what is the aim of this research in the field of organization of traffic flows in regions. Final criterion should be selected for each case individually according to point of view followed in practice. On the other hand, some simplifications remain also in the case of this method. So that, the solution could be also classified as heuristic, but it can make a base for following transport planning activities.

2. State-of-art Level of Knowledge

Modern society development has many factors. One of the key factors is the transport, because it is a condition for the economic development as well as social and regional cohesion. The transport is aimed to reach a sustainable mobility in the field of the sustainable development. The main task of the transport is to provide long-term achievement of increasing transport demand of the society. This task must be done in required time and quality, with high efficiency and reduction of negative impacts to the environment [1]. Sustainable improvement of the transport services is reasonable necessity from the society point of view. It is necessary to increase the quality of the transport vehicles and the organisation of their operation in the transport systems. It is also necessary to improve systems of management and economics, connectivity, coordination and integration of all transport modes [2]. The paper [3] is focused also on integration of shared transport into public transport system.

Public (passenger) transport is important part of the public services, because it influences the standard of living and the lifestyle of population. It is some kind of matchmaker of transport relations within the region so it also influences the formation and development of residential, commercial and industrial structures there. From strategic point of view, it is necessary to prefer public transport instead of individual car transport. Nowadays trends are the establishment of integrated passenger transport systems. Their main task is to connect advantages of all transport modes what is a background for complex system of transport services within the region [4]. Current processes in urbanisation results to higher demand because people move to smaller municipalities while commercial and communal services are concentrated in cities. This trend is caused by increasing of the individual car transport and standards of living. Regional passenger transport is more important nowadays but it is necessary to make it as most competitive to individual car transport as possible [2, 5].

The transport and the region are directly connected. Functionality of all regional structures are highly influenced by transport and the development of the transport means the improvement of availability to commute to work, school, public services or recreation facilities [1]. Public transport within the region must satisfy all reasonable requirements for the transport. They are characterised by the intensity of transport relations within the region. This depends mostly ontime and the entire quality of the transport process [2]. This lasts from very general issues to some very specific ones, e.g. the paper [6] is focused on relation between SARS-CoV-2 virus and possibilities to use public transport. Decision making process of passenger in public transport is discussed by [7]. Transport planning processes should answer these 5 basic questions: Who? (People as a source of the transport); Why? (The purpose of the transport); Where? (Destination of the transport and the transport route); When? (Time aspects of the transport); How? (Which transport mode) [1].

Mathematical method designed for replacement of sequential process of public transport planning is mentioned in the paper [8]. There are followed planning, periodic timetabling and vehicle scheduling are followed together by an integer linear programming model in the paper [8]. Integration of transport on the interface between city and region is highlighted in the paper [9]. There is mentioned the European Commission R&D project NODES focused on innovative ways in this field as well. This project NODES presents these issues also in complex point of view. Analysis of local situation in public passenger transport in conditions of the Czech Republic can be found e.g. in [10].

3. Structure of Public Transport Lines

Public transport lines can be of different character. The lines can be divided according to their routing as follows. Radial – routes go from the edge to the middle (centre) where they meet; diametral – routes go from the edge to the opposite edge via the centre; tangential – 2 or more areas out of the centre are directly connected; circular – circuits around the centre [1]; feeder lines - connection between served locality and backbone transport system. Character of lines should be selected according to social-economic features and topology of the region. It is necessary to follow demand after public transport as well.

Second point of view is division according to character of a line. There are all stops services; fast services connecting major centres of region (e.g. regional express trains) and their combinations like zonal services (part of line as all-stops, part as fast services) and dashboard services (e.g. regional trains when each of subsequent trains serves different stops. Some of these types are illustrated in the Fig. 1. Lines A1, B1 and A2, B2 are example of radial lines (in the point of view of the regional centre marked by number 1). Lines A1, A2 and B2 are diametral in municipalities number 2 and 3.

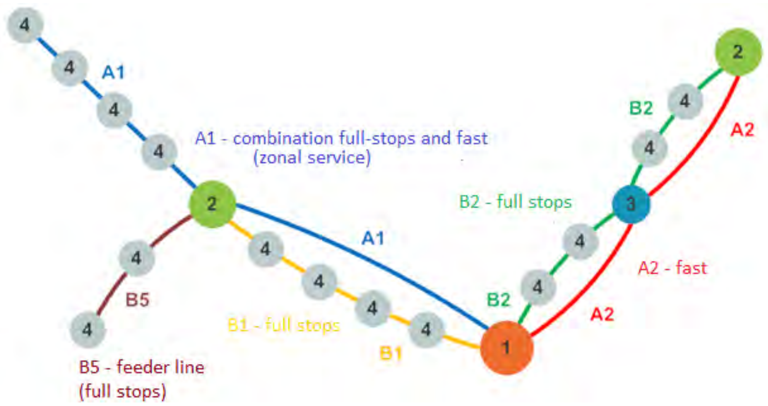

Fig. 1 Selected types of public transport lines

4. Model Supporting Design of Public Transport Lines

There are some individual issues occurred by planning of public transport lines as follows from above mentioned text and as it is confirmed by mentioned paper [8]. On the other hand, we wan't aggregate individual steps by planning in our research. It is due to the fact that each case needs a little bit different approach. For that reason, proposed method works in some subsequent stages and multiple criteria can be applied. Our effort is also to connect mathematic tools with socio-economy and transport features of given locality.

4.1. Model of Demand after Public Transport

Modelling of public transport demand and recognizing of this demand are crucial things for planning of public transport system and its line structure. The trip distribution stage of so called four-step transport model should be applied. The result of this stage is so called OD matrix of traffic flows expressing traffic flow between each pair of centroids in the area. Basic methods for this stage could be based on analogy with gravity interaction, respectively on the principle of entropy maximization. This way applying data for relations between centroids is better than using of data for each individual network segment coming from traffic assignment stage, because route of passengers can be changed according to applied line structure. For that reason, it is better to make traffic assignment for each assessed variant of line structure like it is incorporated in method coming as a result of our research. Software Aimsun Next for macroscopic modelling of transport flows were applied as a computer support of this research (see Fig. 2). It was applied to obtain input data, specifically to obtain OD matrix. The Fig. 2 illustrates traffic assignment of testing (not real) traffic flows operated in-between 26 centroids coming from the case study (presented in the chapter 5). Detail of Pardubice city and its close surroundings is displayed.

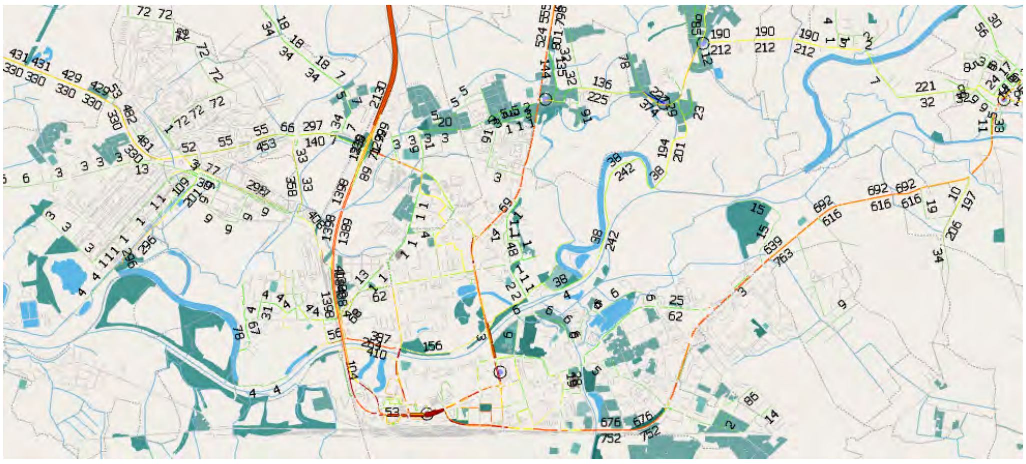

Fig. 2 Transport demand modelling by using of Aimsun Next. Based on OpenStreetMap+contributors

4.2. Proposed Model to Support Design of Public Transport Line Structure

This model is based on following inputs: graph of the transport network consisted of all segments allowing routing of public transport lines; valuation of graph edges (distance, travel time or money); subset of graph vertices noted as stops to be served; OD matrix of traffic flows between each 2 stops (centroids); set of random numbers and some additional specifications to control the computation like the value of probability that a link will be served by a line.

The model is developed in the Microsoft Excel application by using of Visual Basic for Applications programming language. The extent of the code is more than 2,000 lines divided into 16 modules. The model connects the principle of Monte Carlo stochastic simulation with traffic assignment stage of the four-step transport model processed in the way of the AON method. In detail, the computation is based on Floyd-Warshall algorithm.

Maximal extent of the model network is 1,000 vertices and 100 stochastic replications. The program communicates in the way of matrices (to enter inputs and obtain outputs). The aim of the model is to provide proposal subnetwork of the graph served by public transport.

The way of processing is following. Stochastic simulation will generate a subnetwork to be served by public transport. It is generated for each graph link individually according to entered probability that a link will be served or not. Then it is checked if the solution (replication) is acceptable or not. In simple, if it is possible to reach each stop from each stop. This is realized by Floyd-Warshall algorithm. In the case that the solution is acceptable, the traffic assignment method AON is performed. It means that traffic flows from OD matrix are assigned to found most efficient routes according to selected criterion (used by entering of matrix of lengths of links - e.g. km, min, monetary units). The values of all disposable criterions are computed, and the resulting replication can be selected by maximal or minimal (according to context) value reached in selected criterion.

Finalisation of the line structure, timetabling as well as planning of vehicle circulations must be finished in manual way or by application of other methods. The reason for this manual approach is that some local specifics can be handled more carefully.

4.3. Criterions

There are 15 criteria able to be applied within the model. These criteria can be divided according to the part which they are referring about - network, transport flows and public transport subnetwork, see Table 1.

Table 1

Model criteria

Network	**OD matrix (flows)**	**Public transport**
number of relations with extended route length	increase of total travel costs (km, min, monetary units)	number of served edges
share of relations with extended route length	total increase of important relations	length of served subnetwork
number of relations with extended route length minimally about defined limit	average increase of important relations	count of interchange nodes
share of relations with extended route length minimally about defined limit	number of important relations	branching indicator
total extension aggregated for all relations		
average extension of relation (for all relations)		
average extension of relation (for extended relations)		

This structure of indicators can make the model more flexible for different points of view. The indicators related to the network are suitable for the case when the transport authority searches for planar service with an effort to reach almost all localities with such level of quality, but with no regard to volume of traffic flows. Indicators based on minimal limit of extension can make the assessment more realistic. Small extensions (e.g. about single units of %) are sometimes almost irrelevant by travelling passengers (e.g. 1 minute by 100 minutes long journey), but mathematics could assign more relevant meaning than it has in practice. For that reason, it is possible to exclude such small (almost irrelevant) extensions from consideration. Indicators related to OD matrix (traffic flows intensities) can assess the line structure in context of numbers of passenger. The disadvantage is that this can lead to situation that more utilized relations are preferred and extent of public transport services should be reduced on less utilized relations.

The last, but not least, group of indicators takes regard to future operational features of public transport. Length of served subnetwork is illustrative. How higher is this number, it can be invited that providing of public transport should be more demanding (cost, number of vehicles, number of staff members etc.). The indicators count of interchange nodes and branching indicator are specifically suggested for this research. Number of interchange nodes can me mathematically expressed as number of vertices with value of vertex degree of more than 2. This causes, that lines will branch at such node. Branching indicator is derived from it, but it is characterizing all public transport network. When vertex degree is more than 2, this value reduced by 2 is assumed in this case. When the value of degree is 1 or 2, the value of 0 is assumed. This can also refer about the fact what is the composition of public transport network.

5. Case Study – Pardubice Agglomeration

Area selected for case study is located 100 km to the East from Prague and it is situated between 2 neighbour cities of Pardubice (90k inhabitants) and Hradec Králové (95k inhabitants). Network data has been obtained by using ESRI ArcGIS software. Network for presentation in this paper is consisted of 45 vertices (26 with served stops and 19 junctions) and of 65 bidirectionally operated edges. It could be characterized as testing infrastructure, see Fig. 3. Some features of public transport system are simplified (e.g. not all municipalities are incorporated) due to illustration purposes.

Modelled area (Fig. 3) is polycentric and public transport has planar character. It is operated in whole area, not only on the most frequent lines. Newly proposed criterion to minimize branching indicator was applied. Estimated travel time was applied for valuation of edges - time is more important for passengers in public transport, because zone-relational fare with given price for each relation from origin to destination is applied in this locality. Simulation was performed in 5 sets, each consisted of 100 replications (possible variants of line structure). Probability that each individual edge will be served by public transport was set at the value of 0.8. This value was tested on 2 different networks and it provides subjectively suitable results - with acceptable number of replications with unacceptable solution and with suitable number of unserved edges (leading to possible saving of operational costs).

One exception is the railway line, manually set to be operated in every replication due to specific role of this infrastructure. Railway line is considered as direct link from Pardubice to Hradec Králové. This is also an example, how fast services should be implemented parallelly to full-stops ones or how possible bypassing of municipalities occurred in this way can be assessed.

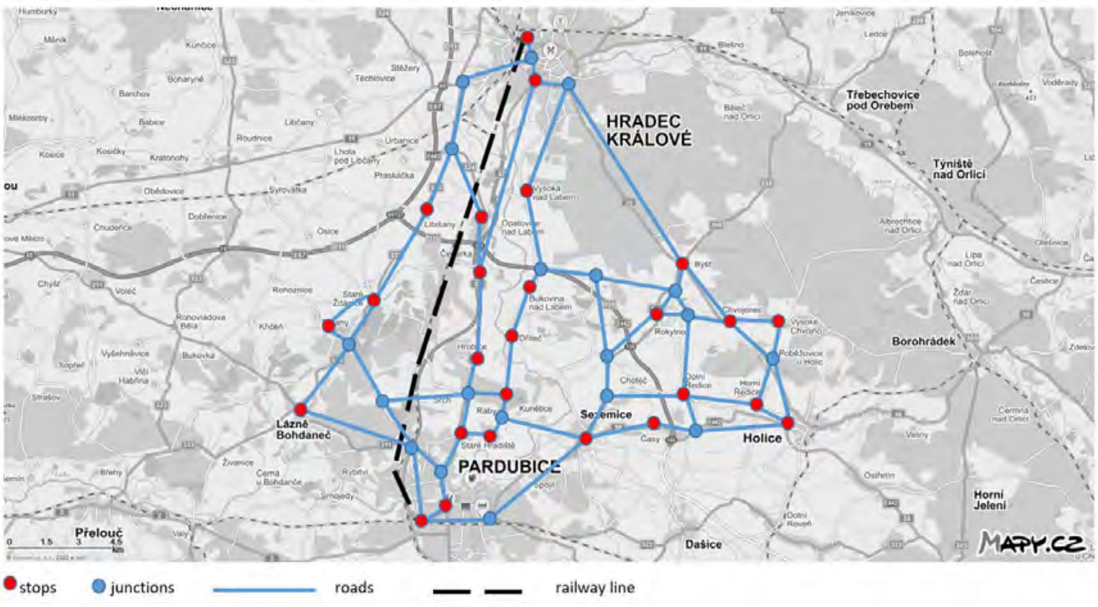

Fig. 3 Agglomeration of Pardubice, case study. Based on [11]

5.1. Discussion of Results

Minimal reached value of branching indicator is 16. It was reached in two from 500 replications. Final variant from these 2 is selected by secondary criterion - total extension of average travel time (in the case when one passenger will travel on each relation). This value is 16.34 min for selected variant (the second one is 20.07 min). There are also 12 vertices marked as interchange nodes (with 3 and more connected served edges). These vertices can be real interchange nodes or places where lines originating in close node are branching. This solution is in the Fig. 4.

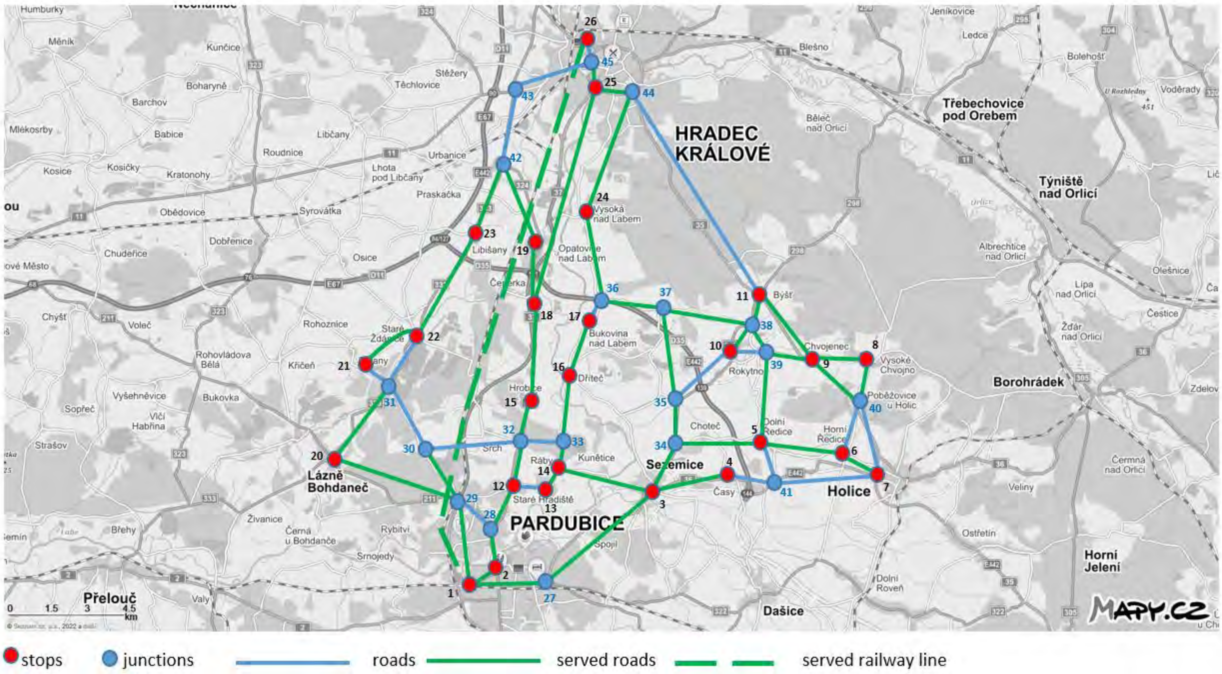

Fig. 4 Obtained solution by minimizing branching index. Based on [11].

Individual generating if the edge is served by public transport or not has also one disadvantage. For example, there are served links connecting nodes 20-31, 29-30, 9-40 and 8-40 in spite of the fact, that there is not any stop on the end. It is possible due to the fact that the acceptability of the solution is checked by the possibility to reach each stop (red vertex) from each other stop. The fact if link leads to some stop is not checked as a part of model simplification. The result in Fig. 4 corresponds also to the fact that all transport relations are considered with the same weight (1 travelling passenger). Links towards Pardubice and Hradec Králové should be more preferred by incorporation of regard to OD matrix.

5.2. Discussion of Model Accuracy

It is necessary to discuss some technical features of the applied model. The simulation was performed 5 times by 100 replications in each set of simulation runs. Finally, 5 variants of solution were recommended. Each comes from 1 set. Some features of these variants are compared in Table 2.

A comparison of individual sets of simulation runs can be applied for illustration of the nature of obtained results, which is able to be characterized as particular and heuristic. From a transport technology point of view the results seem as similar, so this can provide such feedback, that this way is possible. On the other hand, the application of different criteria as well as more detailed studying of individual features and settings in this method represent a theme for feature research.

Table 2

Comparison of recommended variants

Feature	Sim. run 1	Sim. run 2	Sim. run 3	Sim. run 4	Sim. run 5
Branching indicator	19	16	19	19	16
Count of interchange nodes	15	12	17	15	14
Share of extended relations about limit	61.5%	69.2%	53.5%	63.4%	69.5%
Average extension of relation [min]	11.8	16.3	7.1	14.0	20.1
Share of variants with unaccepted solution	62%	59%	61%	59%	58%

6. Conclusions

The presented method illustrates that the defined aim of the research as well as of this paper were fulfilled. Interaction between transport modelling and method supporting the design of the structure of public transport lines were characterized. The principle of Monte Carlo simulation is able to be applied in this field. The possibility to select different criteria in individual cases can support the extension of the scope of application of this method. The model follows the relation to socio-economic and other local features of the solved area.

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Simulation of Air Distribution in a Workplace in an Enclosed Space of a Ship

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Abstract

The article presents the results of a study of the ventilation system during welding in the enclosed space of the ship. An effective method of maintaining sanitary standards in confined spaces (such as enclosed spaces on a ship) is through a rationally designed ventilation system. To create such rational ventilation systems, as a rule, it is necessary to conduct a series of experiments, the purpose of which is to optimize the design of air distribution or exhaust devices. To optimize the design of the air distribution device above the workplace of a welder working in an enclosed space of a vessel, it is necessary to study the influence of technological factors - air consumption, and the coordinates of air velocity measurement, on the average air velocity in the welder's breathing zone. Based on the results of preliminary theoretical studies, the area of experimentation and the intervals of variation of factors were chosen. As a result of the conducted studies of air distribution, a model for the workplace of a welder in a closed ship space was obtained. Carrying out calculations using the obtained model will help determine the rational regime and design parameters of the ventilation system.
KEY WORDS: *ship's enclosed spaces, ventilating schematics, planning experiments in the field of ventilation*

1. Introduction

An effective method of maintaining sanitary standards in confined spaces (such as enclosed spaces on a ship) is through a rationally designed ventilation system. To create such rational ventilation systems, as a rule, it is necessary to conduct a series of experiments, the purpose of which is to optimize the design of air distribution or exhaust devices [1].

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. [2].

To optimize the design of the air distribution device above the workplace of a welder working in an enclosed space of a vessel, it is necessary to study the influence of technological factors - air consumption, G, m^3/sec., and the coordinates of air velocity measurement, l, m, on the average air velocity, m/sec., in the welder's breathing zone. Scheme of the experimental stand is shown in Fig.1.

Air velocities were measured using a high-precision thermo-anemometer.

The optimization parameter average speed at the outlet of the air distributor is designated – Y_i.

Technological factors:

- air consumption, G, m^3/sec., – X_1 (varied based on production data within 100-120 m^3/h);
- coordinates of air velocity measurement, l, m, (accepted based on the working conditions: welding of products on the floor, in a sitting position (Fig. 1);

Based on the results of preliminary experimental and theoretical studies and production experience, the area of experimentation and the intervals of variation of factors were chosen, which are presented in Table 1.

Table 1

Coding factors in the study

Factor	Designation	Factor levels			Variation interval ΔZ_i
		-1	0	+1	
G, m^3/sec.	X_1	0,028	0,031	0,034	0,003
l, m	X_2	1,5	1,7	1,9	0,2

As a plan of the experiment, a plan of a complete factorial experiment of type 3^2 was constructed [3]. The planning matrix and the results of the experiment were calculated from the results of two series of experiments.

The equation describing the technological process is a polynomial of the second degree and has the form:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2. \quad (1)$$

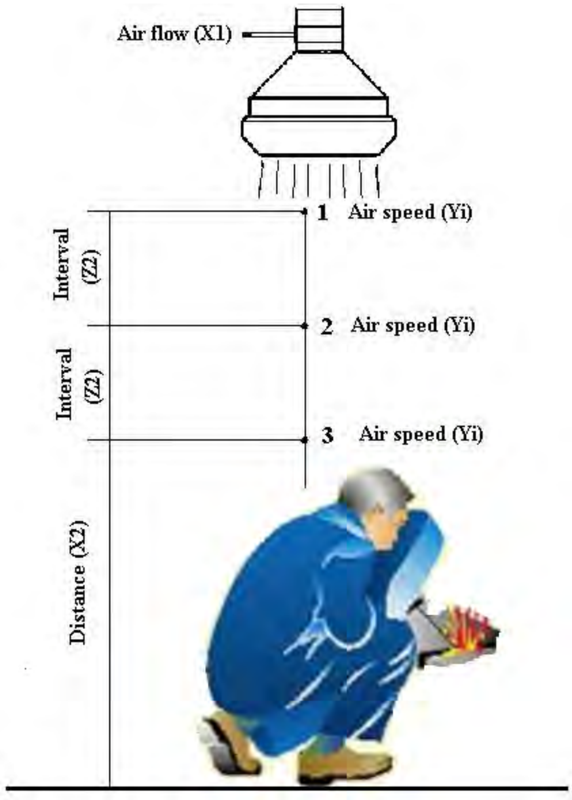

Fig. 1 Scheme of the experimental stand

The coefficients in the regression equations are calculated by the formulas [3]:

$$b_0 = 0{,}55556\sum Y' - 0{,}33333\sum\sum X^2 Y'$$
$$b_1,\ b_2 = 0{,}16667\sum X * Y'$$
$$b_{12} = 0{,}25\sum X_{12} * Y'$$
$$b_{11},\ b_{22} = 0{,}5\sum X^2 * Y' - 0{,}33333\sum Y'$$

where Y' – average experimental value of the optimization parameter (air velocity).

2. Research of Air Distributor

After calculating the coefficients in the regression equation, and substituting the coefficients, the regression equation for Y1 (air velocity) becomes:

$$Y_i = 2{,}06 + 0{,}76X_1 - 1{,}93X_2 + 0{,}02X_1^2 + 0{,}86X_2^2 - 0{,}735X_1X_2. \quad (2)$$

Linear dispersions are calculated by the formula [3]:

$$S^2_{y1} = (\sum(Y_1 - Y')^2 + (Y_2 - Y')^2)/(M - 1),$$

where Y_1 – the result of measuring air velocity in the first series of experiments; Y_2 – the result of measuring air velocity in the second series of experiments; $M = 2$ – is the number of parallel experiments.

The maximum value was obtained in the line-by-line variance for the experience №6 – $S^2_{y6} = 0{,}0121$.

Having determined the maximum value of the line-by-line dispersion, we calculate the Cochran calculation criterion for it:

$$G_p = S^2_{ymax} / \sum S^2_i;$$

$$G_p = 0{,}024 / 0{,}072 = 0{,}333.$$

We draw a conclusion about homogeneity based on a comparison of the obtained Cochran's calculated criterion with a tabular value selected taking into account the parameters [3]:

α_t – significance level, for technical problems we accept 0,05;

f_N – the number of independent estimates of variations taken by the number of experiments N = 9;

f_i – the number of degrees of freedom, taken according to the ratio.

$$f_i = M - 1 = 2 - 1 = 1.$$

Then G_p = 1,94 < G_m = 0,64 – dispersions are homogeneous.

The variance of experience is:

$$S^2_{ymean} = \sum S^2_i / N = 0{,}072/9 = 0{,}008.$$

To test the hypothesis about the statistical significance of the coefficients of the regression equation, the confidence interval of the coefficients was calculated according to the equation:

$$\Delta b = t \cdot C_i \cdot S_y,$$

Then t = 2,26 – Student's criterion; C_i – is a constant accepted by [3].

To determine the significance of the coefficients, you can apply the rule - the coefficient is significant if its absolute value is greater than the confidence interval (we exclude the insignificant coefficient) [3].

The calculation results are summarized in Table 2.

Table 2

Statistical analysis of the regression equation in the study of air distribution efficiency

PARAMETER	Conventions	Estimated value for Y_i
Estimated value of the Cochran criterion	G_p	0,333
Tabular value of the Cochran criterion	$G_{t\ (1;\ 0,05;\ 9)}$	0,64
Conclusion about the homogeneity of dispersions		uniformly
Experience variance	S_y	0,008
Coefficients of equations	b_0	2,06
	b_1	0,76
	b_2	- 1,93
	b_{11}	(not significant not significant)
	b_{22}	0,86
	b_{12}	0,735
Tabular value of Student's criterion	$t_{(0,05;\ 9)}$	3,25
Coefficient dispersion estimation	S_{bi}	0,029
Coefficient Confidence Interval	Δb_0	0,217
	Δb_1	0,168
	Δb_2	0,168
	Δb_{22}	0,206
	Δb_{12}	0,145
Dispersion of inadequacy	S_{inad}.	0,0181
Estimated value of the Fisher criterion	F_p	2,26
Tabular value of the Fisher criterion	$F_{m\ (0\ ,\ 0,5,\ 2)}$	3,63
Conclusion about the adequacy of equations		adequately

After eliminating the insignificant term, the final regression equation will take the form:

$$Y_i = 2{,}06 + 0{,}76X_1 + 1{,}93X_2 + 0{,}86X_2^2 + 0{,}735X_1X_2. \quad (3)$$

The adequacy of the model is determined by calculating the Fisher criterion and comparing it with the table value [3].

The calculated value of the Fisher criterion is calculated by the formula:

$$F_p = S^2_{\text{inad}} / S^2_{ymean.}$$

3. Conclusions

As a result of the experimental studies carried out, a statistical model of the distribution of supply air for the workplace of a welder who works in an enclosed space of a ship has been obtained.

Carrying out calculations using the obtained statistical model makes it possible to determine the rational regime and design parameters of the ventilation system during design.

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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Investigating Households Attitude toward Electromobility

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Abstract

The number of registered electric vehicles in road transport is constantly growing. There are more and more electric buses and passenger cars in cities. Probably, battery electric vehicles represent the future on the roads. Its future expansion depends on economic efficiency. Therefore, this article maps Slovak households' attitudes towards electric vehicles. Respondents in the questionnaire survey answered several questions on the Likert scale. This article aims to find factors that affect the purchase of BEVs (Battery Electric Vehicles) in households. The questionnaire was evaluated using basic statistical methods and correlation analysis.
KEY WORDS: *electromobility; households; survey; economy; efficiency*

1. Introduction

Battery electric vehicles (BEV) are significant for the environment as they reduce greenhouse gas emissions and local emissions in cities [1; 2; 3]. They contribute to sustainability [4]. However, one of their economic disadvantages is the high acquisition costs associated with the costly production of electric vehicle batteries [4; 5]. On the contrary, relatively low operating costs are a positive benefit [6]. Other controversial issues of electric cars include the range related to battery capacity and battery life. In total, several studies, e.g. [7; 8; 9], deal with the issue of battery capacity and lifetime. This article focuses mainly on the economic efficiency of the electric car in Slovak households. A private passenger car does not drive as much during the year as a company car. BEVs may seem suitable for home usage due to their lower daily mileage [10]. Even more suitable is BEV for households equipped with two passenger cars. Families use both for regular commuting, but only one of them for long journeys [11]. There is also an assumption that households with more than one of their cars have higher incomes and will therefore be able to afford BEVs. However, on the other hand, higher incomes can also mean that the family uses cars regularly (trips, holidays) and therefore need a long-distance vehicle [12, 13].

However, hybrid types cannot be forgotten, which can also serve as a replacement for the ICEV (Internal Combustion Engine Vehicle). According to the degree of hybridization, these vehicles have these types [14; 15]:

- Micro hybrid - differs from conventional ICEV in that it has a Start/Stop system and a brake-energy recovery function. It uses this micro-hybrid to recharge the 12V battery. It leads to a reduction in the fuel consumption of the internal combustion engine and reduction in CO2 emissions.
- Mild Hybrid - stands for MHEV (Mild Hybrid Electric Vehicle). It is a vehicle equipped with an electric motor, but it still uses an internal combustion engine to drive the wheels. The e-motor with an auxiliary accumulator with a larger electricity capacity, assists the combustion engine during operation, e.g. when starting or accelerating. Thanks to the battery, it has a higher recuperation capacity, which helps to reduce fuel consumption and CO2 emissions.
- Full hybrid - is a complete hybrid vehicle, which means that it can drive purely on electric power.
- Plug-in hybrid - stands for PHEV (Plug-in Hybrid Electric Vehicle) and is technically a full hybrid with the added ability to charge an enlarged traction battery from a socket or charging station. Thanks to this method of recharging, PHEV vehicles today reach a range of 50 km electric range without having to start an internal combustion engine. It is a great advantage, especially in city centres.

1.1. Electromobility and Subsidies

One way to make BEV and PHEV more accessible is through state subsidies. Each country differs in the support provided for electric vehicles. The most widely used forms of support worldwide include subsidies for the purchase of EVs, traffic regulation, emission and environmental restrictions or, conversely, benefits for the registration or operation of such a vehicle. Several studies have addressed BEV subsidy policy [16; 17; 18].

The Slovak Republic has already implemented two nationwide subsidies with the help of the Ministry of Economy of the Slovak Republic and the Association of the Automotive Industry of the Slovak Republic. Their goal was to support environmentally friendly and low-emission vehicles that do not have only internal combustion engine. The aim of state subsidies is to motivate end consumers to purchase such vehicles, which contribute to meeting the goals of reducing emissions.

The first round of state subsidies started on 11 November 2016. It should last until the end of 2017. The ministry extended the deadline until 30 June 2018. The amount of one financial subsidy was € 5,000 for BEV and € 3,000 for PHEV. There was € 5,000,000 allocated to the project. The total number of correct applications was 831: 514 for BEV and 317 for PHEV. Most applications were for legal entities. Applicants obtained funds in three-year in three-year instalments [19].

There was also the second round of state subsidies in 2019. The ministry published conditions for registration on 18 November 2019, but the date of the start of registrations was at 17 December 2019. Compared to the first round of subsidies, individual applications increased to € 8,000 for BEV and PHEV at € 5,000. The amount set aside for the project was € 6,000,000. Due to the expected pressure during initial registrations on the online system, it was possible to register as early as 11 December 2019. However, this measure did not improve the situation, and within a few minutes, there were several thousand applicants. The system did not withstand such pressure. Therefore, not everyone managed to register and for this reason, the Ministry of Economy cancelled all registrations and set a new registration date of 16 December 2019. Registration of applications on 16 December 2019 ended within 3 minutes and 41 seconds when the 668 applications (for 786 ecological cars) booked all funds. Almost 4,000 applications were submitted in the first 3 hours [20]. The incoming situation with the COVID-19 pandemic slowed down.

A total of 638 applications were approved for January 2021 - subsidies for 659 BEV and 76 PHEV. There were 9 unapproved applications and 147 applicants cancelled their applications.

The Ministry of Economy of the Slovak Republic is preparing the third round of state subsidies now. Its beginning will be in 2023 at the earliest. The specific plan has not yet been published [21].

2. Aims, Materials, Methods, and Hypothesis

This paper aims to describe the approach of Slovak households to electromobility. For this purpose, we used an electronic questionnaire created in Google Forms. In total, the questionnaire contained 10 simple questions. The answers were mainly numerical or quantifiable that means that we used the Likert scale for some questions, using the following rating: 1 - totally agree, 2 - agree, 3 - don't know, 4 - disagree, 5 - totally disagree.

We collected 384 completed questionnaires for this research. It is the minimum required sample. Its determination was based on the number of residential households. The most accurate number is from 2011 when there were in the Slovak Republic [22]:

- 1 709 100 dwelling households;
- 1,852,059 jointly managed households;
- 2,064,635 census households.

These households can be defined as follows [22]: Dwelling household was made up of persons sharing the same dwelling. Jointly managed households consist of persons living together in one dwelling and jointly covering the greater part of main household expenditure (housing, food, household maintenance, heating, electricity, gas, etc.). The amount of shared household expenditure coverage is not relevant. A jointly managed household can also consist of one or more census households. Dwelling household was made up of persons sharing the same dwelling. Jointly managed households and census households were made up of persons permanently resident in dwellings or units other than dwellings. Households are represented by persons with temporary residence in the dwellings due to work or studying case they were the only dwelling occupants.

The Sample Size Calculator was used to calculate the Sample size (Fig. 1). The input data was the confidence level of 95%, the confidence interval of 5 and the population of 1,852,059 households. As can be seen from picture no. 1, the required sample was 384 respondents.

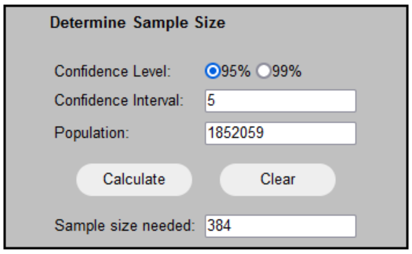

Fig. 1 Sample Size Calculator

We mentioned in the previous text that most of the questions in the questionnaire were numerical (age, number of household members, number of vehicles), or they used the Likert scale. Therefore, we could statistically evaluate the results with correlation analysis. The correlation analysis measures the dependence of the linear relationship through a correlation coefficient r_{xy}. The correlation coefficient can take values from the interval $\langle -1; 1 \rangle$. The value of +1 represents a complete direct linear relationship between the variables. If the correlation coefficient is -1, it is a total indirect linear relationship between the variables. If $r_{xy} = 0$, there is no linear relationship between the variables. If the values approach 0, this does not necessarily mean that there is no dependence between the given phenomena; on the contrary, they may be strongly dependent, but not linear but non-linear [23].

In addition to the graphical evaluation of the questionnaire contained in this article, two scientific questions will be answered using correlation analysis. Question Q1: How strong and what are the dependencies between:

- total household income;
- number of vehicles in the household;
- possible investment in BEV;
- mileage of the most used vehicle.

Question Q2: What is the attitude of households in the following areas of economic efficiency of electromobility:

- acquisition costs of BEV;
- BEV operating costs;
- residual value of BEV;
- BEV charging and range;
- state subsidies for the purchase of BEV.

3. Results

In the first step, the questionnaire focused on demographic data - gender and age of the respondent, members of his household, and location. In the following figures, the graph evaluates the gender of the respondents (Fig. 2) and the number of household members (Fig. 3), which they described in the questionnaires.

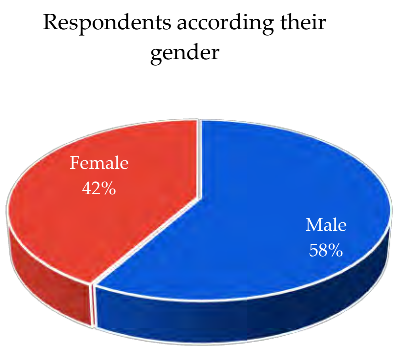

Fig. 2 Gender of respondents. Source: [authors]

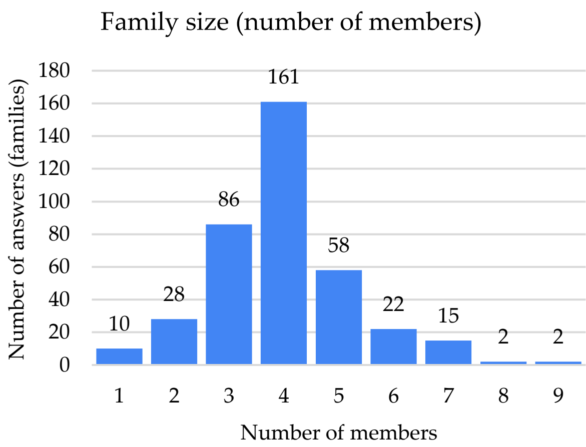

Fig. 3 Size of involved families. Source: [authors]

Fig. 2 shows that up to 58% = 224 respondents were men, and 160 respondents were women. The average family size was 3.98 members, with more than 95% of respondents stating the number of household members in the range of ⟨2; 7⟩.

Because the total household income is quite difficult to determine (sensitive data), the questionnaire contained intervals of household income. These intervals are 500 or 1000 €. The results are in Fig. 4. We achieved an approximately normal distribution of responses.

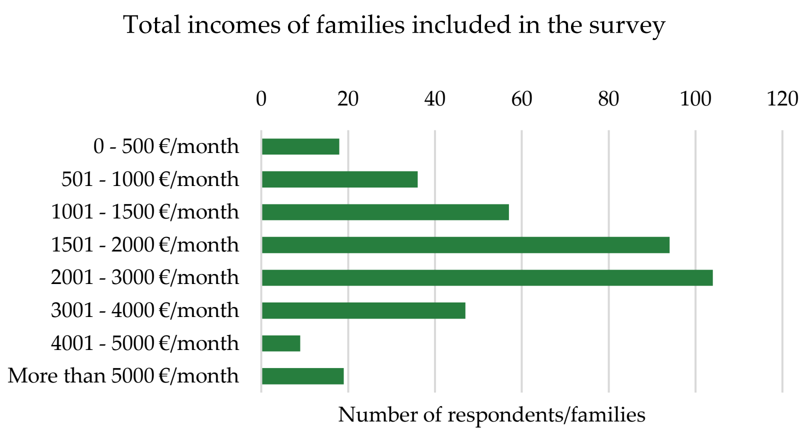

Fig. 4 Income of involved families. Source: [authors]

The further calculations used the midpoints of these intervals. It was possible to calculate the correlation coefficient

(1) between the total income of households and potential investment in BEV.

$$r_{xy} = \frac{n\sum xy - \sum x \sum y}{\sqrt{\left[n\sum x^2 - \left(\sum x\right)^2\right]\cdot\left[n\sum y^2 - \left(\sum y\right)^2\right]}} = 0.4827\ . \tag{1}$$

As can be seen from the calculation, the correlation coefficient is only 0.4827. However, in the area of traffic or economic behaviour of the population, it is a medium value if we take the interpretation according to Cohen [23], according to which the correlation coefficients can be interpreted as follows:

- correlation in absolute value below 0.1 is trivial;
- the correlation in the range of 0.1 to 0.3 is small;
- in the interval 0.3 to 0.5 it is medium;
- at values above 0.5 it is large;
- the correlation of 0.7 to 0.9 is even reported as very large;
- and correlation in the range of 0.9 to 1.0 as almost perfect.

Furthermore, it is also possible to test the statistical significance of the correlation coefficient. We managed to ensure a large number of responses $n = 378$. Therefore, we will test at a significance level of $\alpha = 0{,}01$. We calculate the test criterion according to formula (2).

$$T = r\cdot\sqrt{\frac{n-2}{1-r^2}} = 0.4827\cdot\sqrt{\frac{378-2}{1-0.4827^2}} = 10.7713\ . \tag{2}$$

Now it is necessary to find the value of the critical field (3) and compare the test criterion with the critical field. If it is met, the statistical significance of the correlation coefficient is confirmed.

$$W_\alpha = \left\{|t| \ge t_{1-\frac{\alpha}{2}}(n-2)\right\} = \left\{|t| \ge t_{0.995}(376)\right\} = \left\{10.7713 \ge 2.5758\right\}\ . \tag{3}$$

The calculation shows that the assumption was correct. At the level of significance $\alpha = 0{,}01$, we can state that there is a statistically significant linear relationship between the variables - the total income of households and potential investment in BEV.

Other correlation coefficients are calculated in Table. It is a symmetric matrix of correlation coefficients in which the values above and below the diagonal are identical. As can be seen from the matrix, all dependencies are directly proportional - with increasing incomes, the investment in BEV, the number of vehicles, is also growing on average. There was very little dependence between revenue and mileage per year and almost no dependence between number of vehicles and mileage per year.

Table

Matrix of correlation coefficients. Source: [authors]

	Total Income	**Income per member**	**Cars**	**Investment**	**Mileage**
Total Income	1				
Income p. member	0.7364	1			
Cars	0.3802	0.2074	1		
Investment	0.4827	0.4097	0.1626	1	
Mileage	0.1162	0.0704	0.0668	0.1260	1

The questionnaire also focused on households' attitudes on several issues about BEV. We used the Likert scale to ensure quantification and proper evaluation of results. Respondents expressed if they agree (1) or disagree (5) with the following statements:

S1: My household will not buy a BEV due to its high price;
S2: A BEV has lower operating costs than a conventional car with an internal combustion engine;
S3: I can't sell a used BEV as cheaply as a regular car;
S4: Members of my household will influence the decision of whether to buy a BEV;
S5: Charging the electric car takes too long;
S6: My range also discourages me from buying an electric car;
S7: I think home charging of an electric car would be problematic;
S8: Only state subsidies can convince my household to buy a BEV.

The statistical evaluation did not show significant deviations from the average. However, there were different answers in selected groups of respondents. The following figure compares the responses of three groups: households that do not plan to purchase BEVs (plan to continue using the vehicle with ICEV); households which plan to purchase PHEV or only HEV in the future; households that plan to invest in BEV. Fig. 5 shows the results of this comparison - statements are listed in the previous paragraph.

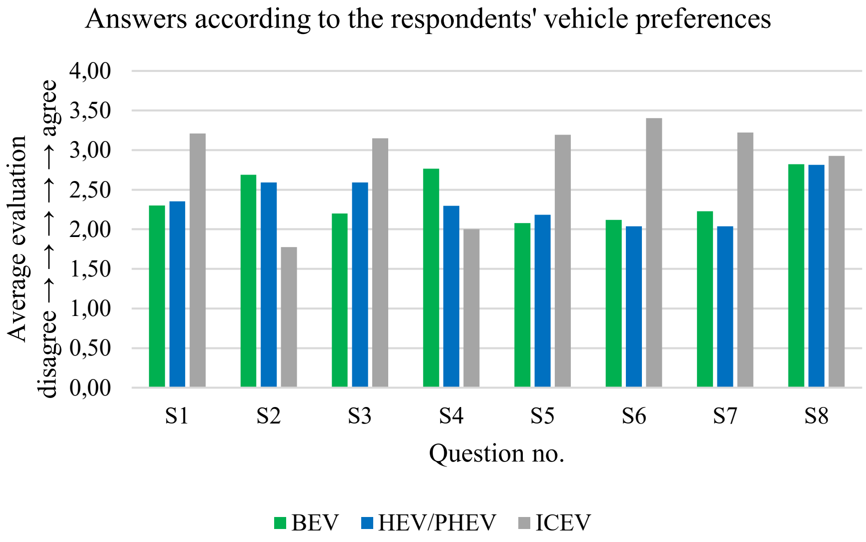

Fig. 5 Opinions of respondents on 8 important statements. Source: [authors]

As can be seen from Fig. 5, respondents with ICEV preference think that BEVs have high acquisition costs (S1: 3.21 > 2.30) as well as operating costs comparable to ICEVs (S2: 2.69 > 1.78). A more significant deviation in the responses of ICEV-preferred respondents is evident in S5, S6 and S7 - the issue of short BEV travel, relatively long charging times and the complicated setup of a charging station. The statement S8 had the most balanced opinions. All three groups of respondents agree that state subsidies can influence their decision to invest in the purchase of BEV.

4. Conclusions

As can be seen from the research contained in this article, total household income is also closely linked to the intended future investments in electric cars. The correlation analysis also showed that other interrelationships between the observed characteristics are weaker or negligible. The research also focused on respondents' views on various aspects of BEV, and it is clear what disadvantages people have a constant preference for ICEV. The importance of state subsidies in electromobility, whose future is questionable in the current situation in Slovakia, was also confirmed.

Further research will focus on the economic efficiency of BEVs in households. In this area, it is necessary to analyse the overall data on the income of individual families. It is also appropriate to compare the mentioned revenues with the so-called TCO, Total Costs of Ownership. These costs included all direct or indirect costs connected with the operation of BEV (electricity for charging, depreciation, periodic technical inspection, maintenance and repairs, tyres, parking fees, vignette, and insurance).

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Importance of Paved Operating Areas for General Aviation Aircrafts in the Czech Republic

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Abstract

This project deals with the activity of the Institute of Air Transport in terms of increasing safety in the Czech Republic. It focuses on the surfaces of runways of general aviation aerodromes, the materials used for their construction and regards to the length of take-off and landing, in comparison with air safety. It focuses mainly on the comparison of cement-concrete coverings and asphalt formations, their important properties and key differences. It describes the advantages of a paved track not only in terms of traffic safety. It sets the trend for further increasing the safety of small aerodromes. It describes the legislative procedure for the implementation of reinforcement together with the necessary construction documentation on the example of Zbraslavice Aerodrome in Central Bohemia.
KEY WORDS: r*unway, paved runway, general aviation, asphalt formation, cement concrete cover*

1. Introduction

The Institute of Air Transport participates in the development of aviation technologies and contributes to the improvement of current technologies. It focuses not only on technical and software circuits, but also on circuits related to the human factor. Operational safety is a key part of the aviation philosophy. Take-off and landings are the most critical part of the flight, and therefore it is necessary to guarantee the safe execution of these processes. Closely related to takeoff and landing is the runway on which this process takes place.

General aviation are aircraft other than commercial or domestic aviation aircraft and military aircraft. General aviation also includes the operation of powered and non-powered aircraft for personal enjoyment, parachute jumps and training flights. The most important operation for small sports aerodromes is the operation of powered and non-powered aircraft. Non-powered aircraft or gliders are concentrated at the aerodrome and takeoff and landings are usually in the same area. Motor planes are different in this aspect and can take off at one aerodrome and land at another. Another difference is that motorized aircraft prefer a paved runway, while a non-motorized aircraft does not prefer a paved runway [1].

2. Types of Aerodromes in the General Aviation Category, in Terms of Runways

General aviation aerodromes can be divided according to a number of parameters. For the purpose of this article, we will divide the aerodrome according to the runway, or according to the surface type. Runways are primarily divided into unpaved and paved. The essence of this division is clear from the name. The most common type of unpaved runway is grass. [2] For paved runways, the main distinguishing feature is the top cover of this surface. They are divided into rigid and non-rigid. The best-known representation of a rigid surface is a cement-concrete cover, for non-rigid is an asphalt pavement. Another type of a non-rigid surface is plastic tiles, which in aviation are considered more of a transitional bridge between the unpaved and paved runway [2, 3].

2.1. Advantages and Disadvantages of Paved and Unpaved Runways

The unpaved runway dates back to the early days of aviation when people used open meadows for takeoff and landing. This is a type of surface that is highly prevalent in general aviation aerodromes, as it is cheap, affordable and relatively easy to repair. Being a living surface, it requires regular mowing and treatment for surface irregularities. A reasonably tolerable surface depends on the weather and the time of year. This limits the aerodrome's operating hours and its overall use. Another disadvantage is the low braking coefficient. Paved runways respond to these disadvantages [2, 4].

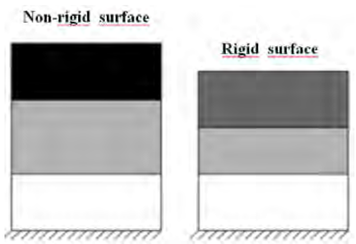

Fig. 1 Difference in road composition [5]

The paved runway has an advantage in terms of utilization and load-bearing capacity. When the runway is being designed, one of the input aspects is the design life and the already mentioned load capacity. Due to the different properties of rigid and non-rigid surfaces (Fig. 1), they will be divided and described separately [4]. The load-bearing capacity of a non-rigid surface is closely connected with its subsoil. When designing, it is necessary to take the entire surface structure as one complex element. Another major difference is the relationship to ambient temperature. At higher temperatures, the asphalt softens and its static load-bearing capacity decreases, leading to rutted runways. However, asphalt is cheaper and less demanding on construction technology. Repairs are cheap and relatively fast [6]. On the contrary, the rigid surface uses the load-bearing capacity of the cover itself - concrete. Its load-bearing capacity is not a function of temperature, so the concrete does not bend, but it may crack. The dimensioning of the rigid surface is usually higher (Fig. 2), it can carry heavier aircraft, but in the general aviation category, the load capacity of the asphalt is also considered sufficient. During construction, it is necessary to pay attention to a quality technological procedure that will ensure a long service life without the need for ongoing maintenance [6, 8].

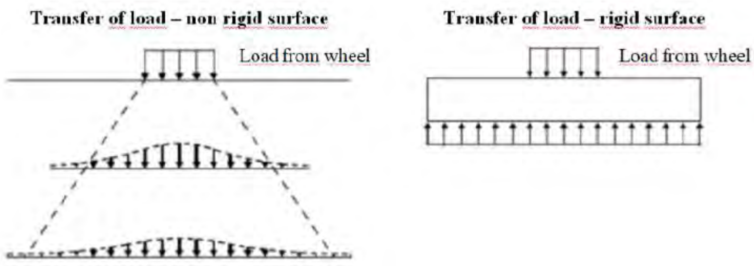

Fig. 2 Rigid and non-rigid surface [7]

2.2. Statistics on Paved and Unpaved Runways at G.A. Aerodromes in the Czech Republic

There is currently no publicly available database showing the number of paved and unpaved general aviation aerodromes in the Czech Republic. For the purposes of this work, data was collected manually. The VFR manual was used as a basis. According to the data, there are 90 aerodromes in the Czech Republic, of which 68 are unpaved, i.e. grassy (Fig. 3). There are 11 concrete and 7 asphalt. Four aerodromes use asphalt-concrete combinations. Another finding is that the VFR manual does not distinguish between unpaved and reinforced runways with plastic tiles. There are at least 4 aerodromes that have used this method of tile reinforcement.

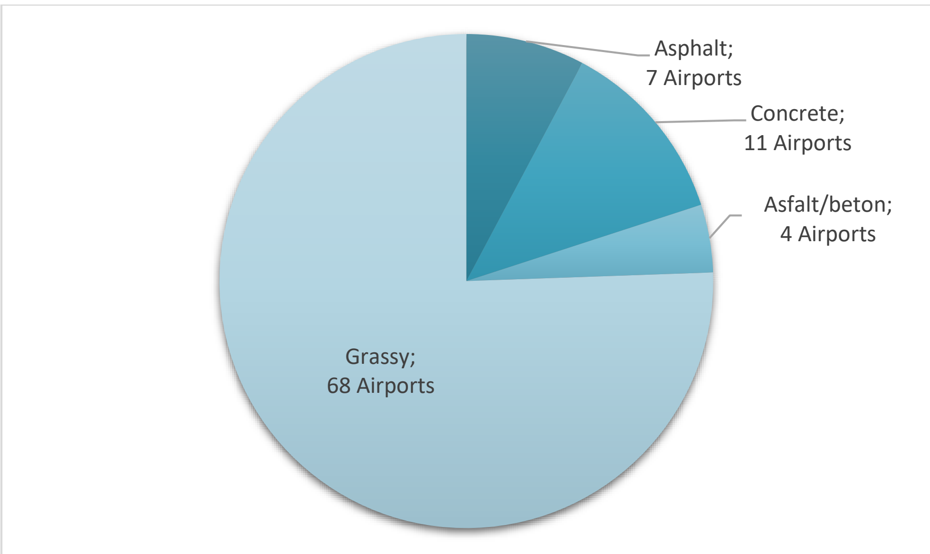

Fig. 3 Statistics of the type of runway surface in the Czech Republic [9]

Other relevant runway divisions can be classified according to the length of the runway. There are 28 aerodromes in the Czech Republic that fall into the category of less than 800 meters (Fig. 4), of which 4 runways are paved. There are 44 runways from 800 meters up to and including 1200 meters. There are a total of 18 aerodromes with a runway length of 1200 meters or more.

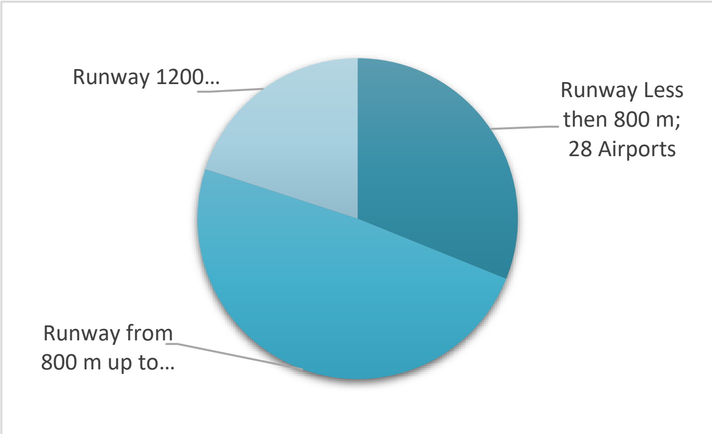

Fig. 4 Runway length statistics in the Czech Republic [9]

The most tolerable runway was taken into account in the compilation of these statistics - some aerodromes have a paved runway in addition to unpaved runways. [9] As part of the project, an analysis of aerodromes in the Czech Republic (Fig. 5) with runways shorter than 800 meters was performed, especially with regard to the aerodrome surroundings, the descent plane, location, natural conditions and annual usability. As part of the project, a comprehensive analysis was performed with the number of 12 evaluated parameters. A list of critical aerodromes has been drawn up. In the conditions of the Czech Republic, it was recommended to implement preferentially paved runways at the following aerodromes in the following order: 1. Zbraslavice, 2. Soběslav, 3. Prachatice-Strunkovice, 4. Hronov.

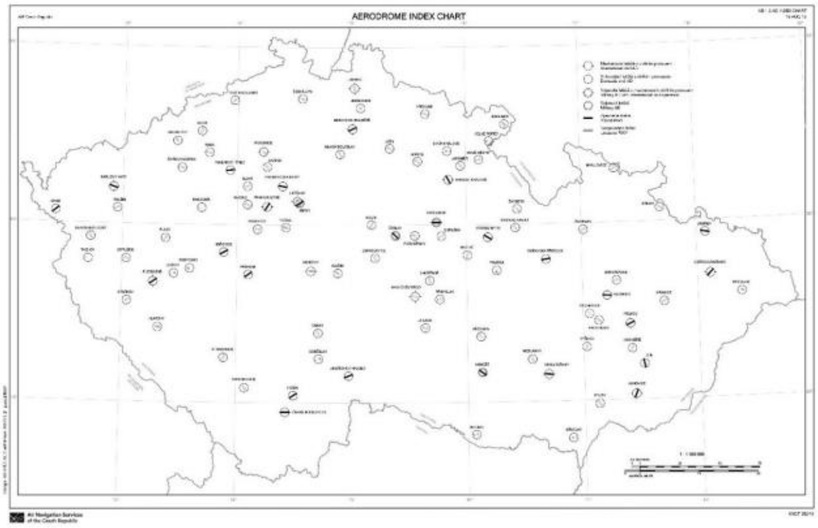

Fig. 5 Aerodromes in the Czech Republic [9]

As part of this project, a project study was prepared for the construction of a paved runway at the public domestic aerodrome Zbraslavice in Central Bohemia. This project is currently in the legislative preparation stage. The actual implementation has a deadline by the end of 2024. The implementation of the remaining three aerodromes will be resolved in accordance with another decision of the Ministry of Transport of the Czech Republic.

2.3. Safety Reasons for the Implementation of Paved Runways

There are many reasons for building a paved runway. One of the main ones is to increase security. The reinforced runway ensures better braking effects, can reduce rolling resistance and the associated length of run and take-off. The braking effects depend on the runway surface, the aircraft tires, the runway contamination and the overall condition of the atmosphere. In this work we will focus on the first variability. Runway quality can be assessed indirectly by comparing safety factors from EASA safety manuals. These coefficients are used in ground preparation to calculate the required take-off / landing / missed take-off distance.

Runway quality evaluation:

- Rolling resistance (Fig. 6) during take-off / interrupted take-off - x 1.2 for dry runway or 1.3 for wet runway;
- Landing braking coefficient x 1.15 for landing on unpaved runways [11].

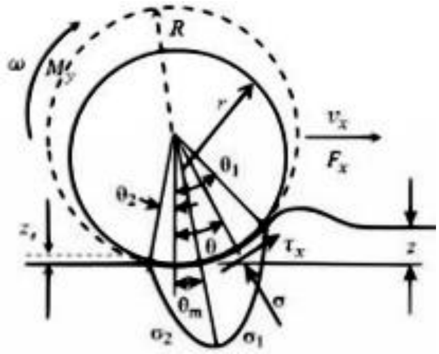

Fig. 6 Tire rolling resistance [12]

Calculation of the increase in the braking coefficient of a paved runway using a macrostructure using the Eq. (1) below:

$$M_g = \frac{WD + M_u\left(S - W\right)}{S}, \tag{1}$$

where M_g – ribbed macrostructure; W – width of the groove; D – groove depth; M_u – without grooved macrostructure; S – distance between grooves

In short, a conventional GA aircraft can take off and land on shorter runways. A negative aspect is the additional unplanned maintenance of aircraft. During repeated operation of aircraft on rough surfaces, i.e. unpaved runways, the landing gear and the overall statics of the aircraft are more stressed, which contributes to increased failure rate and susceptibility of fatal breakage. Another study shows the dependence of the runway surface on the increase of the take-off run length (Table, Fig. 7). Landing distance statistics are not included, but would be similarly dependent as they cause less brake efficiency.

Table

Increase of take-off length by surface [13]

Runway surface	Increasing the starting length
Short grass	10%
Long grass	25%
Wet grass	35%
Waterlogged grass	50% and more

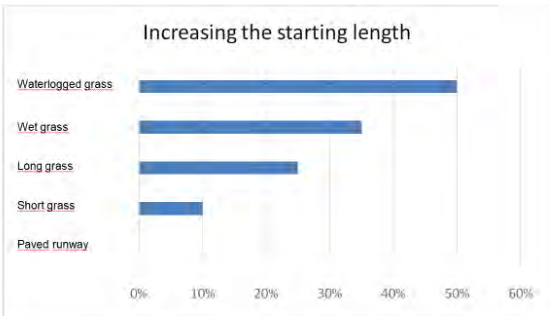

Fig. 7 Increasing the starting length according to the surface

Another reason for strengthening the runway is the fact that the aircraft has a lower chance of sucking a foreign object into the engine intake when taking off from the paved runway, most often when using carburetor heating. Some companies even prohibit some types of aircraft from landing on grass surfaces in the SOPs, as the risk of the propeller colliding with the runway surface increases. Last but not least, the paved runway is better visible from a height thanks to the higher contrast with the surroundings [4]. A good but extreme example of runway strengthening is Lukla Airport in Nepal. Here the runway needed to be strengthened for several reasons. On one hand, it is an unusual location for the aerodrome with an altitude of over 9,000 ft, a 12° slope and the possibility of using only one side of the approach, regardless of the wind direction. The length of the runway is also very limited, measuring only 527m [14].

3. Prerequisites for the Implementation of Paved Runways in the Czech Republic

For the successful implementation of the paved runway, it is necessary to create a construction design and compile the relevant documentation. According to Act 360/1992 Coll. is an authorized project engineer stated for this activity. In the Czech Republic, aircraft construction is governed by two main documents. For domestic aerodromes, this is the Czech regulation L-14 Aerodromes and for international aerodromes the European document CS-ADR from EASA. Here are the standards for what the aerodrome should look like and what aspects it must meet [2, 15, 16].

First of all, it is necessary to check whether the planned construction is not in conflict with the valid zoning plan. This document is publicly available on the municipality's website and contains the conditions under which the land can be built. In the case of the planned paved runway, it is necessary to find out whether the aerodrome is being talked about in connection with the grass surface. If the intended construction is in conflict with the zoning plan, it is necessary to request its change [17]. The next step is land management. Its process is controlled by the local building authority. Here it is necessary to submit an application for a decision on the location of the construction, including the relevant documentation, including all annexes. The main appendix is the documentation itself for the implementation of the new runway, in the Czech Republic according to the requirements of Decree No. 499/2006 Coll [18, 19].

The zoning procedure is followed by the construction procedure. Here, instead of asking whether a building can be located in a certain place, a specific task is solved as to what the building will look like. In the case of aviation, the competent authority is the Civil Aviation Authority, Department of Aviation Construction in Prague. The application is in the form specified in the Czech Republic by Decree No. 503/2006 Coll. This application is accompanied by project documentation, which is prepared in the Czech Republic in accordance with Decree No. 146/2008 Coll., for the issuance of a building permit. At the end of this procedure, a building permit is issued, on the basis of which it is possible to start construction according to the set conditions [18, 20]. The completion of the construction of the paved runway is followed by the approval procedure, according to Act No. 183/2006 Coll. If all the conditions and plans submitted for the construction procedure have been complied with, the building approval is issued, which is the first step in starting your own air traffic on the innovated runways [21].

3.1. Economic Aspects

In addition to the legislative process, the key is to finance the planned construction. The main decision element is the financial demands of the paved runway surface itself. To put it simply, landscaping, labor costs and documentation are more or less fixed, similar to both types of covers. The decision between the cement concrete cover and the asphalt layer of the runway can be divided into two parts, namely short-term and long-term view. The Aviation Construction Authority recommends using road transport documents for small aerodromes in the general aviation category.

The short-term view includes construction costs. When comparing the prices of these two covers, the price list of the transport infrastructure of the municipalities for 2019 was used. According to ČSN 736110, the cement concrete pavement has a service life of 35 years and costs CZK 1,648 / m^2 per material for road structure II. class. In contrast, the asphalt road has a planned service life of only 25 years and a price for the material of CZK 1,615 / m^2. At first glance, it might seem that prices are similar. When comparing prices, it is necessary to register the fact that the cement concrete road is more expensive due to the demanding technological process [22, 23]. A longer-term view of the situation includes maintenance and related repairs. Cement concrete runway is less demanding on ongoing repairs, but when it reaches the end of its life, it is very difficult to repair this road. The asphalt runway is the exact opposite. Ongoing repairs are required, but are relatively quick and less demanding [6, 8].

4. Conclusions

In addition to the already mentioned safety benefits, which are mainly the shorter take-off distance of the aircraft, the paved runway has many other advantages. The paved runway is an indispensable part for the future expansion of the aerodrome. It attracts the attention of the pilot, public and awareness of the aerodrome, which can positively affect the financial situation of the aeroclub and increase the return on investment. Among other things, there is an effort in the future to allow PBN - instrument approach to uncontrolled aerodromes in the Czech Republic. A paved runway could benefit from this change, as deteriorating meteorological conditions would be possible and a waterlogged runway would not be a limitation.

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Substantiation of the Parameters of the Bench for Testing of Railway Wheels for Contact and Fatigue Strength

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Abstract

Strength indicators are important parameters of the railway wheels, as they determine the allowable service life of both the wheel itself and the wheelset as a whole. Therefore, the development of bench equipment that allows in the laboratory to reproduce or simulate the real conditions of the wheel load in order to conduct strength tests, is an urgent scientific and practical task. The purpose of this work is to substantiate the parameters of the bench for testing railway wheels for fatigue and contact strength. As the bench has to test railway wheels for fatigue and contact strength at the same time, the requirements of various normative and methodological documents, which determine the procedure for conducting such tests on separate benches, were combined when determining the parameters of the bench. We determined that the working force of the bench should vary from 10% to 100% of the wheel endurance limit, the duration of the tests should correspond to five million load cycles with a frequency of 5 to 10 Hz. To reduce the duration of the tests, pushing on the wheel was carried out by several rollers, which were evenly distributed around the wheel. For the proposed bench, we obtained the dependence that connects the parameters of the test wheel, the parameters of the bench, the wheel pair axle load and the wheel material endurance limit. The results of this study can be used as a basis for the development of new schemes of benches for railway wheels tests.
KEY WORDS: *railway; test bench; contact strength; fatigue strength; parameter*

1. Introduction

One of the main parameters of the railway wheel is its resource, which determines the allowable service life of both the wheel and the wheel set as a whole. Therefore, the development of bench equipment that allows in laboratory conditions to reproduce or simulate real conditions of wheel pair loading for the purpose of carrying out resource tests, is an urgent scientific and practical task.

Among the types of bench tests, which are regulated before the current regulatory documents [2-5], resource tests include tests for fatigue strength of railway wheels and wheelsets axles. Such tests involve the study of the wheelset parts operation under cyclic loading conditions under the modes defined by current standards and methods. There are many developments on tests for fatigue strength of axles [13, 16, 17]. A number of publications have been devoted to the issue of strength and interaction of wheel-rail [6, 11, 12, 14]. Additional factors that determine the railway wheels life are contact strength and wear of individual surfaces of the wheel (rolling surface, flange). The current normative documents do not provide for bench tests taking into account the influence of these factors. However, there are studies [1] that indicate the advisability of such tests.

To reduce the duration of the general procedure for determining the wheels service life, it is efficient to combine different types of tests with their simultaneous performance using one test sample (railway wheel).

The main purpose of this work is to determine and analyze the technical parameters of the bench for complex tests of railway wheels, which provides a combination of tests for fatigue and contact strength, their simultaneous performance on one bench.

2. Research Methodology

The authors of this work have some experience in the development of benches for testing railway wheels for fatigue strength [7]. Similar developments were conducted by other employees of the Ukrainian State University of Science and Technologies, as well as members of the international scientific community [8, 9]. The application of cyclic loading to different surfaces of the railway wheel (rolling surface, flange) is realized in these benches.

Tests for contact strength involve the creation in the contact zone of a force equivalent to the contact force that occurs in real operating conditions of the wheels. Work in this direction proposes to replace one of the parts of the wheel-rail contact pair (rail [15]) or both parts [1] on rollers and set the load conditions close to real.

2.1. Analysis of Requirements for Tests and Bench Equipment

Interstate standard [2] establishes requirements and characteristics for testing wheels used in wheel pairs of freight and passenger cars of locomotive traction, passenger, freight and shunting locomotives, motor and non-motor wheel pairs of electric and diesel trains, special railway rolling stock:

– endurance limit (F_r) – the maximum force in the contact zone that can be perceived by the wheel for a specified period depends on the wheelset axle load (for example, for wheelsets with axle load up to 230.5 kN endurance limit F_r = 400 kN);
– test duration corresponds to 5 million load cycles;
– load is asymmetric with an asymmetry factor of 0.1;
– load is applied to the wheel rim.

The test method [10] duplicates the standard [2] in terms of endurance, test duration and nature of the load, but indicates the need to apply it to the wheel flange. In addition, the value of the cyclic loading frequency is set – 300…600 cycles per minute (5...10 Hz). Since the interstate standard has a higher regulatory force than the methodology, we believe that the load should be applied to the wheel rim; it also corresponds to the wheelset real operating conditions.

The interstate standard [5] applies to mainline railway cars. It establishes the need to test the wheels for fatigue strength by implementing alternating bending under the action of circular bending moment during 20 million cycles. For wheels of locomotive wheelsets and railcars, the interstate standard [4] defines fatigue strength tests in the form of circular bending under asymmetric loading (its alternation and asymmetry coefficient are not normalized), and the endurance limit is specified at 125 MPa (depends on the wheels design).

Summarizing these requirements, we come conclusions:

– bench for complex tests of railway wheels must provide a load on the wheel, which varies in the range from $0.1F_{max}$ to F_{max}, where $F_{max} = F_r$ is the wheel endurance limit according to [2], which depends on the wheel pair axle load;
– test duration corresponds to 5 million load cycles;
– cyclic loading frequency is 300…600 cycles per minute;
– cyclic load is applied to the wheel rim.

As a basis for the development of a bench for complex tests of railway wheels, we take the bench for resource tests of railway wheel pairs [15], the scheme of which is shown in Fig. 1.

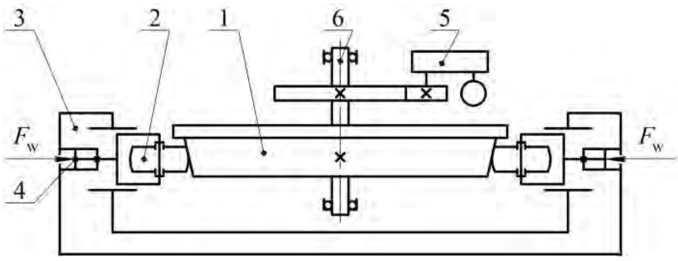

Fig. 1 Test bench scheme: 1 – test wheel; 2 – roller; 3 – frame; 4 – loading device; 5 – bench drive; 6 – axle (F_w – working force of the bench)

In this bench, the roller 2 simulates the rail, and the loading device 4 with the working force F_w creates a force in the contact zone of the wheel-roller pair, equivalent to the force in the contact zone of the wheel-rail pair in wheelset real operating conditions. In this case, the wheel 1 is in contact with several rollers at the same time (at least three rollers); this makes it possible to conduct accelerated tests. To ensure compliance of the conditions of bench tests with the wheelset real operation conditions, the test bench parameters was determined so that the maximum contact pressure in the wheel-roller pair is equal to the maximum contact pressure in the wheel-rail pair.

2.2. Establishing the Possibility of Conducting Comprehensive Tests

Since the bench for complex tests of railway wheels must be tested simultaneously for fatigue and contact strength, we form requirements for the value of the bench working force (F_w):

– force F_w must be pulsating and provide a change in load on the wheel in the range from $0.1F_{max}$ to F_{max} (fatigue strength test);

– cyclic loading frequency is 300…600 cycles per minute (fatigue strength test);

– F_{max} value must correspond to the axle load of the wheelset whose wheel is being tested (fatigue strength test);

– force F_w should ensure the adequacy of the bench tests conditions (compliance with the actual load conditions).

The last requirement for the bench working force value can be met in the case of equality:

$$F_w = 0.5F\left(1+\frac{D_w}{d_r}\right), \tag{1}$$

where F – wheelset axle load; D_w – diameter of the wheel on the rolling surface; d_r – roller diameter.

The dependence of the F_{max} value on the axle load F is specified in the standard [2] (Table 1).

Given that the force F_{max} acts along the common normal to the contact surfaces of the wheel-roller pair (Fig. 2), we take:

$$F_w = \frac{F_{max}}{\cos\beta}, \tag{2}$$

where β – slope of the rolling surface ($\beta = 2.86°$ corresponds to a taper of 1:10 specified in the standard [2]).

Table 1
Dependence of the wheel endurance limit on the wheelset axle load

F, kN	F_{max}, kN
230.5	400
245.3	450
264.9	510
294.3	600

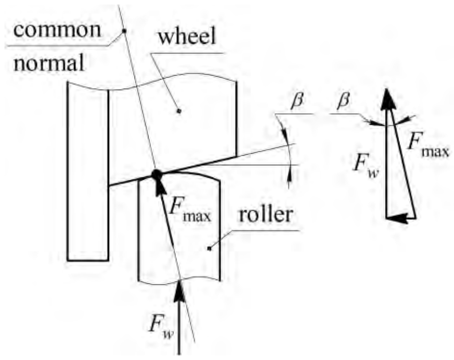

Fig. 2 Scheme of force action in the wheel-roller pair

Combining conditions (1) and (2), we have:

$$0.5F\left(1+\frac{D_w}{d_r}\right) = \frac{F_{max}}{\cos\beta}. \tag{3}$$

Thus, we obtained the dependence, which connects the test wheel parameters (D_w, β), the bench parameter (d_r), the wheelset axle load (F) and the wheel endurance limit (F_{max}).

From Eq. (3) it follows that the roller diameter can be determined by the formula:

$$d_r = D_w\left(\frac{0.5F\cos\beta}{F_{max}} - 1\right)^{-1}. \tag{4}$$

3. Research Results

Preliminary analysis of dependence (4) indicates that the function $d_r(F_{max})$ has a second-class discontinuity. Let determine whether it falls on the area of change of the argument from $0.1F_{max}$ to F_{max}.

Analysis of the data given in the standard [2] showed that the wheel diameter (D_w) does not depend on the wheelset axle load (F). To perform calculations, we take the following values of the wheel parameters [2]: $D_w = 957$ mm; $\beta = 2.86°$. The combination of wheelset axle load (F) and endurance limit (F_{max}) is taken from Table 1.

The $d_r(F_{max})$ dependence for each of the combinations of calculated data is shown in Fig. 3 as a set of curves. The graph shows that the second-class discontinuity of the function $d_r(F_{max})$ falls on the interval of change of force in the contact zone of the wheel-rail pair from $0.1F_{max}$ to F_{max} (on the abscissa axis shows the interval 40… 400 kN for the first combination of forces in Table 1).

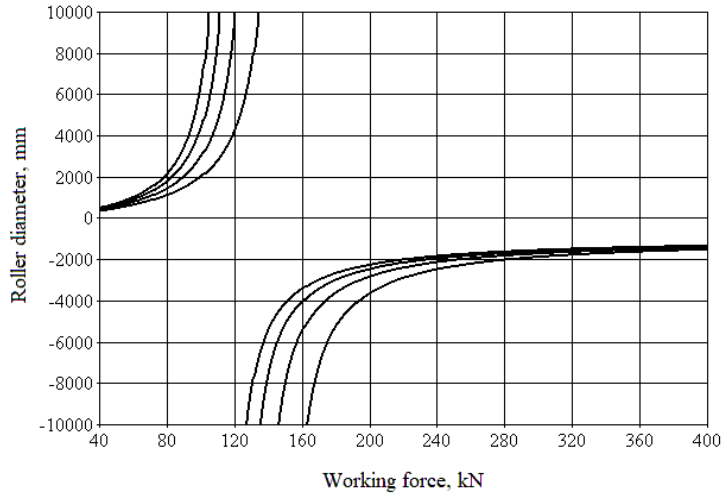

Fig. 3. Graph of $d_r(F_{max})$ dependence

4. Conclusions

During the research, we determined the test bench parameters (roller diameter and working force) and the dependence, which connects the test wheel parameters, bench parameters, wheelset axle load and wheel endurance limit. Based on the results obtained, we conclude that conducting comprehensive tests of railway wheels, which involve combining fatigue strength tests with contact strength tests, and the simultaneous conduct of them on one test bench is impossible.

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Prospects for Increasing the Flight Network in the Ukrainian Aviation Market in the Context of the COVID-19 Pandemic in the Context of the Agreement on a Common Aviation Area

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Abstract

The article examines the prospects for increasing the flight network in the context of the COVID-19 pandemic in the context of the agreement on a Common Aviation Area (CAA). The authors stressed that Ukraine is one of the few countries in the world with a completed aviation development cycle and occupies a leading position in the global market of transport and regional passenger aviation. It is proved that COVID-19 has become a unique challenge and threat to the existence and functioning of one of the largest and most important industries, such as civil aviation. A brief analysis of the work of aviation enterprises in Ukraine testifies to the catastrophic economic situation that has developed at the airfields of our country under the influence of the Covid-19 pandemic. It is proved that the Common Aviation Area agreement allows the gradual introduction into the legislation of Ukraine of more than 60 EU standards and directives in the field of flight safety, aviation security and air traffic management. It was noted that an important factor in signing the Agreement on the establishment of CAA is the production and renewal of the airline fleet with modern aircraft, increasing the level of passenger service and further modernization of airports. With the entry into force of the CAA Agreement, Ukrainian airlines can easily participate in any European airport and compete in different directions with European airlines. The authors highlight the prospects for increasing the flight network in the context of the COVID-19 pandemic in the context of the agreement on a common aviation area.
KEY WORDS: *aviation industry, COVID-19, low-tariff common aviation area, ICAO, IATA, open skies*

1. Introduction

One of the consequences of the coronavirus pandemic was a drop in passenger traffic that fell by 60 percent and even fell to the level of 2003. The aviation industry occupies an important place in society; it is involved in many areas of life: passenger transport, mail, cargo and luggage, agricultural work, construction. The development of international relations and the globalization of economic processes contribute to the development of air transport, which increases the demand for fast and convenient transport links. Ukraine is one of the few countries in the world with a completed aviation development cycle and occupies a leading position in the global market of the transport sector and regional passenger aviation. Aircraft construction in Ukraine today is an extremely promising branch of the national economy. The loss of the possibility of serial production of aircraft in Ukraine is a big problem in the development of the aviation industry, which must be addressed immediately. The aviation industry is one of the high-tech sectors of the economy. Development determines the possibility of transition to a new technological system and, as a result, has a significant impact on the modernization of the economy as a whole.

The theoretical foundations of the formation of the aviation industry as one of the key industries contributing to the economic development of the country have been studied in the works of such scientists [1, 4-25].

Because COVID-19 has become a unique challenge and threat to the existence and functioning of one of the largest and most important industries, such as civil aviation. For their part, international governmental and non-governmental organizations are cooperating to prevent the spread of COVID-19 by air, as well as to minimize the already negative impact of the pandemic on the civil aviation industry and to prepare anti-crisis recovery measures. Consequently, creating favorable conditions for restoring the previous scale and increasing the flow of passengers and solving problematic aspects and prospects of international air transport in the context of the Covid-19 pandemic is an insufficiently researched topic.

2. Methods

The methodological basis of the conducted research is the development of theoretical and methodological principles for the study of problematic aspects and prospects for the development of aviation transportation in the world in the context of the Covid-19 pandemic and taking into account the signed agreement on a common aviation space. The following methods were used in the research: system; historical; terminological; system-structural; comparative; statistical; economic-mathematical; graphical analysis; correlation analysis.

The theoretical basis of the work was the economic research of Russian and foreign scientists. When writing the work, statistical databases of the ISAO, the State Statistics Service of Ukraine, Eurostat, the World Bank, the works of domestic and foreign scientists, special periodicals and Internet information data were used.

3. Results and Discussion

By the end of 2020, Ukraine's airports serviced 70.9 thousand aircraft (compared to 153.9 for the corresponding period of the previous 2019). At the same time, passenger flows due to Ukrainian airports decreased by 63 percent, mail cargo flows - by 12.5 percent and amounted to 6856.8 thousand people and 37 thousand tons, respectively. In general, commercial flights of domestic and foreign airlines served 19 Ukrainian airports and airfields during the reporting period (Fig. 1).

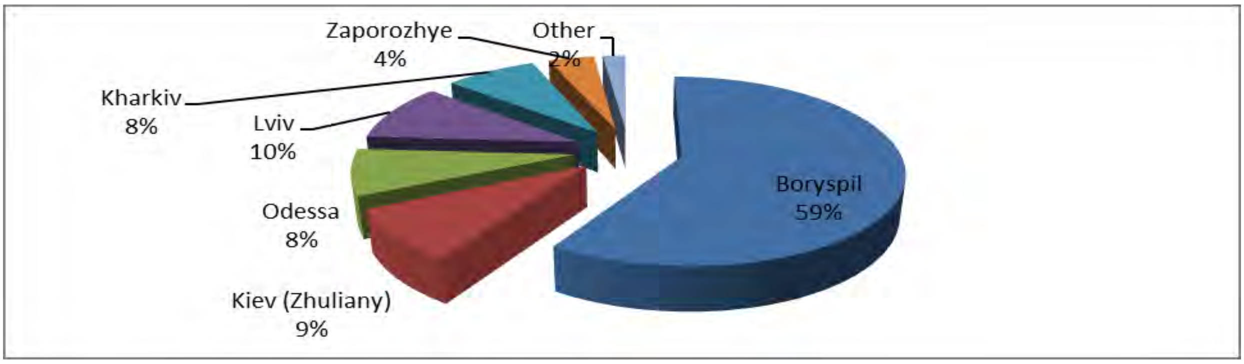

Fig. 1 Passenger flows through Ukrainian airports. Source: Compiled by the author on the basis of generalization of statistical data

The largest number of takeoffs and landings in 2020 was made at Boryspil International Airport – 47,524 flights. Igor Sikorsky Kyiv International Airport (Zhuliany) is in second place with 12,805 flights, and Daniil Galitsky Lviv Airport closes the top 3 (9,850 flights). This is followed by: "Odessa" – 9,282 flights, "Kharkiv" - 7,576, "Dnepropetrovsk" - 4,174, "Poltava" - 4,119, "Zaporozhye" – 4,087, "Kherson" – 1,082, "Ivano-Frankivsk" – 808 flights. Due to the impact of the coronavirus pandemic, the number of flights that Ukraerorukh provided with air navigation services in 2020 fell by 57.6%.

A brief analysis of the work of aviation enterprises in Ukraine testifies to the catastrophic economic situation that has developed at the airfields of our country under the influence of the Covid-19 pandemic. The analysis of statistical data for the first half of this year suggests an improvement in the situation on the Ukrainian air transportation market, which is gradually restoring lost positions (Table 1).

Table 1

Analysis of the work of aviation enterprises in Ukraine under the influence of the Covid-19 pandemic. Source: Compiled by the author on the basis of generalization of statistical data

	Unit of measurement	Total			including international		
		I quarter of 2020	I quarter of 2021	%	I quarter of 2020	I quarter of 2021	%
Airline activities							
Passengers transported	thousand people	2009,2	3492,4	173,8	1802,3	3218,6	178,6
including on regular lines	-„-	1132,1	987,3	87,2	928,6	717,9	77,3
Completed passenger-kilometers	billion passengers km	4,8	7,6	158,3	4,7	7,5	159,6
including on regular lines	-„-	2,3	1,6	69,6	2,2	1,4	63,6
Cargo and mail transportation	thousand tons	42,8	44,9	104,9	42,6	44,9	105,4
including on regular lines	-„-	3,1	3,8	122,6	3,1	3,7	119,4
Completed tonne-kilometers (cargo+mail)	million tons km	167,8	171,4	102,1	167,6	171,4	102,3
including on regular lines	-„-	12,4	16,2	130,6	12,3	16,2	131,7
Completed commercial flights	thousand	19,9	29,4	147,7	16,6	23,7	142,8
including on regular lines	-„-	10,6	12,2	115,1	7,8	7,1	91,0
Airport activities							
Departures and arrivals	thousand	40,8	56,9	139,5	32,3	42,4	131,3
including on regular lines	-„-	28,5	32,8	115,1	23,1	22,9	99,1
Passenger flows	thousand people	4144,2	5479,4	132,2	3726,3	4924,0	132,1
including on regular lines	-„-	3256,1	2966,8	91,1	2846,5	2428,6	85,3
Mail cargo flows	thousand tons	25,0	27,9	111,6	24,4	27,7	113,5
including on regular lines	-„-	19,4	23,0	118,6	19,2	22,8	118,8

According to the results of 6 months of 2021, domestic airlines transported 3,492.4 thousand passengers, which is 73.8 percent more than in the corresponding period last year, but this is only 57.3 percent compared to the indicator for the same period of the reporting year 2019. The high growth rates of passenger traffic volumes of Ukrainian airlines this year are due to both the low base for comparison of last year (the decline in the first half of 2020 reached 67%), and the growing demand for air transport services in the summer season, as the epidemiological situation improves, the removal or mitigation of existing restrictions for flights by many countries, as well as due to the success of the vaccination process and the introduction of COVID certificates (Fig. 2).

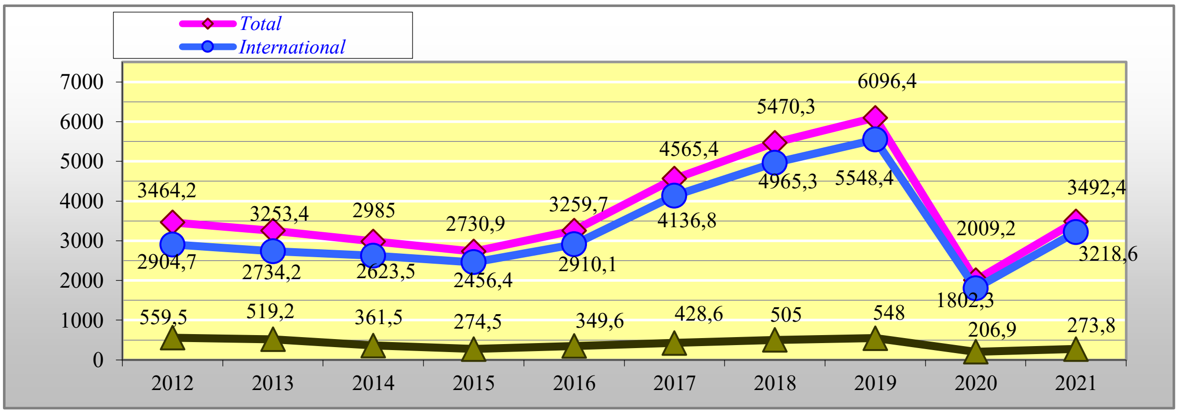

Fig. 2 Dynamics of passenger transportation volumes by Ukrainian air transport. Note: Compiled by the author on the basis of generalization of statistical data

Analysis of statistical data and opinions of aviation industry analysts made it possible to highlight the negative and positive effects of the Covid-19 pandemic on passenger transportation by air (Table 2):

Table 2

Negative and positive effects of the Covid-19 pandemic on passenger transportation. Note: Compiled by the author on the basis of generalization of statistical data

Negative consequences:	Positive consequences:
1. financial losses for air carriers; 2. significant economic decline in the work of airlines and airports in Ukraine; 3. significant reduction in the number of flights; 4. falling turnover of funds; 5. significant reduction of workers; 6. reducing demand; 7. refusal to operate large aircraft; 8. impact on the economic crisis in the tourism industry and other industries of Ukraine	1. the struggle for customers has forced air carriers to become more flexible: they allow rebooking on a free basis; 2. air carriers allow you to reschedule your flight; 3. airports have started using biometric technologies in order to identify passengers and not force them to touch different things once again or communicate with people indoors; 4. introduction of automatic screening to speed up the promotion of queues

After analyzing the statistical data and studying the opinions of aviation analysts and airline executives, we came to the conclusion that it is possible to survive in the conditions of a pandemic thanks to the following measures:

- Creation of state programs to support airlines from the economic consequences of the Covid-19 pandemic. In general, without loans or government assistance, it will be difficult for airlines and airports to overcome the crisis caused by the pandemic. Small carriers that have not yet managed to gain a foothold in the market or serving only seasonal summer flights may be at risk of extinction. Much less will the crisis affect companies with state support or large airlines that have the opportunity to attract significant additional funds.
- Temporary exemption from taxation. Airlines trying to maintain the distance between passengers by keeping a free seat between them will have to raise prices by 50% in order to operate at least with minimal profit.
- Changing dynamics of the air transportation market.
- Transformation of the competitive environment (increase in the number of low-cost airlines, opening of the domestic market for transportation by international multinational corporations).
- International cooperation, in particular, in terms of obtaining international financial assistance.
- Conclusion of key agreements in this area.

The integration of national civil aviation into the system of international relations is a strategically important goal of national economic policy. Achieving this goal allows Ukraine to become a participant in the program for the development of a single European airspace. The establishment of so-called "air bridges" will contribute to the cooperation of Ukrainian air carriers with their European counterparts, the emergence of these relationships to a higher level.

The Agreement on the Common Aviation Area (hereinafter referred to as the CAA or the Open Skies Agreement) is the gradual introduction into the legislation of Ukraine of more than 60 EU standards and directives in the field of flight safety, aviation security, air traffic management, etc. After that, Ukrainian air carriers will have the right to enjoy unlimited commercial rights when carrying out transportation between any points in the EU, provided that the flight is part of the transportation serving the point in Ukraine.

EU air carriers will have unlimited commercial rights to fly to and within Ukraine. An additional benefit for Ukraine will be the recognition by the EU Member States of all certificates issued by Ukraine for aircraft crews and air traffic management. The establishment of so-called "air bridges" will contribute to the cooperation of Ukrainian air carriers with their European counterparts, the emergence of these relationships to a higher level.

The CAA Agreement allows the gradual introduction into the legislation of Ukraine of more than 60 EU standards and directives in the field of flight safety, aviation security and air traffic management. After that, Ukrainian air carriers will have the right to enjoy unlimited commercial rights when carrying out transportation between any points in the EU, provided that the flight is part of the transportation serving the point in Ukraine.

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Projected benefits of joining CAA:

1. improving the quality of service and increasing the level of safety of flights;
2. an increase in the supply of passenger air transportation services on the market, and as a result - a decrease in prices for them;
3. loading of regional airports of Ukraine and harmonious development of transit potential of Boryspil Airport;
4. improvement of methods and increase of efficiency of management of domestic airlines;
5. improving air traffic between the regions of Ukraine and the EU countries - promoting the emergence of new markets for Ukrainian-made products and, in particular, the aviation industry;
6. attracting investments in airports, increasing the number of direct and indirect jobs in aviation, as well as increasing the level of remuneration for aviation specialists.

In addition, since the entry into force of this agreement, the relevant national body of Ukraine is included in the United Sky Committee as an observer.

An important factor in the signing of the CAA Agreement is the production and renewal of the airline's fleet with modern aircraft, increasing the level of passenger service and further modernization of airports.

When Ukraine signs an agreement on a common aviation area with the EU, passengers will benefit more, since air transportation prices may significantly decrease due to the appearance of more carriers, which will increase competition in the market. Tariffs for domestic transportation will decrease several times, and for international transportation - by 1.5-2 times. This will happen due to an increase in offers from air carriers and, accordingly, increased competition. Separate articles of the Agreement are devoted to a system of non-discriminatory pricing, which will also lead to a reduction in air fares. Moreover, the agreement provides for the application of competition rules and control mechanisms of state assistance in the field of civil aviation in accordance with the framework agreements between Ukraine and the EU. Such an agreement means the end of price monopolies in the aviation market, an increase in the number of routes, a new level of consumer protection and new opportunities for the development of tourism in Ukraine. However, the contract itself does not directly affect the ticket price.

Firstly, the document cancels bilateral air transport agreements with each EU country, which impose restrictions on the number of airlines and weekly flights on a certain route. This will allow any airline, not just monopolists, to operate popular flights. When there is strong competition, there are advantages for passengers, especially in the form of lower ticket prices and operator choice. The Irish low-cost airline Ryanair has already announced an "aggressive expansion" of the Ukrainian air transportation market after Ukraine signed an agreement with the EU. It can be assumed that Ireland's main competitor, the Hungarian low-cost airline Wizzair, will not be left behind. Ukrainian airlines can also expand their network of flights to different European cities without restrictions, if they comply with EU aviation regulations. In addition, one of the stages of the agreement implies the recognition of Ukrainian flights in Europe.

Secondly, the reduction of the tariff may be affected by the right of the contractual airline to participate in the transaction at the airport it serves. The action is ground handling of passengers at the airport, so all we do is wait. This is often done by the monopolist of the market, with whom the airline enters into a contract based on the fare, and the passenger pays the ticket price. If the airline does not want to take over the service, thanks to the CAA agreement, it has a wider choice of partners.

The next important advantage for Ukrainians is the introduction of EU norms and standards in aviation in Ukraine. This includes flight safety and consumer protection in aviation according to EU regulations. Both European and Ukrainian airlines, for example, are forced to pay significant compensation from 200 to 600 euros for long delays or cancellations of flights related to the airline. In addition, the carrier's task is to provide passengers with meals and hotels when the plane cannot take off.

With the entry into force of the CAA Agreement, Ukrainian airlines can easily participate in any European airport and compete in different directions with European airlines. Who knows, maybe they will be able to earn the love and respect of European travelers and attract new investments.

Although this is a disadvantage for Ukrainian airlines, they cannot yet register for domestic flights and must fly only from the final point of Ukraine, unlike European companies that will operate on the domestic Ukrainian market. Naturally, the tourism branch will be the first to benefit from the CAA agreement. This agreement applies not only to passenger flights, but also to cargo and mail. Therefore, when the agreement comes into force, it is likely that the trade turnover between Ukraine and the EU will grow and new investors will come. In addition, with the entry into force, an increase in business is expected at Ukrainian airports, whose passenger traffic will increase due to an increase in the number of flights. The result is new partners, investments and development. At the same time, a powerful new wave of coronavirus is growing in the world, which significantly affects the tourism and aviation industry [2, 3].

For further stable development of the aviation industry, increase in traffic volumes and market share, it is proposed to implement the measures presented in Fig. 3.

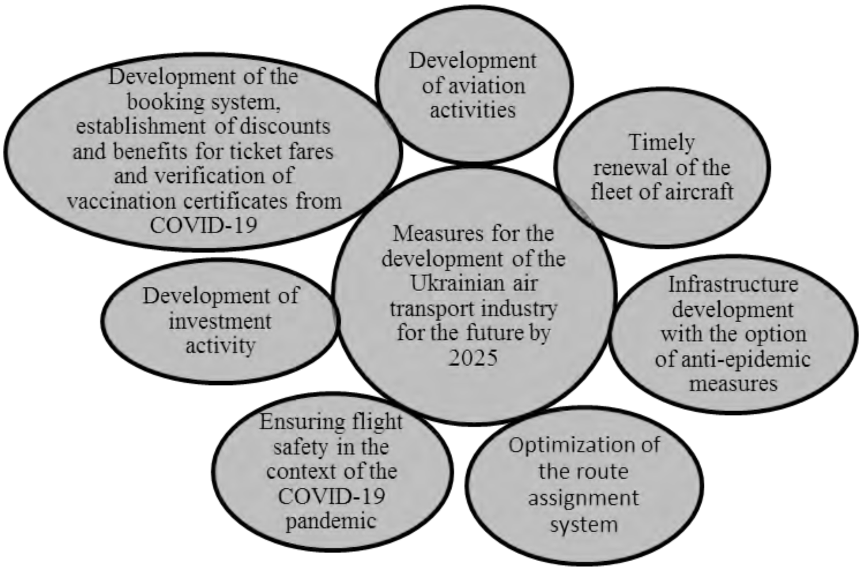

Fig. 3 Proposed directions for improving the air transport industry in Ukraine in order to increase the efficiency of its functioning

Consequently, in the competitive struggle, scientific inventions and the latest technological processes play a key role in the economic survival and development of airlines. As the requirements for aviation systems increase, modern technologies are being introduced annually and IT support is being improved. The state of the air transport infrastructure must comply with international standards. Namely: the development of ground handling at airports (for example, routine maintenance and repair of aircraft at airports); Increase activity at airports and other terminals, activities in the fire brigade and fire brigade at airports, as well as effective airport and air traffic management. It is necessary to include an integrative concept of aviation security and financial security of airlines, which is especially important for airlines from developing countries, in particular Ukraine, which compete fiercely with world aviation leaders.

The issue of the development of the aviation industry is quite relevant today. Taking into account the requirements of the aviation industry and its development, airlines must respond in a timely manner to changes that have occurred in the external and internal environment, take risks and be ready for upcoming changes in order to remain competitive and occupy certain positions in the international aviation services market.

4. Conclusions

The crisis associated with the spread of the pandemic has radically changed all business processes of passenger transport in Ukraine. Airlines operating evacuation flights at the beginning of quarantine were the first to find new working conditions. At the same time, the coordination of the relevant flights was carried out with bureaucratic efforts at five different levels in the approval body. Prospects for the creation of full-fledged operators of the transport market in the world remain illusory: according to various estimates (FIATA), the negative consequences of the pandemic for transport companies will last from three to four years (without deterioration). But in the near future, the borders of European countries will be closed again due to the spread of the "second wave" of the pandemic.

According to analysts' forecasts, in 2020 the economic output of national airlines will be only a third of last year, while the corresponding cost of air transportation on the world market in 2021 will be about 45% of the indicator of 2019 (according to IAT). The main risk for the operator here is possible political influence, changes in the regulatory environment, the implementation of a market approach, which involves minimizing social functions. The need to provide state loans to Ukrainian airlines to support their activities in crisis situations, reduction of tariffs and commissions at airports remains urgent. Equally important is the need for government assistance to maintain qualified workers in the aviation industry, including the need to introduce special benefits and credits for airlines to pay salaries to employees who retain enterprises through the pandemic.

Create government programs to help airlines overcome the economic consequences of the Covid-19 pandemic. In general, due to the pandemic crisis, it will be difficult to manage loans or government assistance to airlines and airports. Small airlines that have not yet proven themselves on the market or that make only seasonal summer flights may be at risk of extinction. Government-subsidized companies or large airlines that can attract significant additional funds will be significantly less affected by the crisis. With the entry into force of the CAA Agreement, Ukrainian airlines can easily participate in any European airport and compete in different directions with European airlines.

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Development of IoT Solution Prototype for Reliable and Sustainable Transport System in Uncertain Epidemiological Conditions

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Abstract

In the frame of current research authors has developed a prototype of the Internet of Things, which reflects the obtained measurement data, in real time. The resulting data provides a convenient opportunity to analyze the quality of air in public transport vehicles – humidity, level of CO2 and temperature. Developed also notifications component, records can be filtered from the selected database if the defined CO2, temperature or humidity measures are exceeded.
Using developed prototype, experiments (measurements) were performed in public transport company's "Rīgas Satiksme" vehicles such as: trolley bus, tram and bus. The goal was to determine if air is being ventilated in public transport in a sufficient level, as well as to observe the temperature and humidity differences during the routes. Results of research are positive and authors can make assumption about the possibility to use such kind of IoT prototypes to make public transport system more reliable and sustainable also in uncertain epidemiological conditions.
KEY WORDS: *prototype, IoT, sustainability, public transport, safety, reliable transport system.*

1. Introduction

The actuality of the topic of current research is related to the rapid climate change and environmental degradation, which is also complemented by the currently unsafe epidemiological situation in the world. One of the existing problems of the modern world is that CO2 pollution from vehicles score for a quarter of the total amount of CO2 pollution [1]. Climate change and environmental degradation are an existential threat to both Europe and the World as a whole. The need for reliable and sustainable transport has been an international issue for the past 50 years [2]. Greener transport is an essential solution to significantly reduce fuel consumption and air pollutants, as well as to reduce the amount of greenhouse gas emissions such as CO2 emissions, which could consequently contribute to sustainable development in the transport sector [3]. Clean air in public transport vehicles is significant for passenger's health.

One of the challenges that can potentially negatively affect the sustainable development of the public transport system is outbreaks of epidemics or pandemics. Studies have shown that a pandemic can affect humanity and the functioning of the world in several ways, such as causing economic damage and long-term negative shocks to economic growth, and in countries with weakly developed authorities and harbingers of political instability, pandemics can increase political tension and instability [4]. At the end of 2019, the world was shaken by the Covid-19 virus, which forced people to make changes in various daily processes, including the operation of the public transport system [5].

Taking into account all the above information, there is reason to believe that the Covid-19 virus is a serious threat to the sustainable development of the public transport system, which is an important part of the normal functioning of society. This is precisely why, in order to reduce the risks of outbreaks of epidemiologically unsafe conditions, it is important to respond to changes in the epidemiological situation in a timely and preventive manner.

The beginning of adapting the public transport system to the COVID-19 challenge and ensuring the sustainability of public transport system, have been done by authors in [6-11].

The SARS-CoV-2 virus that caused the worldwide Covid-19 pandemic has infected more than 500 million and killed more than 6 million people worldwide, and the number is still rising [12].

While scientists were still trying to understand this new virus, cities were trying to find different strategies and solutions to prevent the spread of the Covid-19 virus. One of the epidemiological safety measures was social distancing, limited travel or movement, and finally a stay-at-home order [13].

Changes were also introduced in the public transport system during the pandemic. Passenger transport was, in some places, stopped or drastically reduced [14].

The goal of current article is to explore and practically apply the possibilities of the Internet of Things, to monitor the quality of air in public transport vehicles. To reach the goal, some tasks have been stated. It is significant to analyze the current situation and to develop a prototype for monitoring the quality of air (Co2 level, humidity and temperature) in transport vehicles. It is needed also to perform experiments with developed prototype and obtain data, to be able to make assumption about the possibility to use such kind of IoT devices for the sustainable development of the public transport system also in potentially unsafe epidemiological situation.

2. The Effect of COVID-19 Pandemic

6 million passengers were transported in the Riga region in 2020, which is 32% less compared to 2019 [15].

The demand for public transport decreased both because part of the population began to work from home and, accordingly, these people no longer needed public transport, and also because the large number of people who are typically on the same public transport increased the risk of infection with Covid-19 virus [14].

When thinking about why the changes in the public transport system are significant at the societal level, it is important to mention that although a large part of society was able to change their work habits and do work remotely, still a large part of society, such as people working in helping and in the fields of human care, unfortunately, there was no such possibility. Thus, for these people, public transport is a vital necessity to be able to get to the workplace [5].

It should be mentioned that the Covid-19 virus affected not only the public transport system, but also many other important spheres at the national level, which, accordingly, can also potentially be considered as a challenge for the sustainable development of public transport.

According to the June 2020 survey of the European Committee of the Regions and the Organization for Economic Cooperation and Development, in which 300 regions and municipalities of the European Union participated, the Covid-19 crisis had a significant impact on many regions and municipalities throughout the European Union [16].

Respondents indicate that one of the biggest challenges in overcoming the health crisis is the lack of technical means and equipment, the lack of financial resources at the local level and the lack of coordination with other levels of government.

According to the 2021 European Commission data, the gross domestic product (GDP) indicators in Latvia decreased by 3.5% in 2020, and the unemployment rate increased - up to 8.2% in 2020, in contrast to the indicators in 2019, which were 6.3% [17].

Such data show that the Covid-19 pandemic has also affected the financial situation of the countries, which, as previously mentioned, is one of the challenging factors that can potentially affect the development of the sustainability of the public transport system.

In addition to the impact of the economic situation in many sectors, the Covid-19 virus crisis has also had a significant social and political impact [18].

The pandemic has also affected the ability of residents to pay for their housing, as many people can no longer afford rent or mortgage payments, thus increasing the risk of homelessness without preventing the spread of the Covid-19 virus [18].

The global pandemic has created a series of international and domestic policy issues. The Covid-19 health crisis is an exogenous shock to the wider international system, disrupting international politics and creating new tensions between adversaries and allies alike [19].

Specialists predict that this could undoubtedly have a significant impact on the geopolitical situation in the coming years [19].

The pandemic also poses challenges to national stability and may create the potential for political violence and internal armed conflict [19].

Even now, two years later, the Covid-19 virus and limiting its spread, both in general and also within the framework of the public transport system, is still a topical issue for the public.

Summarizing the available information, it can be concluded that the Covid-19 virus pandemic has been of great importance in the context of the state's functioning, business operations, and public welfare. Taking into account all the above information, there is reason to believe that the Covid-19 virus is a serious threat to the sustainable development of the public transport system, which is an important part of the normal functioning of society.

This is precisely why, in order to reduce the risks of outbreaks of epidemiologically unsafe conditions, it is important to respond to changes in the epidemiological situation in a timely and preventive manner.

3. Designing of IoT System Solution

The Covid-19 virus showed how important it is to take quick and effective decisions to be able to reduce the spread of the virus. Also, one of the influencing factors is to reduce the risks of disease in places where there is a large gathering of people.

An important role in decision-making was influenced by publicly available statistical results on morbidity from the World Health Organization, but there is a lack of freely available data on the real-time situation from places where there is a high risk of contracting the Covid-19 virus, such as public transport.

Secondly, the time of execution of decisions, every day or week in which the defined work tasks, which are intended to reduce or help prevent the further spread of the Covid-19 virus, are not implemented may result in a higher rate of morbidity on the surrounding population. Which, accordingly, can later escalate the situation to the point where governments have to apply the highest restrictive measures affecting the entire development and economy of the country.

Based on what was experienced during the Covid-19 virus pandemic, and taking into account the fact that the spread of the virus has not been stopped, only limited, it is only a matter of time when there will be the next wave of high morbidity or the next strain of the Covid-19 virus.

In conditions where there are no criteria for limiting or reducing the virus, the Covid-19 virus spreads rapidly, and several mutations of the virus have been observed, such as omikron, delta, etc.

The public transport passengers themselves, who want to travel with their preferred public transport, do not have the opportunity to make sure that the public transport is not overcrowded at the given moment and whether safe and comfortable movement is possible. This type of data would help to better analyze and even potentially build correlations between heavy public transport congestion and Covid-19 cases, taking into account the incubation period. The real-time availability of such data would help to make fact-based decisions on which public transport route requires additional flights to ensure a safer and more favorable passenger transfer.

Studies by several scientists have proven that inadequate environmental conditions in indoor spaces that are not ventilated or that have an inadequate room temperature negatively affect people's well-being, comfort and productivity [20].

In addition to the above, CO2, humidity and temperature sensors are used to perform measurements, which are connected to the Internet of Things network and the data is sent to the database or stored in local memory.

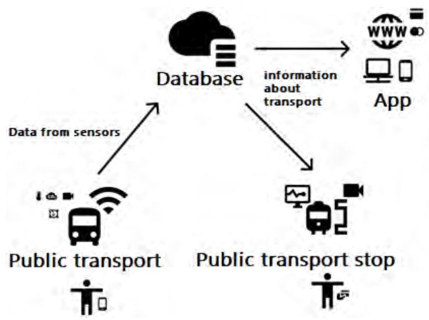

Fig. 1 Architecture of the solution

Looking at architecture of the solution shown in Fig. 1, it can be observed that the solution consists of several blocks: • app block functionality, which is described below in 3.1. point; • public transport block, which is described below in 3.2. point; • public transport stop block, which is described below in 3.3. point; • cloud server databases – the environment to which all information from IoT sensors will be sent, with the possibility to view the data, for any user, as well as, this data will be used by the app for its operation.

3.1. App Functionality

The final consumer - the passenger - is important for the sustainable development of the public transport system. The functionalities listed below would improve the convenience for passengers to buy a ticket and make sure of the safety of public transport, in the unsafe conditions of the pandemic. App Functionality:

- view real-time information about the public transport route and the location of public transport;
- view information about the public transport itself: *whether free places are available in public transport, as well as zones and seats for people with mobility impairments; *air and temperature indicators of public transport and whether there is well-ventilated air in public transport, guided by the CO2 sensor.; *whether public transport is not delayed;
- to give the user the opportunity to purchase a ticket for the selected route or transport in time, using the dedicated app, thus reserving his seat. Also, this type of reservation system would help the public transport dispatcher to decide whether an additional flight is necessary;
- receive notifications about changes in the route or arrival times of public transport at the stop;
- receive a warning message that there is a person in public transport who has been diagnosed with the Covid-19 virus and is violating epidemiological safety requirements. Alert information would be sent if the person no longer has an active Covid-19 certificate and is registered in the app with Bluetooth enabled.

3.2. Public Transport

In order for the app to reflect data from the cloud database, it is necessary to provide public transport with:

- For IoT devices, such as a device that performs measurements related to air temperature, humidity and CO2 levels;
- A Wi-Fi router, with an Internet connection, to which IoT devices would be connected, which would send data - measurement results - to the database. Also, the Wi-Fi router would improve the quality of using public transport for passengers, providing the opportunity to use the Internet for free. In addition, public transport should be equipped with a hand disinfection stand, with the possibility to take a face mask.

3.3. Public Transport Stop

At a public transport stop, while passengers are waiting for transport, on a digital monitor it could be possible to view current information about the public transport that the individual is waiting for, as well as information related to public transport routes and its current events, also providing the opportunity to buy a ticket.

It would be necessary to install video surveillance cameras at bus stops, the data of which could be used in the future to study how to develop bus stop infrastructure.

4. Prototyping

During the prototype development process, the MH-Z14A CO2 sensor was attached to the nodeMCU Internet of Things development board, along with the DHT11 temperature and humidity sensor.

A mockup board was used during the prototyping process to facilitate the prototyping process.

The schematic diagram of the prototype gives an insight into how the connection between the sensors and the NodeMCU development board is made. (Fig. 2).

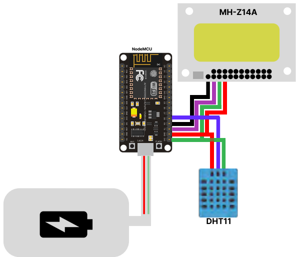

Fig. 2 Illustrative scheme of the prototype

When interconnecting the NodeMCU development board with the sensors, wires that are adapted for the layout board were used, thus making the work easier (Fig. 3).

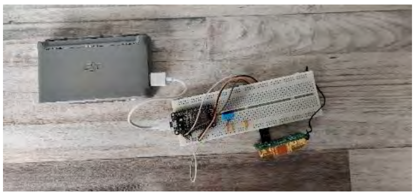

Fig. 3 Connection of the prototype

In order for the prototype to fully send messages to the MQTT broker, which serves as a server that collects information from all reporters, the prototype needs to be configured accordingly (Fig. 4.). In addition to the above, the MQTT broker service was installed on the computer, so the local IP address of the computer was used when configuring the MQTT broker for the NodeMCU development board. In the foreground environment, Tasmota's standard functionality allows the user to perform configuration tasks using the terminal environment, as well as view notifications.

Fig. 4 Device configuration

Nowadays, there are several MQTT broker service providers available. As part of the development of the prototype, the Eclipse Mosquitto service was used.

4.1. Experiments

With the developed prototype, measurement results were carried out in public transport to check whether sufficient air circulation is carried out. Also, with a temperature and humidity sensor, it was checked whether the air temperature is controlled and whether it is the same between different public transports. The developed prototype was placed in the middle part of a trolleybus and a bus (Fig. 5).

Fig. 5. Experiments in public transport vehicles

The prototype was placed in a cardboard box, but the IoT device's sensors were placed outside the cardboard box to allow for measurements. The prototype was attached to the handle with the help of adhesive tape. The authors of the current paper chose the location of the prototype for the following reasons:

- The air ventilation system is not observed at the junction of the bus and the trolleybus, where passengers can be;
- Researchers [21] recommend placing the CO2 sensor in the middle of the room.

When taking measurements on public transport, the prototype sent all messages to the Firebase database.

The authors of the paper, after carrying out the measurement, concludes that there is a difference in the dynamics of CO2 increase and decrease, depending on the type of public transport.

Measurements were made at moments when public transport did not spend extra time standing in traffic jams, and all the spaces available to passengers were not occupied.

Summarizing the obtained experimental results, it can be observed that, for example, there are larger temperature fluctuations in the tram than in other public transports, because there is no device in the tram that can control the air temperature or humidity in it, but minimal temperature fluctuations can be observed in the other public transports.

Comparing the temperature in the trolleybus and the bus, it can be observed that the temperature was the highest in the trolleybus, but the lowest in the bus.

On the other hand, the lowest amount of CO2 emissions was in the tram compared to other public transports.

5. Conclusions

Authors of the paper concludes that the internet of things continues to develop nowadays and its presence can be observed in medicine, industry and other fields. In addition to the above, the Internet of Things provides a wide range of ways for data to be sent, such as using the MQTT or LoRaWan protocol.

Aa prototype of the Internet of Things was developed, which consisted of a CO2, humidity and temperature sensor. The measurement data was sent using the MQTT protocol.

Measurements were made with the developed prototype in a tram, trolleybus and bus. The analysis of the measurement was carried out on the website, which the authors of the work developed to reflect the obtained data in the form of graphs.

After carrying out the measurements, authors of the work concludes that there is a significant difference between the dynamics with which the CO2 level rises in different types of public transport, as well as the temperature fluctuations exist during the route.

The most important observation of the study was comparing the high-floor tram with the bus. During the measurements, no significantly increased CO2 concentration was observed, which could potentially cause harm or affect the well-being of public transport passengers, but it should be taken into account that the measurements were made at moments when all the seats in public transport were not occupied, and the air conditioner was working and the window was open.

Authors of the work concludes that the developed prototype is a useful solution to be able to perform measurements in public transport, and also the developed solution provides an opportunity to connect several Internet of Things devices using the advantages of the MQTT protocol.

All of this make possible to make assumption about the possibility to use such kind of IoT prototypes to make public transport system more reliable and sustainable also in uncertain epidemiological conditions.

Acknowledgements

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Evaluation of Seaports and Terminals Possibilities to Adapt to Changes in Market and Economic Conditions

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Abstract

During the last years the changes in logistics and transport chains were observed. These changes impacted the operation of seaports and terminals that had to adjust their activity to a new market and economic conditions. In favourable economic conditions very high specialization of seaports or terminals activity allows increasing the productivity of logistics chains. However, vast changes in the market environment may lead to a decrease of ports and terminals economic efficiency or even threaten their functioning. Therefore, ports and terminals' should elaborate on development plans and assess technical possibilities to reorient their activity on handling other cargo types and diversify the services. Importantly, ports and terminals should have tools to evaluate the possibilities to adapt to new market conditions in order to take rational decisions on allocation the of investments in the development of water and land infrastructure and superstructure.
In the article the evaluation of possibilities to adapt ports and terminals to a new market and economic conditions is analysed in detail. Multi-criteria forecast method was considered to evaluate the possibilities (potential capacities) of ports and terminals, taking into account possible changes in the market and economic conditions. The case study has been examined to show the implementation of the presented approach.
KEY WORDS: *seaports and terminals; terminal adaptation; transport chain, port infrastructure and superstructure evaluation; market and economic conditions*

1. Introduction

Significant changes in performance of logistics and transport chains are observed during last years. These changes were related to restrictions influenced by COVID-19, changes in location of suppliers and recipients involved in supply chains and other factors [9]. These factors influenced the need to adapt operation of some ports and terminals to new market and economic conditions.

There are ports and terminals that for many years directed their efforts for high specialization of performed activities to increase the quality of services, productivity, as well as economic efficiency. It should be noted that very high specialization of ports and terminals operation increases efficiency of the logistics and transport chains. However, in case of significant changes in market and economics conditions the ports and terminals deep specialization and focusing on servicing specific cargo type may cause problems that sometimes even may lead to closing of terminals' operation [2, 7]. There are terminals, for example servicing LNG, oil or chemical products, for which reorientation on servicing other types of the cargo could be very complicated and costly. Therefore, it is easier to adapt general cargo terminals and multipurpose (universal) terminals during short period to service new cargo types [4, 5, 7].

To better adapt to changes in market conditions, seaports and terminals elaborate and regularly review development strategies and plans for future investments in water and land infrastructure and superstructure. Taking of these strategical and tactical decisions deals with the need to both analyse factors related to ports' operation in changing market conditions and create forecasts of potential throughput, capacity, economic efficiency, etc. In order to do this, decision-makers have to possess the tools that will allow them to take rational decisions.

Conducted literature analysis revealed that the issue of ports and terminals' adaptation to changes in market and economic conditions should be analysed in more detail, considering the possibility to reorient terminals' activity to handling of other cargo types and diversify the services. The article aims to present multi-criteria forecast method and related simulation program that may be used by seaports or terminals to evaluate their existing and potential development possibilities.

2. Literature Review

Seaports and terminals may be involved in servicing specific cargo type or different loads. Multipurpose ports, like Wismar (Germany), Koge (Demmark), Szczecin (Poland), etc., as well as multipurpose terminals operating in seaports (e.g. "Vakaru Krova" in Klaipeda seaport) handle different types of cargo. The main types of cargo serviced in multipurpose small and medium-sized ports or separate terminals located in big seaports include: bulk cargo (e.g. grain, fertilizers, coal, etc.); liquid cargo (e.g. liquid fertilizers, liquid food production, etc.); general cargo (e.g. machinery, steel production, wood industry production, etc.); oversize cargo (e.g. wind meals components, spear parts for energy and chemical industry, etc.); containers; agriculture products and other [2, 4-5, 7, 12]. These cargo flows are regularly analysed by seaports and terminals and are used in simulations of their forecasts and facilities development.

When evaluating the operation of land infrastructure (roads, railways, port's or terminal's territory, etc.) and waterborne infrastructure (navigation channels, inland waterways, quay walls, etc.), it is expedient to: investigate potential cargo flows and their forecasts; investigate the possible volumes of cargo handled at quays and piers, workload and possible handling capacities; assess the potential berth's handling capacity considering land and water sides; determine the maximum possible parameters for ships in terms of cargo type and navigational conditions; identify preliminary investments for the development of the infrastructure and superstructure, etc. [1, 5, 8, 13].

Multipurpose terminals that have development possibilities and available territories, compared to specialized terminals, may focus their development strategies on servicing main possible cargo, such as general cargo, some types of bulk and special liquid cargo, oversize cargo for the more effective use of port infrastructure and superstructure [4, 7, 12]. In order to do this, it is necessary to: evaluate and forecast possible cargo types and quantities possible to service during short- and long-lasting periods; assess the optimal and maximum capacity of the existing and planned port infrastructure (quays, railways, roads, and other land and water areas, etc.), taking into account the existing and potential cargo flows; after assessing the capacity and the existing and potential cargo flows and setting priority objectives, it is necessary to prepare an optimal development plan of the territory, including alternative plans. These plans must cover infrastructure and superstructure facilities, such as: sites for bulk and general cargo (their location, warehouse parameters - surface, capacity, coatings, etc.); covered warehouses for bulk and packed cargo (their location, capacity, type of warehouse, construction materials, etc.); tanks for liquid cargo (their location, diameter, capacity, construction materials, etc.); handling equipment (cranes, gantries, possible handled volumes of cargo, etc.); internal roads and parking places (movement schemes for vehicles and handling equipment, including entry/exit gates and truck parking/storage areas) [1, 4, 8]. After assessing port's infrastructure and superstructure, the preliminary number of employees to achieve optimal and maximum throughput should be estimated and the initial costs of facilities construction, including other possible works (demolition, etc.), should be estimated.

Analysis of available literature revealed that there are different methods to analyse and forecast seaports' capacity and throughput. Forecasts of containers throughput based on selective deep-ensemble model [6], on interval analysis [14] or nonlinear subseries [10] were considered. Different parameters of ports operation were predicted, including capacity, profits, etc. [11, 3]. However, there is a need to develop holistic method to conduct forecasts that could be used to evaluate ports and terminals possibility to adjust to changing market conditions.

3. Research Methodology

Based on literature review analysis, the methodology to conduct the research has been proposed. The methods of statistical forecasting of cargo flows in seaports are usually based on the values of past and present cargo flows, as well as the analysis of their probability characteristics. Various forecasting methods may be applied to assess cargo flows, but in the analysed case it is proposed to use the multi-criteria forecasting method [1]. The multi-criteria forecasting method [1, 8] allows to identify the expected volumes of cargo flows, as well as evaluate possible ways to optimize the ports and terminals activity. The predicted freight flow after time period *t*, assuming a multi-criteria dependence, can be calculated using the Eq. (1) [1, 8].

$$Q_t = \left(Q_o + bt\right)M \ , \tag{1}$$

where Q_o – quantity of cargo at the last statistical point; M – multi-criteria forecasting factor; t – calculated time period, years; b – forecast coefficient calculated using statistical data [1, 12].The multi-criteria forecasting factor is calculated by estimating the influence of possible selected factors and factor weights (Eq. (2)). The main factors that may affect the cargo flows of the small and medium-sized ports and terminals are: global economic situation; regional economic situation; total impact of ports or terminals development; impact of competitors' development; impact of possible restrictions in neighbouring countries (political implications); potential impact of logistics platforms (mostly effects general cargo flows); habited effects (mostly impacts bulk cargo flows); other effects (hydro meteorological conditions, epidemics, etc.). These factors list may be extended if needed. In this way, the multi-criteria forecasting factor can be presented as follows [1, 12]:

$$M = \frac{1}{\eta_k}\sum F_i \cdot k_i \, , \tag{2}$$

where: η_k – the correlation coefficient for the specified factors can be assumed about 0.95; F_i – the factors mentioned above; k_i – factor weighting coefficients, the total of which must be equal to one.

By calculating specific freight flows, forecasting flow parameters, and considering the results of a specific previous periods (freight flow statistics), the forecasting accuracy can be calculated. The square of the variance (square of the error) of the random variables for specific flows may be calculated as follows (Eq. (3)) [1, 12]:

$$\sigma_y^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - m_y\right)^2 . \tag{3}$$

The standard of random variables or the magnitude of the prediction error is then calculated using Eq. (4) [1]:

$$e = \sigma = +/-\sqrt{\sigma_y^2} . \tag{4}$$

To determine the scatter of the predicted values, it is appropriate to calculate the coefficient of variation δ according to the Eq. (5) [1]:

$$\delta = \frac{S_{my}}{m_y} . \tag{5}$$

When creating the forecast of cargo flows, it is important to consider coefficient of variation, according to its size the stability of the flows is defined. For transport (freight) flows, when the coefficient of variation is δ up to 20%, the flows are considered constant. This forecasting methodology can be used to forecast the cargo flow in ports and individual terminals or berths and determine the type and size of necessary port infrastructure and superstructure development [1, 8, 12].Based on the current and forecasted optimistic cargo flows, expected ship sizes, cargo storage time in warehouses, a simulation program for the assessment of infrastructure and superstructure operation has been developed. This program includes the following basic input data: freight flow, t; the carrying capacity of the vessel, t; the amount of cargo loaded per month, t/month; berth availability per month, t/month; the required amount of cargo in the warehouse, t; the permitted load in the warehouse, t/m²; terminal single line capacity, t/h; the number of technological lines; the minimum required number of berths; the minimum number of ships at berth for cargo transportation; the maximum number of vessels for cargo transportation; the time of arrival and departure of the ship, h; average pilot waiting time, h; the time required between moorings, h; additional time due to contingencies, h; time of berth occupation during stevedoring operations, h; berth occupation time for additional operations, h; warehousing time, days; navigation period, days/year; the coefficient of time utilization of loading operations; coefficient related to changes in vessel size; coefficient related to terminal non-working days; coefficient related to changes of terminal's service time for other reasons; quay length utilization factor; quay working time ratio due to meteorological conditions; storage coefficient; storage capacity utilization rate; the utilization rate of the warehouse space; the maximum length of the calculated ship, m; length of one berth, m; the capacity utilization factor of the vessel; design ship loading rate, t/h; distance between ships, m; the total quay occupancy rate; existing berth length, m; number of storage levels; the coefficient of the vertical loading form (cone, rectangle) of the cargo; actual warehouse (territory) area for storage, m².

The developed simulation program allows to obtain the following permeability parameters of berths and storage sites: warehouse capacity, t; required storage area, m²; ship service terminal time, days; the maximum possible number of vessels at berths per year; the possible maximum cargo flow at the terminal according to the existing berths, t/year; the required storage capacity for maximum flow (according to the existing quays), t; the necessary warehouse area for cargo flow (according to the existing quays), m²; possible maximum flow according to the existing storage area, t/year; the number of vessels required to carry the cargo flow; berth capacity per month, t/month; the minimum number of berths required to supply monthly traffic at the set capacity; the minimum number of vessels at berths per month; the maximum number of vessels for cargo transportation per month at the quays; berth occupation time during loading operations, h; required berth length, m; the required storage capacity according to the assigned cargo flow, t; the required storage area according to the set flow, m²; ship service terminal time, days; the possible maximum number of vessels at the required berth length per year; the possible maximum cargo flow at the terminal according to the existing berths, t/year; required storage capacity for maximum flow (according to existing quays), t; warehouse area for the received flow (according to the existing quays), m²; the possible maximum cargo flow according to the existing storage area, t/year; the number of vessels required to carry the planned amount of cargo; the total number of vessels for cargo traffic.

4. Case Study of the Port Terminal Diversification into Multipurpose Terminal

On the basis of theoretical methods, presented in Section 3, the cargo handling forecasts were carried out with the use of developed simulation programs for the selected case study. The case study covered certain multipurpose terminal that handles selected cargoes, including liquids. Possible factors were considered to conduct calculations of multi-criteria forecast coefficient (Table 1, Fig. 1). These factors allow to access the impact of market and economic conditions on terminal's operation.

Table 1

Possible factors considered in calculations of multi-criteria forecast coefficient for selected liquid cargo

Factor (F_i)	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Global economic situation	1	0.98	0.99	1	1.02	1.04	1.04	1.03	1.02	1.02	1.01	1.02
Regional economic situation	1	0.98	0.98	1	1.02	1.03	1.03	1.04	1.05	1.04	1.03	1.03
Total impact of ports or terminals development	1	1	1.1	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Impact of competitors' development	1	1	1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Impact of possible restrictions in neighbouring countries	1	1	1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Potential impact of logistics platforms	1	1	1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Habited effects	1	1	0.9	0.9	0.9	1	1	1	1	1	1	1
Other	1	0.8	0.9	1	1	1	1	1.1	1.1	1.1	1	1

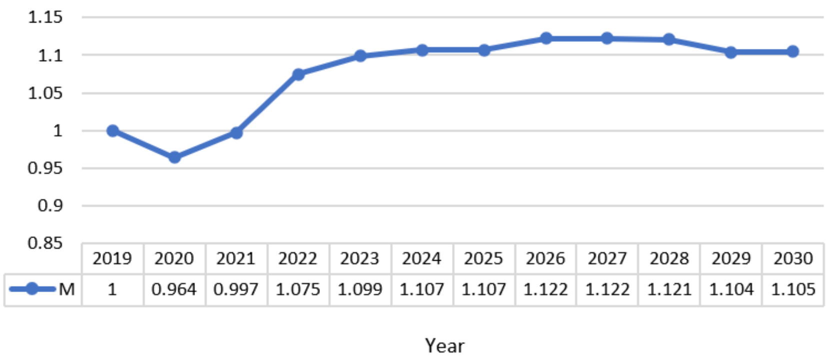

Fig. 1 Multi-criteria forecast coefficient for the liquid cargo

Considering assumptions set, the magnitude of the prediction error e was calculated and achieved 7.3 thousand tons and the calculated coefficient of variation δ was equal 0.085. That allowed to create multi-criteria forecast (real, optimistic, and pessimistic) for liquid cargo up to 2030 (Fig. 2). Assumptions and selected results of calculations necessary to evaluate terminal's potential for selected case study is presented in Table 2. The calculations were conducted using developed simulation program. For the set assumptions it was possible to calculate i.a. time of ships service in terminal, warehouse capacity, requested ships number for cargo flow and other parameters.

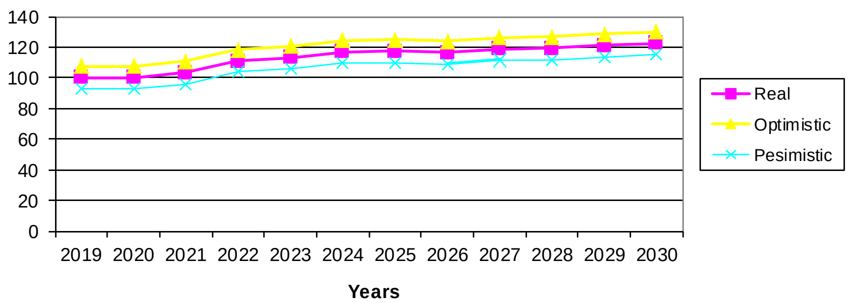

Fig. 2 Liquid cargo multi-criteria forecast up to 2030 in thousand tons

General cargo handling capabilities and terminal parameters are calculated using the methodology presented in Chapter 3.

Table 2

Selected input and output parameters considered in calculations of terminal's capacity

Abbreviation	**Factor (F_i)**	**Calculated value**
Q	Cargo flow, t	170 000
Q1	Ship capacity, t	20 000
Q2	Cargo flow per month, t/month	14 166.67
Q3	Quay capacity per month, t/month	58 536.18
Q4	Required amount of cargo in the warehouse, t	20 000
Q5	Permitted load in warehouse, t/m^2	10
NT	Productivity of single loading line, t/h	220
N1	Number of technological lines	1
T	Navigation in port, days/year	360
T1	Time for arrival and departure of the ship, h	4
T2	Pilot waiting time, h	2
T3	Time required between ships mooring, t	6
T4	Additional time due to contingencies, h	2
T5	Time of berth occupation during stevedoring operations, h	102.27
T6	Birth occupation time for additional operations, h	4
T7	Cargo storage time in warehouse, days	40
K1	Coefficient related to time of cargo loading operations	0.8
K2	Coefficient related to changes in vessel size	0.8
K3	Coefficient related to terminal's non-working days	0.8
K4	Coefficient related to changes of terminal's service time for other reasons	0.8
K5	Coefficient related to quay length	0.8
K6	Coefficient related to quay working time related to hydro-meteorological conditions	0.8
K7	Coefficient related to cargo storage in warehouse	0.7
K8	Coefficient related to warehouse capacity	0.95
K9	Coefficient related to warehouse square	0.95
L1	Planned ship's length, m	160
L2	Length of one quay, m	176
A	Coefficient of ships' capacity	0.9
M1	Planned loading capacity, t/h	220
Q6	Calculated possible maximum cargo flow for terminal (with existing quays), t/year	2 615 385
T8	Calculated time of ships service in terminal, day	5.32
S1	Calculated warehouse area for cargo flow Q6 (according to the existing quays), m^2	41 514
E1	Calculated storage capacity for cargo flow (according to the existing quays), t	276 068.4
N6	Calculated required number of vessels for cargo traffic	10.625

5. Conclusions

Multi-criteria forecasting method had been presented and tested on selected terminal examples that proved its applicability. The simulation program, which allows evaluating current and potential possibilities of ports and terminals for servicing cargo flows, was developed. Implementation of this program enables ports and terminals to assess the possibilities of changing their activities more accurately.

It should be noted that the forecasting simulation program presented in the article can be used to optimize the decisions taken by port and terminals managers while planning development strategies and investments in ports infrastructure and superstructure. It could be implemented to evaluate the development possibilities and may be adjusted to the needs of different terminals considering changing market and economic conditions.

Using mentioned calculation method and simulation program, it is possible to optimize ports and terminals' activity. Additionally, the performance of more efficient operation of ports and terminals may attract new cargo flows and increase their profits. It also supports better organization of work and in consequence the increase of ports and terminals competitiveness level.

The research results may be of interest to ports authorities and terminals operators, as well as transport and forwarding companies that cooperate with seaports. Our future research will focus on a more detailed investigation of cargo flows forecasts and methods of seaports' possibilities evaluation.

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Changes in Transportation due to the Influence of SARS-CoV-2

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Abstract

2020 and 2021 were years dominated by COVID-19. Fear of an unknown pathogen, circulating conspiracy theories, introduced administrative restrictions and their loosening significantly influenced social life and all economic sectors. Large changes were also observed in transport, manifested by a decrease in the transport volume and lower revenues. The article presents the changes on Polish transport market and shows the correlation between their level and the introduced sanitary restrictions. The analysis of the available data revealed: fragility of the transport system and its lack of resistance to unexpected events; relatively quick adaptation / overcoming of difficulties on the railways, especially in the transport of goods; changes in social mobility; differences in individual countries, and draw the conclusions about: the possibility of quick adaptation of rail transport in crisis situations; the existing transport potential in the railway sector; the need to adopt solutions that make transport immune to unexpected events. The article uses data obtained as a result of a review of world literature, studies of many institutions and organizations as well as obtained from the Office of Rail Transport and individual carriers
KEY WORDS: *transportation, railway, COVID-19, SARS CoV-2*

1. Introduction

The first information in the media about the new virus observed in the Chinese city of Wuhan in December 2019 did not cause any particular disturbance in the transport environment. The distant Chinese problems were not expected to shake the economies of almost all countries in such a drastic manner. However, the rapid development of the disease in Asian countries caused that on January 30, the World Health Organization (WHO) announced the global epidemic threat and on March 12, the state of the COVID-19 pandemic[1]. Within a few days, the transport paralysis caused by the preventive actions of individual governments spread across Europe. Administrative decisions stopped international traffic and severely limited the domestic one. The first European country which implemented a lockdown was Italy, fighting with COVID-19 in February in the northern regions[2]. Shortly afterward, other countries issued similar decisions limiting mobility throughout the country to prevent the spread of the pathogen.

Concerning mobility and transport, many papers were published describing impact of COVID-19 in individual countries, e.g. concerning: China[3], Italy[4], France[5], Germany[6], Sweden[7], UK[8], US[9], Canada[10].

2. Transport Sector – Global View

2.1. Air Transport Overview

In 2020 aviation has been in its gravest moment in history with a collapse in air travel demand globally. In all regions losses in passenger traffic revenues were recorded: Africa – USD 14 billion, Asia/Pacific – USD 120 billion, Europe – USD 100 billion, Latin America/Caribbean – USD 26 billion, Middle East – USD 22 billion, North America – USD 88 billion[11].

Since 2019, total air connectivity has declined by almost 70% in Frankfurt, London, Paris, Istanbul and 53% in Amsterdam[28]. As a result of the introduced administrative restrictions, the number of air travels has significantly decreased, which was reflected in the airlines global results (Table 1):

- Approx. € 372 billion loss of gross passenger operating revenues of airlines;
- Overall reduction of 50% of seats offered by airlines;
- Overall reduction of 60% passengers (-2,703 million)[11].

Table 1

The COVID-19 impact on world scheduled passenger traffic for year 2020, compared to 2019 levels

	1Q 2020	2Q 2020	3Q 2020	4Q 2020	Total 2020	1Q 2020	2Q 2020	3Q 2020	4Q 2020	Total 2020
	Passenger number changes [%]					Passenger revenue changes [$, million]				
International	-20.90%	-96.90%	-78.80%	-84.70%	-73.80%	-5,040	-30,882	-29,870	-23,458	-89,249
Domestic	-15.20%	-86.30%	-34.10%	-50.10%	-47.10%	-857	-5,571	-2,378	-2,990	-11,795
Total	-19.20%	-94.20%	-68.00%	-75.30%	-66.80%	-5,897	-36,453	-32,247	-26,448	-101,045

Source: own elaboration based on[11]

2.2. Railway Transport Overview

In the first months of 2020 domestic railway traffic decreased by approximately 80% for all national rail services during lockdowns and international one was stopped in almost all countries. Passenger services suffered more than freight, but the pandemic affected both types of transport. In 2020 r. railways lost € 26 billion in revenue in the European Union (EU27), including passenger service – € 24 billion and freight – € 2 billion[12]. Table 2 presents losses in 2020 in EU27 railway sector.

Table 2

Revenue changes 2020/2019 in railway sector

	1st half 2020	07/2020	08/2020	09/2020	10/2020	11/2020	12/2020	Total 2020
Passenger Services	-40%	-38%	-35%	-39%	-46%	-51%	-51%	-41%
Freight Services	-15%	-13%	-12%	-9%	-7%	-4%	-3%	-11%
Infrastructure	-14%	-8%	-8%	-8%	-8%	-9%	-10%	-11%

Source: own elaboration based on[12]

2.3. Road Transport Overview

Global road transport activity was almost 50% below the 2019 average by the end of March 2020. During the March/April lockdown, some European toll operators lost up to 90% of traffic and 80% of revenue. The total loss in revenues in freight and passenger transportation in 2020 was more than $ 1 trillion (-679 billion - transport of goods, -500 billion – passenger transport). Ban of public transport and international movements across Europe, with the highest impact on the tourism sector, caused significant drops in turnover in road transport: bus & coach urban/local -42%, bus & coach intercity -70%, bus & coach tourism -82%, taxi -60%[13].

The road traffic reduction compared to the previous year in individual cities around the world differed significantly depending on the adopted regulations helpful in limiting the spread of the SARS-CoV-2. Sweden was the least restrictive of mobility, not introducing travel bans, but only recommending behaviors limiting the spread of the virus. In comparison of presented periods of time, the decrease in traffic in Stockholm is lower than in other selected cities. Weekly traffic reached the lowest levels in the initial period of the pandemic in all cities. Weekly mobility in the week to the average traffic figures from the same week one year earlier are presented in Table 3.

Table 3

Road traffic reduction in selected cities in selected periods of national emergency, year-on-year

City	16-22.03.2020	11-17.05. 2020	6-12.07.2020	31.08-6.09.2020	19-25.10.2020
Barcelona, Spain	-73%	-65%	-31%	-38%	-35%
Manchester, UK	-67%	-53%	-53%	-42%	-42%
Stockholm,Sweden	-48%	-29%	-39%	-10%	-3%
Madrid, Spain	-86%	-73%	-59%	-59%	-32%
Milan, Italy	-74%	-61%	-42%	-35%	-29%
New York, US	-74%	-74%	-52%	-39%	-39%
Sao Paolo, Brazil	-75%	-75%	-60%	-50%	-42%

Source: own elaboration based on data [14]

3. Mobility in Correlation with COVID-19 Restrictions

The specificity of SARS-CoV-2, among others elements, is related to its easily penetration of the human body and quick replication. In the first period of the epidemic, there was no verified information on what type of remedial actions would bring the most reliable results. Polish government made decisions aimed at limiting the development of the epidemic and protecting the population based on the recommendations of international organizations and the experiences of other countries. The restrictions, introduced for the first time in March, generally concerned reducing gatherings of people in public areas, lowering social mobility, and increasing the possibility of keeping distance between people. The introduction and subsequent elimination of restrictions were associated with changes of infections during subsequent waves of COVID-19. From 04.03.2020 till the end of 2020, the total number of cases in Poland reached over 1,295 million (number of tests taken 7,204 million). According to the Ministry of Health in the same period more than 28,5 thousand infected patients died. The National Vaccination Program was started 8th of December 2020.

Table 4 presents the state of the COVID-19 regulations against the dynamics of infections calculated for the periods between the dates of implementation/easing the COVID-19 restrictions.

During the first wave of disease (March-May 2020) the most significant decrease in mobility was recorded in places such as restaurants, shopping centers, museums, libraries, and cinemas. However, in the following weeks, there was an increase in the mobility of Poles. Since the end of April 20, Poland has started the phase of easing some of the restrictions related to the coronavirus epidemic. Table 5 shows changes for each day compared to a baseline value which is the median value, for the corresponding day of the week, during the 5-weeks 03.01-06.02 in 2020.

Table 4

COVID-19 Regulations in Poland against the dynamics of infections

Date of Regulation Implementation	Dynamics of Infections	Scope of Regulations
04.03.2020		Official information on the first case of COVID-19 infection in Poland.
14.03.2020	3400%	Announcement of an epidemic threat with imposing restrictions on people's movement
23.03.2020	229%	Introduction of the state of the epidemic in Poland with i.a. ban of moving beyond essential household, job and health purposes
16.04.2020	192%	Obligatory covering mouth and nose in public places
04.05.2020	-7%	Lifting some restrictions – opening shopping centres, hypermarkets, and hotels.
18.05.2020	14%	Easing restrictions: increase of the number of passengers to 30% of all seats and standing places combined, opening restaurants, schools and some sports facilities.
30.05.2020	17%	The next stage of elimination of restrictions – lifting the limits of people in shops, post offices, restaurants, and places of religious worship
01.06.2020	-9%	Increasing the number of passengers to 100% of seats or 50% of all seats and standing places, resumption of internal passenger flights.
06.06.2020	52%	Opening the hotels, sports facilities and places of culture, enabling gatherings of up to 150 persons
13.06.2020	-24%	Lifting restrictions on land traffic at borders
16.06.2020	-8%	Resumption of international passenger flights.
17.07.2020	-13%	A partial lifting of restrictions on sports facilities
06.08.2020	106%	Return of some restrictions. Obligatory wearing protective masks. Division into green, yellow and red counties depending on the infections increase on which the restrictions scale depends as well. The strictest restrictions in red counties – among others limitation of the local public transport up to 50 % of the total capacity
08.10.2020	490%	Whole country declared the yellow zone with maintaining the red category for the counties with highest infection rates.
16.10.2020	80%	New restrictions in yellow and red zones. Further areas are included in red zones. Among others, limitation to 50 % sitting places or to 30 % of all places in public transport, Closing swimming pools, aqua parks, fitness clubs, sports events without an audience, universities and high schools – online or hybrid teaching
23.10.2020	77%	Additionally to the previous restrictions – restaurants and bars only takeaway service. Only five persons outside the single household are allowed to meet.
30.10.2020	59%	Closing the cemeteries except for the planned ceremonies
04.11.2020	14%	Closing: commercial centres except for essential shops, hotels except for business trips, cinemas, theatres, museums, online teaching in primary schools.
28.11.2020	-39%	Opening the commercial centres for the period around Christmas time.
17.12.2020	44%	National quarantine till 17.01.2020 (hotels remain closed, incl. business trips, closing commercial centres & skiing centres) all previous restrictions remain.

Source: own elaboration

Table 5

Community mobility changes due to the coronavirus (COVID-19) outbreak in Poland from March to June 2020

29.03.2020	11.04.2020	30.04.2020	7.05.2020	21.05.2020	23.06.2020
Retail & recreation					
-78%	-76%	-28%	-32%	-16%	1%
Parks					
-59%	-57%	25%	16%	47%	89%
Transit points, incl. railway/metro station, bus/taxi stop, motorway parking space, car rental					
-71%	-64%	-44%	-46%	-38%	-23%
Workplaces					
-36%	-48%	-38%	-32%	-27%	-21%
Residental					
13%	17%	10%	12%	9%	4%

Source: own elaboration based on data[14]

4. Transport Market in Poland

In the weakest months – April and May 2020 road and air transport was almost frozen. The situation in the passenger transport sector in 2020 per month is presented in Fig. 1.

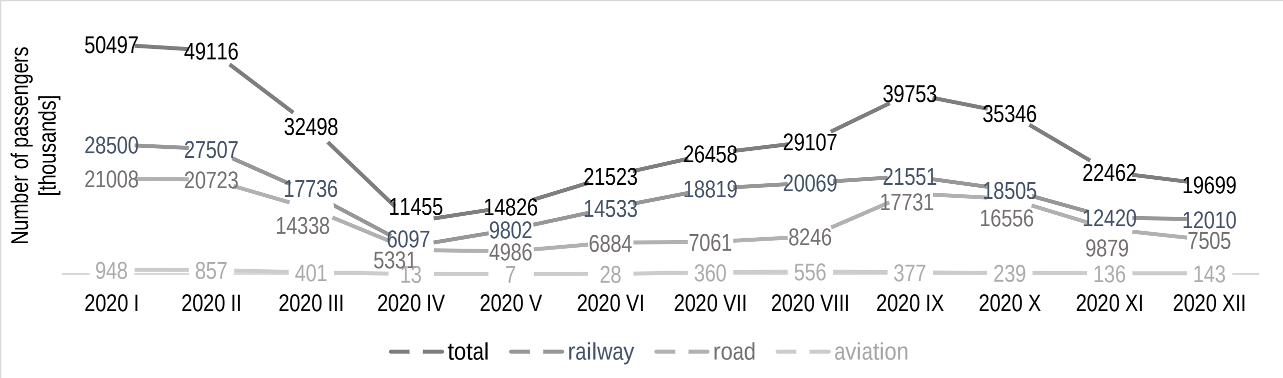

Fig. 1 Passenger transport in Poland by type of transport in 2020. Source: own elaboration based on data[15]

The passenger rail transport sector was severely affected and all Polish operators suffered as a result of the restrictions introduced and the stay-at-home order. The transport performance measured in the pass-km decreased in 2020 by 42.65% compared to 2019, and the operational performance measured in the train-km by 6.29%.

Throughout the year, changes in the average travel distance of passengers in rail transport were observed compared to 2019. The highest decrease– nearly 30% was in April 2020, when Poland was subject to the travel ban. Information on individual months is presented in Fig. 2.

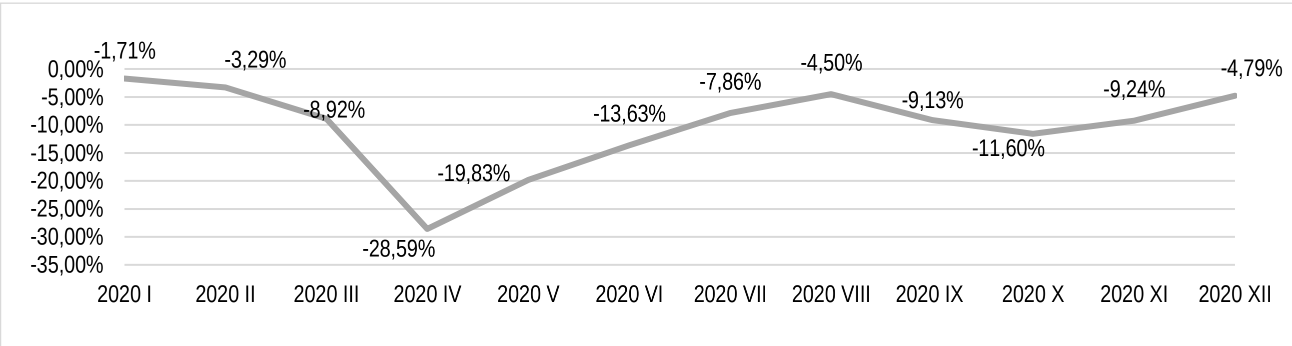

Fig. 2 Average distance changes of rail passengers 2020/2019. Source: own elaboration based on data[16]

The year 2020 brought changes not only in the number of passengers but also in market share. There has been a decline in the share of road and air transport and an increase in the share of rail in the transport market. Although the number of passengers traveling by trains decreased significantly, only exceeding 207 million, the market share of railways increased by 5% compared to the previous year, and by 10% compared to 2018. In the aviation sector the biggest losses were recorded, whose share, with the number of passengers of 4 million passengers, decreased by 2/3. The road sector lost 3% of the market compared to 2019 and 8% compared to 2018. River and sea transport, due to their insignificant share in the volume of transport in Poland, have been omitted in this section. Fig. 3 shows the changes in modal skehare in Polish passengers transport market in 2020 compared to 2018 and 2019.

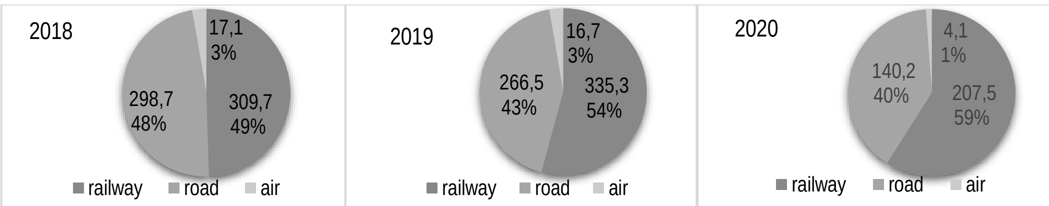

Fig. 3 Modal split in Poland in 2018-2020; number of passengers in M, Source: own elaboration based on data[15]

Freight transport has been less affected by the crisis than passenger transport. The disruption of logistics chains with the Asian countries that were first under the impact of the epidemic was already marked in January in sea and rail transport. The freight transport market was quite stable throughout the year 2020, although the transport volume was lower than in the previous year. The largest decrease in the transport volume was observed in April and May 2020 due to the strongest restrictions introduced in Poland as in the large number of countries worldwide alike.

The railways were characterized by a decrease in the transport of goods close to 20%. May was the worst month for road transport, when slightly more than 82% of the volumes of goods compering to the corresponding month of the previous year were transported. Maritime transport turned out to be the least stable transport sector, with the greatest fluctuations in the volume of the transported goods. In April, it was only 68% of the volume of the corresponding period in 2019. In

June and December 2020, the total transport volume exceeded by 10% the level of the corresponding months in 2019.

Fig. 4 shows the transport volumes by the type of transport in the subsequent months of 2020.

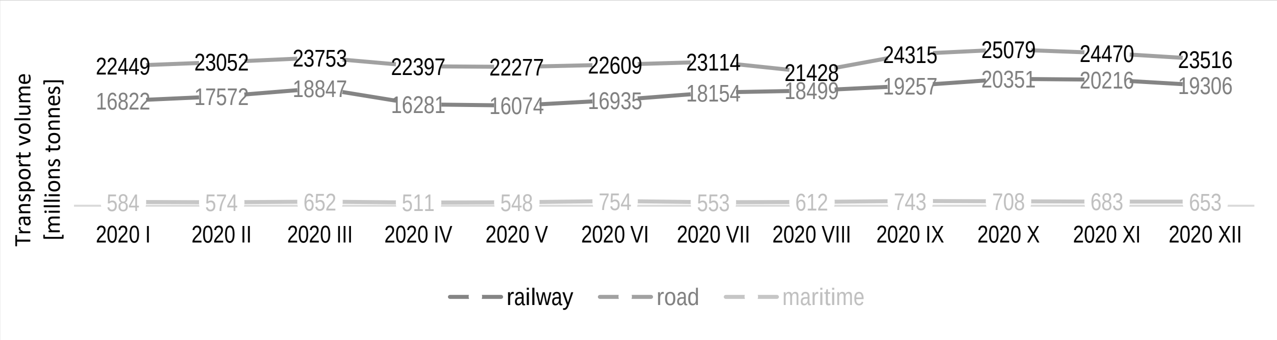

Fig. 4 Freight transport in Poland by type of transport in 2020, Source: own elaboration based on data[15]

Fig. 5 shows the changes in individual sectors in the following months of the year in relation to the corresponding months of 2019.

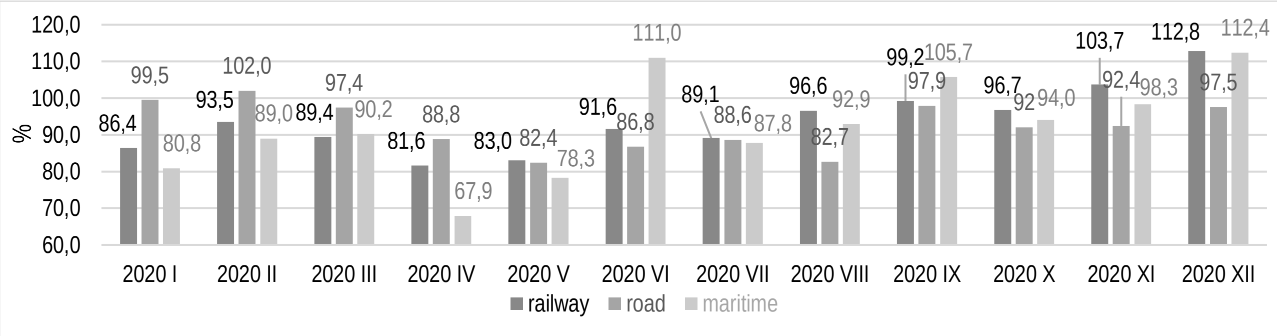

Fig. 5 Change of freight transport volume in relation to the corresponding period of the previous year Source: own eleboration based on[15]

The share in the freight transport market in 2020 did not change significantly. The largest share was retained by road: 55.2% (in 2019 - 55.6%), railway: 43.3% (in 2019 - 42.9%), maritime: 1.5% (in 2019 - 1.5%).

5. Conclusions

The COVID-19 crisis had a significant impact on the world economy particularly affecting transport. Mobility restrictions imposed on society due to the need to prevent the spread of the pathogen drastically reduced travel. This resulted in a significant limitation of passenger transport and shortened the length of the journey. The least resistant to the crisis turned out to be air transport, which was limited in the first place, and in the worst period - at the beginning of the epidemic, it almost was completely put on hold. In freight transport, the situation was much better. Rail freight transport turned out to be the most stable, in which the drops in the volume of transport in the first half of the year, with the exception of two months of the most restrictive limitations, remained globally at the level of 15%. In the second half of the year, the volumes if the freight transport globally approached the previous year's level and even exceeded it in November and December. Rail transport has shown features that make it relatively resistant to the pandemic crisis:

- good network of national and international connections;
- relatively low, compared to other modes of transport, the number of employees in relation to the amount of goods/people transported, which significantly reduces the possibility of transmitting infections;
- automation of operational processes.

Transport in Poland as shown in the article was affected to a similar extent by the crisis caused by the epidemic and related restrictions. Travel bans and the closure of many public activities resulted in a sharp and deep decline in transport, mainly in passenger transport. The extraordinary scale of this world crisis has needed the reaction of individual governments and international organizations. The necessity and the size of respective protective measures in Poland in relation to the economy, and in particular to transport, may be the subject of further analyzes.

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Special Features of the Vertical Loading on a Flat Car Transporting Containers with Elastic-Viscous Links in their Interaction Units

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Abstract

The research deals with the special features of determination of the vertical loads on the frame of a flat car transporting containers with elastic-viscous links in their interaction units. This modification will improve the strength values of a flat car through a decrease in the dynamic loading. The solution was substantiated with the modelling of the loading on a flat car. The maximum accelerations to a flat car were 5.4% lower than the accelerations in its typical diagram of interaction with the containers. The maximum stresses were by 7% lower than those in the typical structure. It should be noted that the measures proposed could improve the fatigue strength of the frame of a flat car by 5.2% in comparison with that of the typical structure.
The research will reduce the loading on the bearing structure of a flat car, and, consequently, the maintenance costs and the cost of storage of the freight transported, and contribute to the database of materials on design of promising flatcar structures.
KEY WORDS: *transport mechanics; flatcar; improved structure; vertical loading; strength of the frame; container transportation.*

1. Introduction

Higher efficiency of the transport industry determines the expediency of multimodal systems. And the promising among them is container transportation, including by flat cars. They are fitted with fixed or hinges fittings, i.e. units for fastening containers. The amount of containers transported by rail can be increased by the use of long-base flat cars. These cars are customized for simultaneous transportation of some containers, for example, four 1CC containers or two 1AA containers.

It should be noted that a longer flatcar frame causes the natural displacements of the bearing structures in the vertical plane. The cyclic nature of these displacements results in the accumulation of fatigue stresses and, consequently, crack development. Therefore, there is a need to repair the bearing structures of flat cars or withdraw them from the inventory fleet. Besides, such defects in operation endanger the safety of a flat car. It may also pose an ecological threat regarding freight transportation by rail. Therefore, there is a need to develop the methods aimed at lower loading on the frame of a long-base car.

2. Analysis of Publications

The issue of the determination of the loading on the construction of flat cars in operations and the measures for decreasing this loading was studied through the analysis of scientific publications.

Article [1] research with the issue of how deformations in the frame of a flat car can affect the strength. The authors used experimental methods of research, particularly, electric strain-gage testing. Strain gages were mounted on the most loaded zones of the structure calculated theoretically. They found the maximum loaded structural elements of a flat car; however, they did not consider any solutions of how to decrease stress state.

The special construction features of a long-base flat car are studied in [2]. The research presents the calculated of the stress state of a flat car during the main operational loads and the dynamic testing. The modelling of the strength of the flatcar frame for multimodal transportation is presented in [3]. The researchers determined the most loaded components of the flatcar structure during the main operational loads. It should be noted that the authors of these publications did not decisions any measures for decreasing the loading on the frame of the flat cars under study.

The peculiarities of the determination of the strength of a flat car are described in [4]. And the article presents the theoretical calculation and the testing of the stress. The engineering proposals taken at the creating stage of the car proved to be rather efficient; they authors also presented their substantiation. However, they did not analyze the effect of the structural peculiarities of the designed flat car on its fatigue strength.

The analysis of a new wagon structure for combined transportation is presented in [5]. The substantiation of the design solutions proposed was made through calculation of the loading of the wagon in ANSYS and ADAMS/Rail. It was found that the values of dynamics and strength under study did not exceed the allowable values. However, the researchers did not study the potential to decrease the stress state of the wagon construction in order to improve its fatigue strength.

The calculated of the stress state for a long-base car is presented in article [6]. The calculation was made for two loading variants, at which the maximum bending moments were obtained. The maximum stresses in the construction were calculated with the finite element method.

The issue of the possibility to apply the methods of theoretical and experimental research into the stress of the construction of long-base cars is studied in [7]. The article presents the calculation for the fatigue strength for the construction of cars.

It should be noted that the measures for obtaining better strength values in construction of flat cars were not proposed in the studies mentioned.

The use of flexible interactions in the construction of flat cars to ensure its better reliability under operational loads is substantiated in [8, 9]. The article presents the imitation models for determination of the loading on the construction of cars. However, the solutions proposed do not compensate the vertical loading on the construction of flat cars.

The analysis of literature makes it possible to conclude that there is a need to investigate the possibility to compensation the vertical loading on the construction of a flat car for better operational efficiency.

3. Purpose and Main Objectives of the Article

The objective of the article is to study of the vertical loading on a flat car transporting containers with elastic-viscous interactions in the units during bouncing oscillations. Tasks to achieve the objective:

– mathematical modelling of the dynamic loading of construction of a flat car; and
– stress calculation of the construction of a flat car.

4. The Main Material of the Article

The dynamic loading on construction of a flat car and, consequently, on the containers placed on it, can be compensated by means of introduction of elastic-viscous links in the interaction units And this decrease is achieved through transformation of the kinetic energy to the construction of a flat car from the containers during bouncing oscillations into the work of elastic-viscous friction forces occurring in the superstructures for container fittings.

This solution requires the mounting of fixed fittings on special superstructures (Fig. 1).

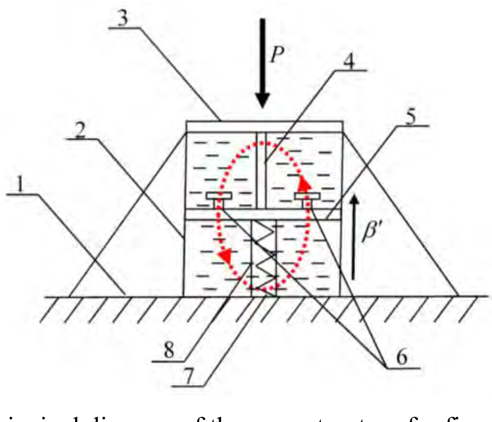

Fig. 1 Principal diagram of the superstructure for fixed fittings

In its middle superstructure 1 has cage *2* covered with plate *3* for mounting a container fitting. Plate *3* through shaft *4* interacts with piston *5*, which has two throttle valves *6*, inlet and exhaust. A viscous substance is placed above and under the piston. During bouncing oscillations the vertical loading P transfers to plate *3*, and from it – to piston *5*. Thus, piston *5* moves downward and the viscous substance flows through the open throttle valve from the hollow under the piston to the hollow over it. When piston *5* moves upwards the substance moves in the opposite direction. The return of piston *5* is fulfilled with a spring *7* located in the lower part of the cage in telescopic-type element *8*.

It should be noted that the use of the superstructures proposed can increase the tare weight of a flat car, therefore, their components can be made of composite materials that are lighter than steel and can ensure the required strength in operation.

The solution proposed was substantiated with the mathematical model of the loading for a car. The research was conducted by the example of a long-base car of Model 13-7024 (Ukraine), (Fig. 2 [10]).

Fig. 2 Flat car Model 13-7024

The construction of this car contains of the frame of two sub-frames in the end parts, two T-section welded side walls with variable rigidity consisting of 22-mm top and bottom sheets and 8-mm vertical sheets, two end beams, six intermediate beams, two additional intermediate beams, four T-section diagonal braces, which transfer the longitudinal loading from the center sills of the sub-frames to the side walls.

The calculation diagram of the car is shown in Fig. 3. The flat car consisted of three bodies – one bearing structure and two 18-100 bogies. It was also assumed that the two containers displaced symmetrically.

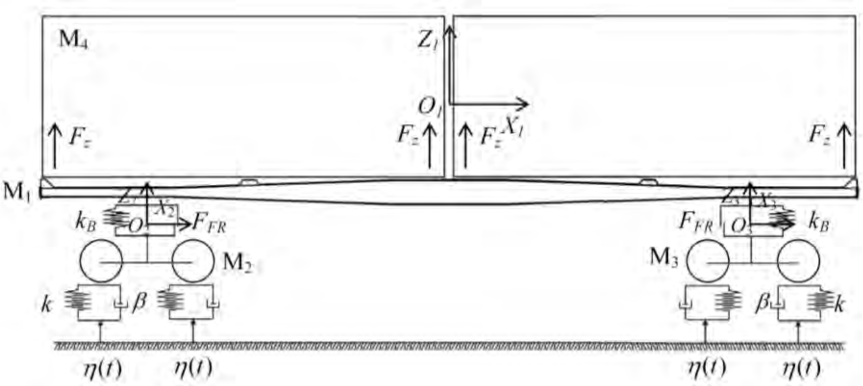

Fig. 3 Calculation diagram of a long-base car

The system of differential motion equations has the form:

$$\begin{cases} M_1 \cdot \ddot{q}_1 + N_{1,1} \cdot q_1 + N_{1,2} \cdot q_2 + N_{1,3} \cdot q_3 = -F_{FR} \cdot \left(sign\left(\dot{\delta}_1\right) + sign\left(\dot{\delta}_2\right) \right) - k'\left(y_1 - y_4\right) - \beta'\left(\dot{y}_1 - \dot{y}_4\right)_z; \\ M_2 \cdot \ddot{q}_2 + N_{2,1} \cdot q_1 + N_{2,2} \cdot q_2 + B_{2,2} \cdot \dot{q}_2 = F_{FR} \cdot sign\left(\dot{\delta}_1\right) + k\left(\eta(t) + \eta(t)\right) + \beta\left(\dot{\eta}(t) + \dot{\eta}(t)\right); \\ M_3 \cdot \ddot{q}_3 + N_{3,1} \cdot q_1 + N_{3,3} \cdot q_3 + B_{3,3} \cdot \dot{q}_3 = F_{FR} \cdot sign\left(\dot{\delta}_2\right) + k\left(\eta(t) + \eta(t)\right) + \beta\left(\dot{\eta}(t) + \dot{\eta}(t)\right); \\ M_4 \cdot \ddot{q}_4 = \left(-k'\left(y_1 - y_4\right) - \beta'\left(\dot{y}_1 - \dot{y}_4\right)\right) - M_4 \cdot g, \end{cases}$$

where M_1 – the mass of the construction of a long-base car; M_2, M_3 – the masses of running parts of the car; M_4 – the mass of the containers; N_{ij} – the elasticity characteristics; B_{ij} – the energy dissipation function; k – the rail rigidity; β – the damping factor; F_{FR} – the friction force in the in suspension of the running parts; δ_i – the deformation of the suspension; $\eta_i(t)$ – the rail irregularity; k' – the rigidity of the pullback spring; β' – the coefficient of viscous resistence of the substance in the cage.

Equation included that:

$Z_1 \sim q_1$ – the coordinate describing the bouncing of the frame of the flat car;

$Z_2 \sim q_2$ – the coordinate describing the bouncing of the first running part;

$Z_3 \sim q_3$ – the coordinate describing the bouncing of the second running part; and

$Z_4 \sim q_4$ – the coordinate describing the bouncing of a container.

The system of differential equations was solved with the method of variations for arbitrary constants. And the results obtained were tested in MathCad. The starting conditions were assumed to be zero [11-13]. The acceleration of the flat car was 2.61 m/s^2, which is 5.4% lower than the accelerations to a flat car with consideration of the typical diagram of interaction with the containers.

The acceleration obtained was used in the stress state calculation for the flatcar construction. Its spatial model was created in SolidWorks (Fig. 4). The stress state determination was made with the FEM in SolidWorks Simulation [14-16]. The calculation model takes into account the vertical load P_v to the bearing structure (Fig. 5), which consisted of the static and dynamic loadings calculated with the imitation model.

The continuum model of the bearing structure was formed with tetrahedrons [17, 18]. The model consisted of 58375 elements and 20219 units. Steel 09C2Cu with a yield stress of 345 MPa was chosen as the structural material [19, 20]. The model was fastened to the center plates. The von Mises criterion was used as the design criterion [21, 22].

The stress state of the construction of a flat car is presented in Fig. 6. The maximum stresses were arise in the central part of the frame – 147.1 MPa, which is 7% lower those in the basic design.

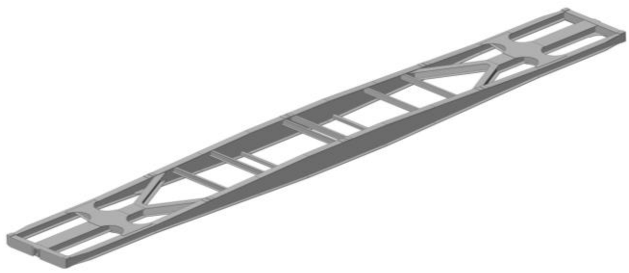

Fig. 4. Spatial model of construction of a flat car

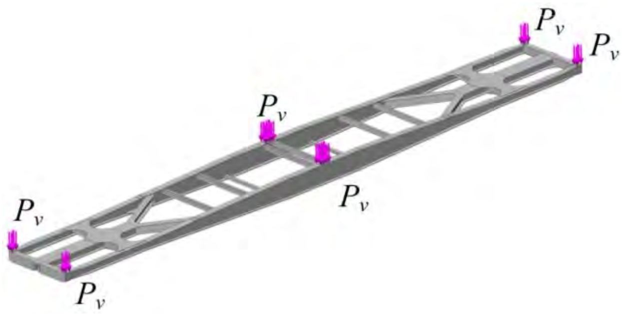

Fig. 5 Calculation diagram of a flat car

The static analysis of the construction of a flat car were use in the fatigue strength research. And it was found that the measures proposed would improve the fatigue strength of the construction by 5.2%. The results of the research were used for calculation of the biaxiality indicator of the construction of a car (Fig. 7).

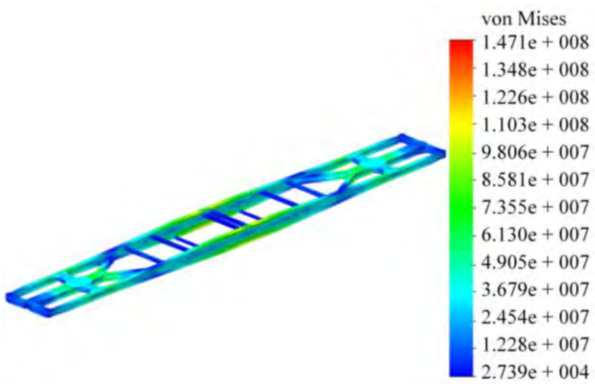

Fig. 6. Stress in the construction of a flat car

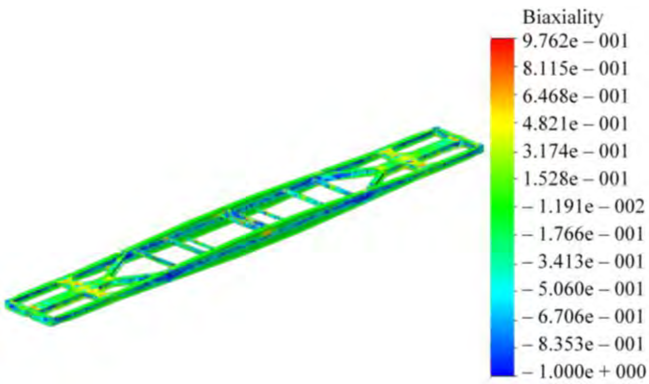

Fig. 7 Biaxiality indicator of the construction of a flat car

This indicator characterizes the ratio of the minimal stress in the bearing structure to its maximal value. Thus, the maximal indicator was recorded in the vertical sheets of the bolster beams.

5. Conclusions

The article deals with the imitation modelling of the loading on the construction of a flat car. It was found that the acceleration the flat car was 2.61 m/s^2, which was 5.4% lower than the accelerations on the typical flat car.

The research also included the strength determinate for the construction of a flat car. The maximum stresses were recorded in the middle part of the frame and amounted to 147.1 MPa which is 7% lower those in the basic design.

The results of the determination for the fatigue strength of the construction of a flat car demonstrated that the measures proposed would improve the fatigue strength by 5.2%.

The research will reduce the loading on the bearing structure of a flat car, and, consequently, the maintenance costs and the cost of storage of the freight transported, and contribute to the database of materials on design of promising flatcar structures.

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Rail Passenger Transport before and during Pandemic COVID-19 in Slovak Republic

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Abstract

Pandemic Covid-19 has influenced all sectors of the economy. Lockdown and other measures meant bankruptcy for many companies. Rail companies providing rail passenger services have a specific status because most services in rail passenger transport are provided as public service obligation (PSO), only some services are provided on a commercial basis. The paper deals with the comparison of rail passenger transport services in the train kilometers and passenger kilometers PSO and commercial services before and during the pandemic COVID-19. We researched the synergistic effect of the change in rail transport performances in terms of social costs.
KEY WORDS: *pandemic COVID-19, rail transport performances, passenger kilometers, train kilometers, economic effectiveness*

1. Introduction

The transport sector has been one of the sectors of the economy most affected by the COVID-19 memory after health care. Restrictive measures in each country were aimed at significantly reducing mobility during the peak in individual waves of the pandemic and the recommended Home Office and distance education for all, or some levels of education before, resp. at the peak of the pandemic. This has led to a significant reduction in mobility as such at the height of the pandemic and to an even greater use of individual car transport with a partial relaxation of the measures. Public transport carriers have disrupted some connections or introduced a weekend timetable during the working week. Often the reason was not measures as such (especially in the later stages of the pandemic) but problems with a lack of executive staff (e.g. bus drivers, train drivers) who also became ill with the corona virus.

Air transport is one of the most affected transport sectors, but rail passenger transport has also been hit hard by the pandemic. From the available statistics (e.g. OECD, EUROSTAT, national statistics) it can be seen that there has been a decrease in transport performance in passenger km. We researched how this reduction and whether it affected the transport performance in train kilometers and how it affected the economic efficiency of rail passenger transport in the Slovak Republic.

2. Literature Review

Almost immediately after the COVID-19 pandemic, the articles in scientific journals first dealt with the virus as such from a medical or biomedical point of view, and later the authors began to address the impact of the pandemic on various sectors of the economy. Public transport is one of the most disrupted sectors of the COVID-19 pandemic [10]. Right at the beginning of the pandemic countries around the world adopted various restrictions and policies to prevent the spread of the pandemic, which resulted in a sharp drop in the demand for transportation [19]. Based on extensive analyses of the survey results, Zhang et al. revealed the realities of lockdowns, restrictions of out-of-home activities and other physical distancing requirements, as well as modal shifts [18]. Rothengatter et al. [14] discussed the dual role of the transport sector in the Covid-19 pandemic: spreading the virus around the world and being most negatively impacted by the pandemic. Pandemic situation altered significantly the transport mode choices, having a strong negative impact on bus and shifting bus users towards private modes, both motorized and non-motorized [15]. The study Echaniz et al. showed similar results [8]. The results of their survey conducted in March 2020 in Spain showed that public transport was the most affected transport mode, with a considerable increase in the use of the bicycle and walking trips. At the same time, changes were observed in the behaviour of shopping trips, including a considerable decrease on the use of large supermarkets. The study from Germany also showed a preference for individual motoring over public passenger transport [9].

Many studies have researched passenger behavior and perceptions of various measures to prevent the spread of the virus in public transport. For example, Abdullah et al. researched measuring changes in travel behavior in a developing country (Pakistan) [1]. Their research showed that passengers put more priority on pandemic-related items such as infection concern, social distance, hand sanitizers' availability, and cleanliness, etc. Almlof et al. analyzed the propensity to stop travelling by public transport during COVID-19 for the holders of 1.8 million smart cards in Stockholm, Sweden, for the spring and autumn of 2020 [3]. Their results showed that socioeconomic status affect the change in behavior during the pandemic and that exposure to the virus is determined by citizens' socioeconomic class. Working from home has been the 'new normal' during the period of lockdown, except for essential services that require commuting. Hensher et al. developed a model to identify the incidence of working from home and what impact this could have on the amount of weekly one-way commuting trips by car and public transport [12].

The issue of the impact of the pandemic COVID-19 on the rail sector has also been examined by various authors in many countries. Tan and Ma researched whether commuters will take rail transit during the COVID-19 pandemic [16]. Their results showed that: occupation, commuting tools before the COVID-19 pandemic, walking time from residence to the nearest subway station, the possibility of being infected in private car and the possibility of being infected in public transport have significant influence on the commuters' choice of rail transit. Aghabayk et al. in their study investigated the effect of the spread of COVID-19 on crowding perception and crowding disutility in metro rail system of Tehran [2]. Dedik et al. analyzed the impact of the measures on passenger frequencies in 2020, examining the amount of their fall in individual months of the first half of the year 2020 on the long-distance route Bratislava–Žilina–Košice [7]. Gnap et al. dealt with the question [11]: is there any correlation between transport performance and infrastructure or investment in infrastructure in relation to the mentioned countries, and, if so, is there a connection between the selected countries where this correlation occurs? They stated that greater investment can also be expected in the construction of high-speed railways, given the decisions of some EU Member States not to resume national air transport where there is good railway infrastructure, even after the end of the COVID-19 pandemic. Tardivo et al. focused on examining the necessary steps in the rail sector will need to address to better continue to provide services throughout future crises, taking into account the environment [17]. From another point of view, Coppola and De Fabiis dealt with the issue of pandemics and rail transport [5]. They researched at assessing to what extent keeping a one-meter interpersonal distancing on-board trains is sustainable for public transport companies. Their outputs suggest the need for public subsidies in order for the railways undertakings to cope with revenue losses and, at the same time, to maintain service quality levels.

At present, it is necessary to research how the COVID-19 pandemic has affected passenger behavior, the economic performance of transport companies as well as the spending of public funds on public passenger transport. In this study, we will focus on how the pandemic affected rail transport performance under PSO and how it subsequently affected subsidies per unit of output.

3. Methodology and Data

Our first goal was to find out what effect the pandemic had on the performance of rail passenger transport. We therefore examined the performances in the individual months in the two years before the pandemic (years 2018 and 2019) and in the years of the pandemic (years 2020 and 2021). Due to the fact that transport performances in passenger kilometers were not available, we compared performances in train kilometers.

Our second aim was to find out how the COVID-19 pandemic affected rail passenger services under public service obligation (PSO) and open access services. We researched the development of rail transport performance in train kilometers which realized such as services under PSO separately for incumbent and others rail companies providing these kind of rail services. In this case, we took into account the longer period before the pandemic, from 2012 to 2019.

Finally, we examined the impact of the pandemic COVID-19 on economic efficiency of rail passenger transport. On the one hand, we found out how efficiency changed in relation to train kilometers, on the other hand, how a pandemic affected economic efficiency in terms of passenger kilometers. For train kilometers, we chose unit subsidies as an indicator, which we found out as follows:

$$E_{tkm} = \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} tkm_j}, \tag{1}$$

where E_{tkm} – effectiveness of subsides to train kilometers; S – total subsidies per year; i – rail companies providing the rail passenger services under PSO; n – number of undertakings providing rail passenger services under PSO; tkm – train kilometers realized under PSO

For economic efficiency in terms of passenger kilometers we chose subsidies too by the formula:

$$E_{pkm} = \frac{\sum_{i=1}^{n} S_i}{\sum_{j=1}^{m} pkm_i}, \tag{2}$$

where E_{pkm} – effectiveness of subsides to passenger kilometers; S – total subsidies per year; j – rail companies; m – number of undertakings providing rail passenger services; pkm – total passenger kilometers.

The data were obtained from the national statistical database DATAcube [6], data published by the Ministry of Transport and Construction of the Slovak Republic [13], from the Annual Reports of the Železničná poločnosť

Slovensko (incumbent in Slovak Republic) [4] and from the internal materials of the infrastructure manager of the Slovak Republic. We did not obtain transport performance in passenger kilometers in person for services provided under PSO and open access services. Therefore, we have used the transport performance of all carriers providing rail passenger transport services, regardless of whether they are services under PSO or open access.

4. Results and Discussion

The research examined the development of transport performance in train km in order to determine their change before and during the COVID-19 pandemic. Figure 1 shows the development of rail transport performances by months two years before the pandemic (blue color) and during the pandemic (red color).

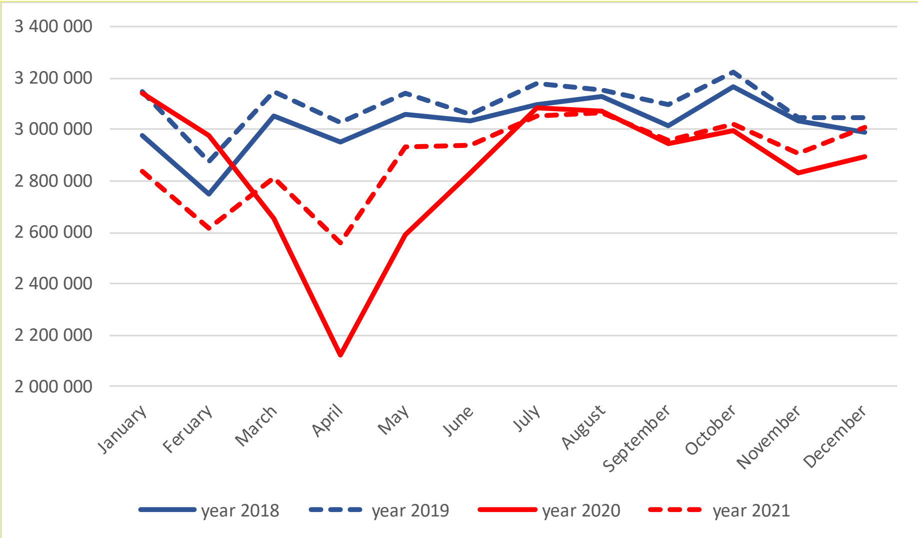

Fig. 1 Rail passenger transport performances in Slovak Republic. Source: authors by ZSR, 2022 [20]

As can be seen from Fig. 1 the most significant decrease in output in wolves occurred in the months when the most stringent measures were introduced. In April 2020, output in train kilometers decreased by 28.1 percentage points compared to April 2017.

Fig. 2 shows the development of rail transport performances of services performed as services under PSO compare to open access services.

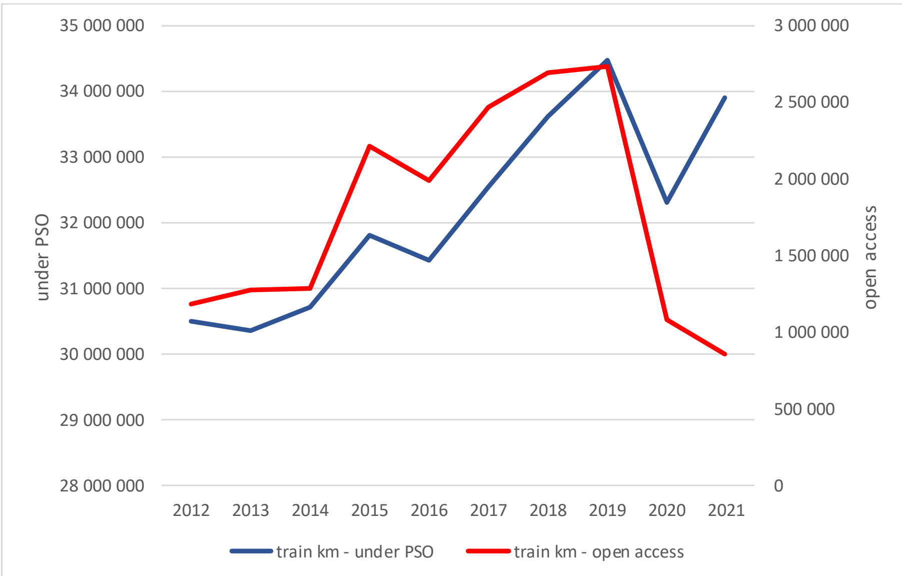

Fig. 2 Comparison of rail passenger transport performances realized under PSO and open access. Source: authors by ZSR, 2022 [20] and Ministry of transport and Construction of the Slovak Republic, 2022 [13]

Transport performances realized under PSO were provided by two carriers until 2020 - the national carrier ZSSK and the private carrier RegioJet. Since 2021 (timetable 2020/2021), only a national carrier has provided these services. As can be seen from Figure 2 pandemic COVID-19 caused mainly a reduction in transport performance realized as open access. The decrease in these outputs was almost 70% and did not even reach the level of 2012. The decline in services performed on the basis of PSO was caused mainly by the cancellation of some train connections and the introduction of Saturday's schedule at the time of the hard lockdown.

The COVID-19 pandemic also had a significant impact on the economic efficiency of all sectors of the economy. In the railway passenger transport sector, in addition to non-investment subsidies for the provision of services for voters, other funds were spent in connection with the purchase of disinfectants and the provision of other measures announced by the Ministry of Health. In Table 1 the transport performances and subsidies are described for incumbent and private operator.

Table 1

Transport performances under PSO and subsides in rail passenger transport companies

Year	Transport performances in train km		Subsidies in Euros	
	Incumbent	Private operator	Incumbent	Private operator
2012	29 357 991	1 014 783	228 639 078	5 658 030
2013	29 120 687	1 168 087	212 629 427	7 221 882
2014	29 594 953	1 196 838	214 105 453	7 223 002
2015	31 168 983	1 200 106	238 306 436	8 357 392
2016	31 418 066	1 202 350	243 951 075	8 416 569
2017	31 398 835	1 197 453	247 674 631	8 438 482
2018	32 347 206	1 207 859	263 096 793	8 663 603
2019	33 182 656	1 223 867	290 213 847	10 592 664
2020	31 935 006	1 128 536	333 861 753	11 408 004
2021	33 867 537	x	311 793 002	x

Source: Authors by Ministry of transport and Construction of the Slovak Republic. 2022 [13] and Annual Report of ZSSK, 2020 [4]

More than 97% of rail passenger transport services under PSO for the entire period under investigation were provided by incumbent, which logically results in significantly higher non-investment subsidies. Table 2 shows the comparison rail transport performances in passenger and train kilometers of the incumbent and the private operator.

Table 2

Total transport performances in rail passenger transport

Year	Total transport performances			
	in mil. passenger km		in thousand. train km	
	Incumbent	Private operators	Incumbent	Private operators
2012	2 413	46	30 491	1 067
2013	2 422	63	30 356	1 215
2014	2 503	80	30 724	1 351
2015	3 081	330	31 801	2 789
2016	3 194	401	31 438	3 170
2017	3 760	113	32 553	2 515
2018	3 815	100	33 618	2 636
2019	4 004	89	34 480	2 665
2020	2 118	62	32 310	1 836
2021	1 966	N/A	33 914	808

Source: authors by ZSR, 2022 [20] and DATAcube, 2022 [6]

Transport performances in rail passenger transport developed very differently. While incumbent's train kilometers performance in 2020 decreased by only 4% compared to 2019, passenger kilometer performance fell by more than 47%. If we compare the decrease in performance in train and passenger kilometers at a private operator, we can see that these performances decreased approximately the same, by about 31%. This is mainly due to the fact that the private operator provided rail passenger transport on one line (Bratislava - Komárno) and the Bratislava region had the least strict measures during the entire pandemic period. The second factor is that this track runs parallel to the road, which experienced significant congestion during peak time. The unfavorable development of passenger rail transport performance was reflected in a reduction in the efficiency of non-investment subsidies spent, as shown in Fig. 3. In 2021, the unit subsidy (per passenger kilometer) is not accurate due to the unavailability of data from private operators.

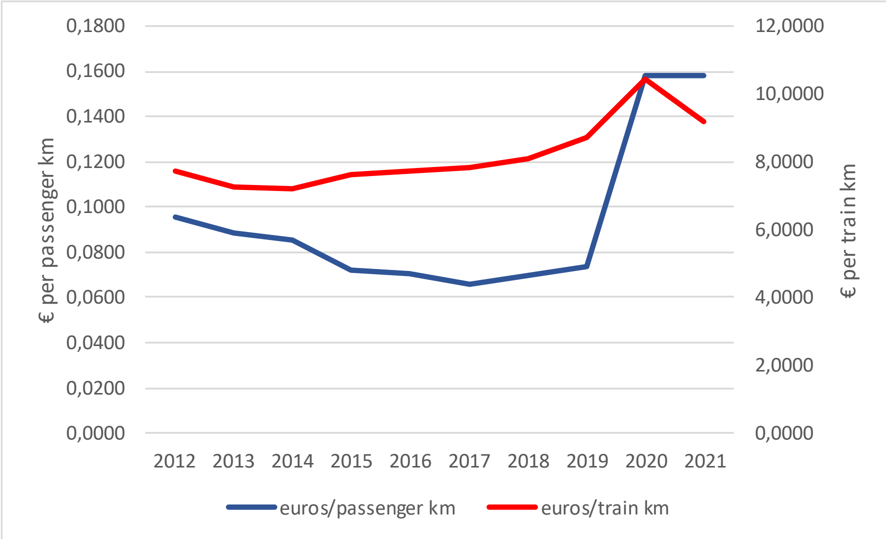

Fig. 3 Non-investment subsidies per passenger and train kilometer

As can be seen from Fig. 3 the increase in non-investment subsidies per train-kilometer is significantly smaller than per passenger-kilometer. Such a development was not only in the Slovak Republic, but also in the other European countries. It was caused on the one hand by the inability to flexibly (from day to day) disrupt and introduce train connections, on the other hand by introducing stricter measures during a bad epidemiological situation, e.g. determination of distances between passengers, etc.

5. Conclusions

The COVID-19 pandemic has brought a number of problems of a medical, economic, technological character, etc. Many countries initially introduced a total curfew due to the high mortality rate of patients who received the corona virus. In the later period, the measures were not so strict, although the decline in mobility by public transport was significant. Rail passenger transport is a sector that has been hit hard by the pandemic. Many international train connections were canceled for a long time, while domestic trains were less used at the beginning of the pandemic because people were afraid to travel by public transport. All this has led to less efficient use of state resources for rail transport.

We can assume that similar situations will occur to a greater or lesser extent in the future. Based on the experience of the previous period, it is necessary that measures be taken at the level of the government that will be effective, but at the same time will not place such a significant burden on the state budget. Likewise, railway companies will need to have processes in place to be able to adapt more effectively to the changes resulting from such situations.

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Improvement of Locomotive Dynamic Qualities by Investigating Effectiveness of the Rotary Hydraulic Vibration Dampers

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Abstract

The article proposes a method for modeling the dynamic processes of a rotary vibration damper, which makes it possible to investigate the influence of various factors on its performance. Mathematical modeling of the damping process made it possible to study changes in the power characteristics of a rotary hydraulic damper depending on the size of the gap between the surfaces that perform reciprocating rotational movements, on the frequency and amplitude of oscillations, as well as on the properties of the working fluid, which will make it possible to adjust the performance parameters of the absorber in order to increase its efficiency.
KEY WORDS: *rolling stock, suspension damping element, rotary hydraulic vibration damper*.

1. Introduction

One of the directions for the development of the transport network in Ukraine is the transition to high-speed ground transport. The increase in the speed of vehicles entails increase in the requirements for ensuring the safety and efficiency of its use.

Theoretical studies and experimental data show that because of the tightening of requirements for the traction and braking qualities of locomotives with an increase in travel speeds, it is necessary to improve the spring suspension of the 1st stage in terms of increasing the efficiency of vibration damping.

On modern rolling stock, one of the main damping elements of the suspension, which provide damping of vibrations of the body and wheels, are hydraulic vibration dampers [1-3]. The main purpose of using these vibration dampers is to ensure a smooth increase in the resistance force with an increase in the suspension deformation rate and limit the maximum force when certain speeds are reached both in the compression and rebound strokes, since hydraulic dampers experience heavy loads up to 90-110 kN (rod speed 1,5 m/s) and require constructive measures to protect them (their service life does not exceed 100,000 km) [2].

Analysis of the available studies [3-7] shows that the problem of damping efficiency should be solved on the basis of an integrated approach, one of the components of which is the study of the influence of various factors on the performance of vibration dampers in order to increase their efficiency.

One of the directions for solving the problem of creating vibration dampers can be hydraulic viscous friction dampers of a rotational type. In these absorbers [8], the mechanical energy of vibrations is converted into thermal energy due to the occurrence of viscous friction forces in the fluid that fills the gaps between the surfaces, which perform reciprocating rotational movements.

To date, quite a lot of designs of rotary hydraulic vibration dampers have been developed and studied. Rotary hydraulic vibration dampers are known, which can be attributed to uncontrolled dampers, since the possibility of regulating their performance is only at the time of design creation [9, 10].

The disadvantage of these devices is the inability to change the moment of friction of a viscous working fluid placed in the body of the vibration damper, the low efficiency of damping vibrations and shocks in different temperature ranges, along different sections of the track and at different dynamic loads and speeds due to the small volume of the working fluid, the absence regulation of the moment of sliding friction of the working medium placed between the rotor shaft and the housing, which reduces the efficiency of the rotary hydraulic vibration damper of the spring suspension of the locomotive when changing speed.

The aim to obtain the required energy intensity of the damper and increase its efficiency in various temperature ranges, when rolling stock moves along different sections of the track, at various dynamic loads and speeds, has led to the creation of controlled dampers, in which it is possible to control the damping characteristics in the process of train movement. In this design, the absorber's energy capacity depends on the viscosity and density of the liquid, the gap between the plates, the microgeometry of the working surfaces, and the contact area between the liquid and the rotating parts. A change in the above mentioned parameters during its operation can also be the control function of the absorber.

A representative of controlled hydraulic vibration dampers of the rotary type is a damper, in which an inductance coil is fixed on the body, acting on the magnetic fluid used as a viscous working fluid [11, 12]. This solution allows you to change the friction moment that prevents the rotation of the rotor, depending on the applied axial force to this device from the shock-absorbing object, by inducing an electric field of the required strength, under the influence of which the magnetic fluid changes its viscosity, providing the optimal value of the moment of viscous friction forces.

It is especially necessary to note the nonlinear relationship between the viscosity of the magnetic fluid and the field strength. This property of the working fluid makes it possible to easily adjust its characteristics during operation of the vibration damper by changing the parameters of the generated magnetic field. Through the use of controllable vibration dampers, it is possible to obtain improved driving performance in relatively unimportant track conditions.

However, the greater the speed of the vehicle or the worse the condition of the track, the greater the amplitude of movement, the work of friction forces and resistance to movement, the higher the temperature of the working fluid, which leads to a change in its viscosity, resulting in a decrease in the friction force of the fluid passing through the gaps.

Therefore, the study of the influence of various factors on the performance of rotary vibration dampers in order to increase their efficiency is important scientific problem.

In this regard, the purpose of the article is to create a methodology for modeling the dynamic processes of a rotary vibration damper, which will make it possible to study the influence of various factors on its performance, which will make it possible to effectively control its damping properties.

2. Research Results

To determine the work for the oscillation period of the simplest coaxial-cylindrical damper, consisting of one movable and one fixed surface, the gap between which is filled with Newtonian and non-Newtonian fluid.

Let the cylinder of radius R (Fig. 1) with generatrix length H separated by a gap filled with Newtonian fluid from a stationary outer concentrically located surface, moves reciprocally and rotationally relative to the latter. The perturbation to the movable cylinder is transmitted from the object performing harmonic reciprocating movements by a crank mechanism with a crank length r.

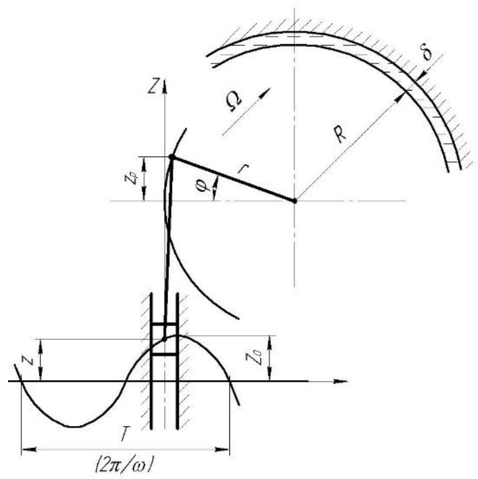

Fig. 1 Scheme for calculating the work of viscous friction forces with coaxial working surfaces

Moment of external force required for uniform rotation of the cylinder with angular velocity Ω:

$$M_H = F\tau R = 2\pi H \nu\rho\Omega \frac{R^3}{\delta}, \tag{1}$$

where $F = 2\pi RH$ – «friction» surface area, m^2; τ – shear stress in the liquid layer, kg/m ^{2}:

$$\tau = \nu\rho\Omega \frac{R}{\delta}. \tag{2}$$

Empirical dependencies of effective viscosity ν organosilicon compositions, which are the basis for magnetic suspension, are equal to:

– for high viscosity polymethylsiloxane fluid (PDMSF):

$$\nu = \frac{\nu_0}{\sqrt{1+k_1 D}}; \tag{3}$$

– for rubber solutions in low-viscosity PDMSF:

$$\nu = \frac{\nu_0}{1+k_2 D}, \tag{4}$$

where H, R are width and radius of cylindrical coaxial surfaces, m; δ is width of the gap separating movable and fixed surfaces, m; ν_0 is kinematic viscosity of the working fluid at a shear rate close to zero, cm^2/s; ρ is liquid density, kg/m^3; $D = \frac{V}{\delta}$ is shear rate 1/s, where V is linear velocity of the relative movement of the movable and fixed surfaces, m/s.

The recommended values of the empirical coefficients are $k_1 = 2,4 \cdot 10^{-5}\nu_0$, s and $k_2 = 0,25 \cdot 10^{-5}\nu_0$, s.

Considering it fair that the volume of a colloid is equal to the sum of the volumes of its constituent parts, the authors of [13] propose an expression for determining the colloid density:

$$\rho = \rho_s c_s + \rho_a \left(c_v - c_s\right) + \rho_f \left(1 - c_v\right), \tag{5}$$

where ρ_s, ρ_a, ρ_f are density, respectively, of the solid phase, surfactant and carrier liquid (base).

For liquids based on hydrocarbons and mineral oils, in which oleic acid plays the role of a stabilizer, the densities ρ_a and ρ_f are very close and amount to about 900 kg/m^3. In this case, expression (5) is simplified:

$$\rho = \rho_s c_s + \rho_f \left(1 - c_s\right). \tag{6}$$

The papers [13, 14] present the results of studying the properties of magnetic fluids. Dependences for finding the viscosity of magnetic fluids are shown. So, at a low concentration of solid particles in the absence of a magnetic field, the viscosity is estimated by the Einstein's formula:

$$\eta = \eta_0 \left(1 + k c_v\right), \tag{7}$$

where η and η_0 are viscosities, respectively, of the system and the liquid base; c_v is volume fraction of particles; k is coefficient (for spherical particles k = 2,5 for prolates with ratio 1:5 k = 6,0).

At a relatively high concentration ($c_v \geq 0{,}1$) to evaluate the effective viscosity, the formulas are used:

$$\eta = \eta_0 / \left(1 + a c_v + b c_v^2\right), \tag{8}$$

where $a = -2{,}5$; $b = \left(2{,}5 c_v^* - 1\right) / \left(c_v^*\right)^2$ (c_v^* – limiting volume fraction of particles in close packing, when the system loses fluidity).

In addition, the Vend formula is known:

$$\eta = \eta \exp\left[\left(2{,}5 c_v + 2{,}7 c_v^2\right) / \left(1 - 0{,}609 c_v\right)\right]. \tag{9}$$

When applying a magnetic field $\omega_g < \dot{\gamma}$ and in the limit when the particle is oriented along the field lines $\omega_g = 0$, and the moment of friction forces is maximum. The increase in viscosity due to the orientation of the particles is found by the formula:

$$\eta_r = 1{,}5 \eta_0 c_v \frac{\xi - th\xi}{\xi + th\xi} \sin^2 \alpha, \tag{10}$$

where ξ is argument in Langevin function; α is the angle between the vectors of the field strength and the fluid shear rate.

Then the effective viscosity of the magnetic fluid:

$$\eta_{ef} = \eta + \eta_r . \tag{11}$$

Elementary work of the moment *M* of force of viscous friction *dQ* when turning the radius *r* crank through a small angle $d\phi$, rad:

$$dQ_H = Md\phi . \tag{12}$$

In the absence of movement of the damped object (Fig. 1), the damper rotation angle is found from the relation:

$$\phi = arctg\frac{E}{z} + arctg\frac{S^2 - E^2 - r^2 - z^2}{2\cdot r\sqrt{z^2+E^2}} . \tag{13}$$

With sufficient accuracy for practical calculations, the determination of the angle of rotation ϕ of crank *r* can be made according to the formula:

$$\phi = \arcsin\frac{z}{r} . \tag{14}$$

In this case, for a specific ratio of the dimensions of the drive mechanism close to the real one, the difference in the calculation of the angles ϕ according to formulas (13) and (14) does not exceed 1,1%.

The angular velocity of rotation of the rotor can be expressed by the following formula:

$$\Omega = \dot{\phi} = \frac{d\phi}{dt} = \frac{V}{r} = \frac{\dot{z}}{r} = \frac{z_0\omega\cos\omega t}{r} , \tag{15}$$

where z_0, ω is amplitude value and angular frequency of oscillations of the damped object, cm, 1/s; *V* is linear speed of the moving surface, m/s.

The work of viscous friction forces for 1/4 of the oscillation period:

$$\frac{1}{4}Q_H = \int_0^{\frac{\pi}{2}\omega} Md\phi = \int_0^{\frac{\pi}{2}\omega} 2\pi H\nu\rho\frac{R^3}{\delta}\cdot\frac{z_0\omega c\cos\omega t}{r}\cdot\frac{z_0\omega\cos\omega t}{r}dt .$$

Considering $dt = \frac{1}{\omega}d(\omega t)$,

$$\frac{1}{4}Q_H = \frac{2\pi H\nu\rho R^3 z_0{}^2\omega}{\delta\cdot r^2}\int_0^{\frac{\pi}{2}}\cos^2\omega t d\left(\omega t\right) . \tag{16}$$

The integral included in expression (16) is tabular, and for the full period of oscillations the integral is equal to π. Then the work of friction forces for the full period is:

$$Q_H = \frac{2\pi^2 H\nu\rho R^3 z_0{}^2\omega}{\delta\cdot r^2} . \tag{17}$$

Expression (17) will be written as:

$$Q_H = \pi\left(\frac{2\pi H\nu\rho R^3}{\delta\cdot r^2}\right)\cdot\left(z_0\omega\right)\cdot\left(z_0\right) , \tag{18}$$

where the expression in the first brackets is the vibration damper parameter, i.e.:

$$\beta_H = \frac{2\pi H\nu\rho R^3}{\delta\cdot r^2} . \tag{19}$$

It is known that an expression of the form $A = \pi ab$ is the area of an ellipse with semiaxes *a* and *b*.

In our case, formula (17) can be written as:

$$Q_H = \pi\left(2\pi H\nu\rho\frac{R^3}{\delta\cdot r^2}z_0\omega\right)(\omega), \tag{21}$$

where $P_H = 2\pi H\nu\rho\dfrac{R^3}{\delta\cdot r^2}z_0\omega$ is the maximum value of the viscous friction force for the oscillation period, kg.

So, the value of the damper parameter with Newtonian fluid is found from expression (19), and the values of the dissipative force and the work of this force over the period of oscillations are found from the formulas:

$$P_H = \beta V = \beta\, z_0\omega\,; \tag{21}$$

$$Q = \pi\beta V z_0 = \pi\ \beta\ z_0{}^2\omega\,. \tag{22}$$

The parameters of an absorber with a non-Newtonian fluid are calculated in a similar way, the dependence of the effective viscosity of which on the shear rate is described by expression (4).

The proposed method was used to calculate the power characteristics of a «six-surface» rotary vibration damper with a magnetic fluid made on the basis of PDMSF used as a working fluid. The calculation takes into account only coaxial cylindrical gaps. Full values of the power characteristics of the absorber parameter , the maximum value of the dissipative force P_0 and work Q this force (due to unaccounted for end working clearances) will be greater than those obtained by 5-6% [15].

The calculation results are presented in the form of graphical dependences of power characteristics (β, P_0, Q) of absorber on Figs. 2-6 with frequency f = 1,7 Hz and amplitude of oscillations of the bolster structure z_0 = 2,5 sm.

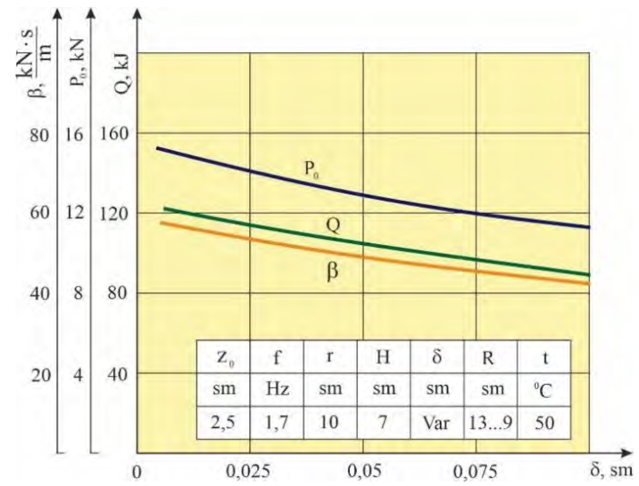

Fig. 2 The dependence of the power characteristics of the absorber depending on the size of the gap δ

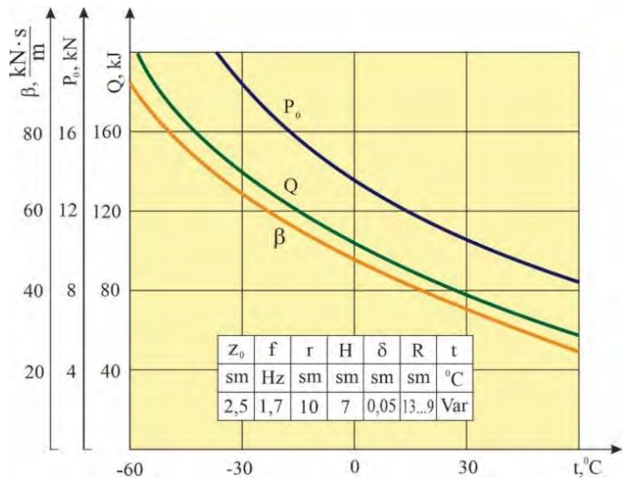

Fig. 3 The dependence of the power characteristics of the absorber depending on working fluid $t^\circ C$

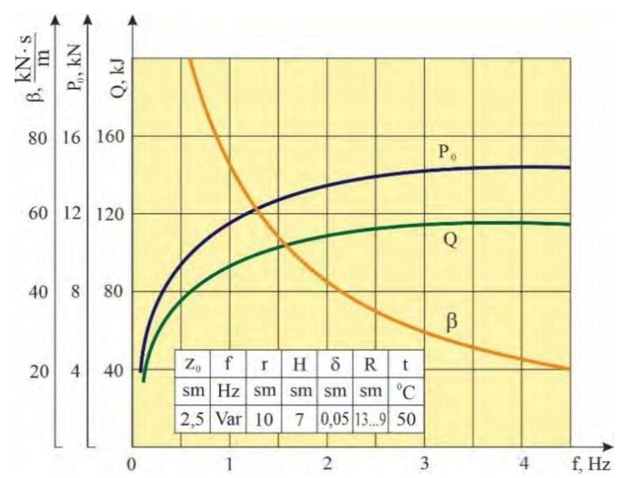

Fig. 4 The dependence of the power characteristics of the absorber depending on the oscillation frequency f

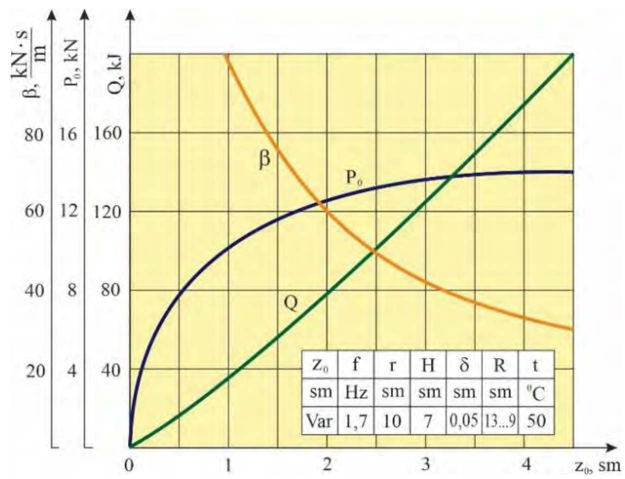

Fig. 5 The dependence of the power characteristics of the absorber depending on the amplitude of oscillations z_0

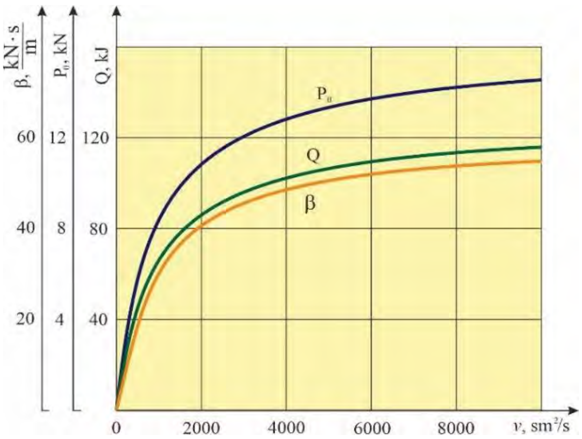

Fig. 6 Dependence of absorber power characteristics on viscosity ν

3. Conclusions

The analysis of damping suspension elements use on high-speed rolling stock of ground transport showed that controlled rotary hydraulic vibration dampers are the most effective.

Mathematical modeling of the damping process made it possible to study changes in the power characteristics of a rotary hydraulic damper depending on the size of the gap between the surfaces that perform reciprocating rotational movements, on the frequency and amplitude of oscillations, as well as on the properties of the working fluid, which will make it possible to adjust the performance parameters of the absorber in order to increase its efficiency.

Acknowledgement

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Co-Modality as a Tool for Improvement of Public Transport

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Abstract

The constantly increasing passengers' requirements on the quality of passenger transport services are forcing the authorities and public transport providers to develop and improve various solutions how to keep at least partially competitiveness of public transport with private car mobility. This article was financially supported by the European Union's Horizon 2020 research and innovation programme. The article contains the results from the ongoing Ride2Rail project and describes the benefits of the co-modality implementation through which door-to-door mobility will be reached, and it will contribute to the improvement of the quality of public transport. The article aims to analyse, propose, and evaluate the possibilities of integration of co-modality within public transport and its gained benefits and expected impacts on the involved stakeholders.
KEY WORDS: *public transport; co-modality; passengers' requirements*

1. Introduction

The changing of human behavior caused by worldwide globalization is reflected in their traveler habits. The jobs in rural areas are on the decline and there is a boom in job opportunities in big cities and it causes the increasing growth of big cities. People try to move closer to cities offering many job opportunities, which increases the attractiveness of the city and the cost of living there. Many residents cannot afford to pay such expensive rents, so they choose to live in rural areas around the large cities from which residents are forced to daily commute to work. Public transport is not as available there as in the large cities, therefore commuters prefer to use private cars to get to work. Commuters often use private cars on their own without any additional passengers. Statistics included in the Ride2Rail project shows that car occupancy rate for commuting trips in European countries is around 1,1 person per vehicle [6]. These commuters' travel habits have a negative impact on road traffic conditions, urban parking policy and increase the production of greenhouse gases. It is necessary to change these long-standing unsustainable travel habits [5]. One way in which these habits could be changed is co-modality. Co-modality encourages travelers to use public transport in collaboration with shared mobility for commuting from rural areas to urban areas, thanks to the increasing availability of public transport [14]. The main goals of co-modality are to connect all transport modes into the one, unified network system, to make the public transport more available and to decrease the production of green gas emission by transport. This concept will ensure the sustainability and effectiveness of all transport modes [12]. The possible way how to achieve the co-modality goals is to use a co-modal approach. Co-modal approach focuses on a global approach to transport where the combination of different transport modes is ensured. It does not take care about the negatives of transport modes, but it tries to find and use optimal and rational combinations of transport modes [14]. Public transport becomes more available for end users, which will decrease the number of private cars on the roads mainly in city centers. It also helps to cover the first and last mile and the closely related door-to-door mobility. One of the possible solutions, how to reach co-modality, is to integrate the shared mobility into the public transport [8, 9].

2. Ride2Rail Project Goals

Ride2Rail project partners tried to create the intelligent framework which allows to combine the shared mobility (ride sharing) and public transport. This solution supports the co-modal approach, and it should be used in low demand areas from which the travelers commute to bigger cities. Ride sharing is perceived as an effective and flexible feeder for high-capacity transport modes (bus, rails, etc.). Co-modal approach is going to be tested in a diverse urban and rural context in 4 demo sites [6].

3. Literature Review

The authors of article [13] compared the energy consumption between railway and passenger car transport. Particularly this article compared energy consumption on 1 person-kilometer in simulated condition between diesel train unit 813-913 and diesel and gasoline cars. Evaluation of article shows that the passenger cars can be also very effective in energy consumption, but mainly when the car is highly occupied (4 or more passenger in the car) also sometimes low occupied public transport vehicles should be greener-less than low occupied passengers' cars.

Author of the final thesis [8] described the factors that can influence the travelers during their selection of the modes of transport. The factors are divided into two group. First group is formed by economic criteria (acceptable price, multimodal travel ticket, comparison of cost of transports between different modes). The second group is formed by non-economic criteria (availably, quality of information and booking systems, travel time, number of transfers, safety, quality of transport means, environmental aspects).

With those articles is closely related the articles [3] and [7] where is the importance of the information provided to users during the trip planning described. The article also explains importance of mobile application which contains all relevant data in one place can make travelling by public transport more attractive. The smart mobile application could encourage travelers to use public transport if it contains all required and important data. The article contains description of Travel Companion application. Ride2Rail project deals with this Travel Companion application and it try to find rational solution how to solve upper mention issues (low occupancy of all means of transport, implementation of co-modality, door-to-door mobility transport solution, necessary data for user in one place). One of the Ride2Rail project goals is to make mobile application allowing to connect the ride sharing and public transport (ride sharing is a feeder for high-capacity transport modes) and to provide all relevant information for travelers. Offers generated by Travel Companion application contains information for travelers about travel solutions, prices, environmental factors of selected transport solutions and many more. Beside this, the application also allows traveler to share their rides with other travelers as complementary for public transport. This solution helps to make the transport more sustainable and ecological friendly [6, 10].

4. Implementation of Co-Modality into the Selected Region

Proposed and created solution of Ride2Rail project could be implemented across whole EU even globally across the countries of the whole World. For evaluation of the solution of Ride2Rail project was selected the region of Banská Bystrica located in Slovak Republic. The most famous center of this region is county city Banská Bystrica, which offers many job and educations opportunities. The population is around 110 631 and is made up mostly of people in working age and this proportion is equal to a national level. However, this population group is expected to develop unfavorably, as the region is made up of a larger group of post-working age population than pre-working age population. There are 135 inhabitants of post-working age for every 100 inhabitants of pre-working age. 30% of mentioned population of this region live outside of Banská Bystrica, whom majority have to daily commute to this city. The Fig. 1 contains the distribution of population within the Banská Bystrica region and the Fig. 2 contains the distribution of job opportunities [8].

One of the most important visions of integration of ridesharing within the public transport is the expansion of mobility, in which ridesharing will create a so-called feeder for public transport, especially in areas with insufficient public transport with low number of provided services and from these areas there are no direct services to the larger cities and there is a need to transfer many times [2].

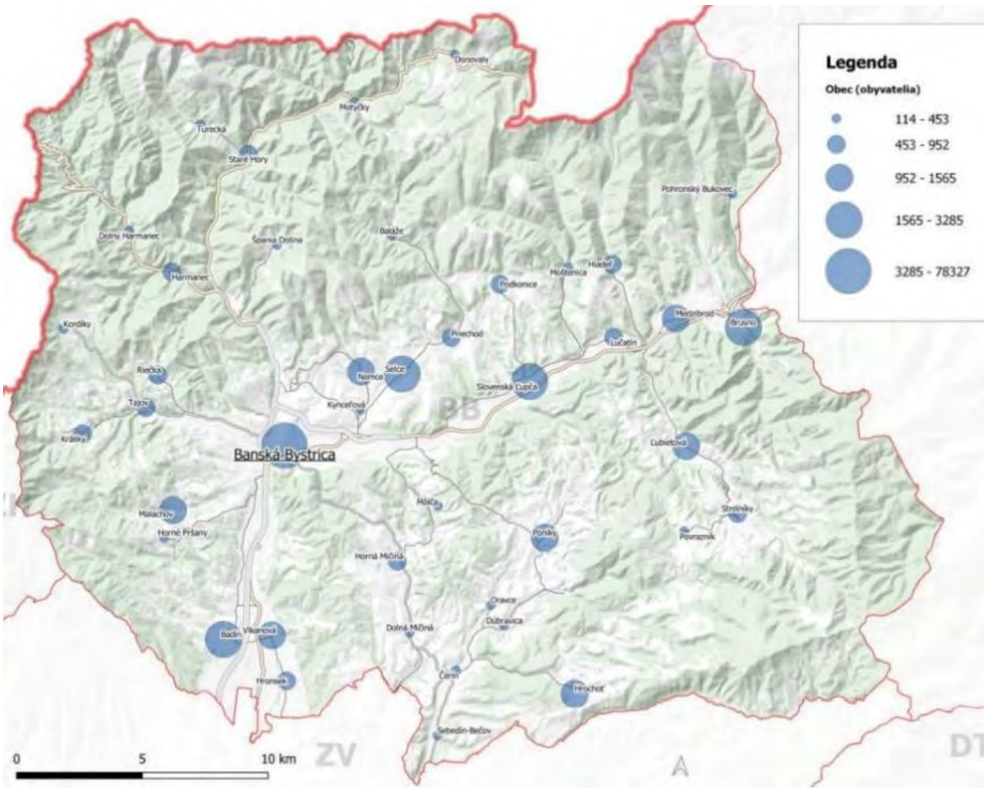

Fig. 1 Distribution of population within the Banská Bystrica region

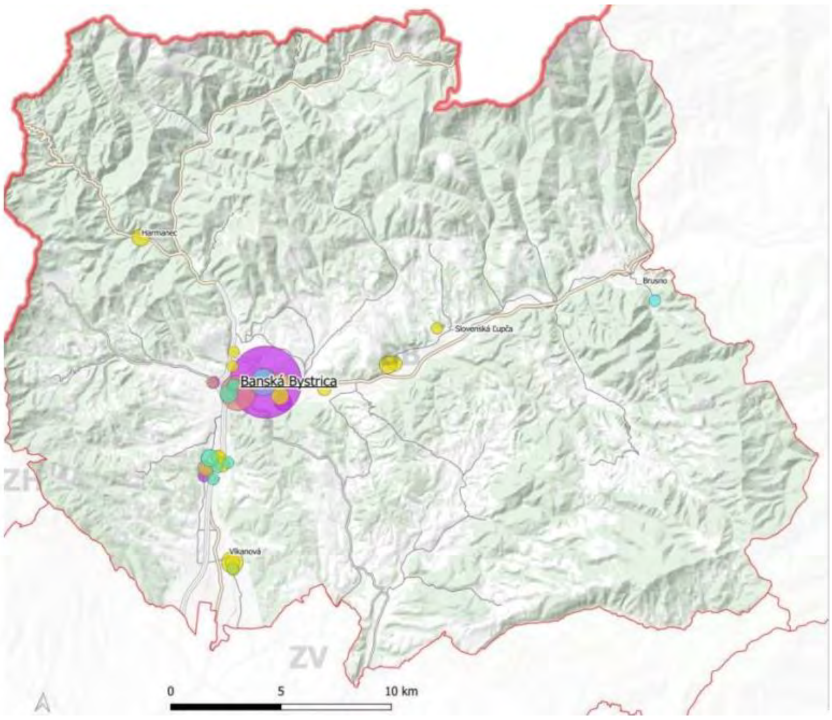

Fig. 2 Distribution of job opportunities within the Banská Bystrica region

The best way to integrate private cars into the public transport is by using the solution proposed in Ride2Rail, where the driver provides a shared ride to the nearest stop of the high-capacity transport lines and then all travellers (if any) complete their journey by public transport [4]. This method is acceptable within the BBSK because the intervals of the high-capacity transport lines are sufficient between each line during both peak and off-peak periods to transport passengers to and from that point throughout the day, while the complementary lines do not run at such frequent intervals. This way of using ride sharing also serves to cover the first and last mile. Ride sharing should ensure a reduction in transport distances by private cars, there will be a reduction of private cars on the roads, also a positive impact on urban parking can be expected, the occupation of all means of transport, including private cars, will increase. In terms of environmental impact, the unit CO2 production from transport will be reduced [11]. Last but not least, public transport accessibility will be increased. Fig. 3 and Fig. 4 compare the isochrone distance of passengers to the railway stations, which are perceived as high-capacity lines in the Banská Bystrica region. Fig. 3 shows the 10 minutes commuting distance by walking, and Fig. 4. shows 10 minutes commuting distance by private car. It is clear from this representation that rail transport (among other things), by integrating individual modes of transport, becomes much more accessible also to the inhabitants of remote villages who would have no way of reaching these stations without the use of the private car, unless there is sufficient passenger transport operating in their territory [8].

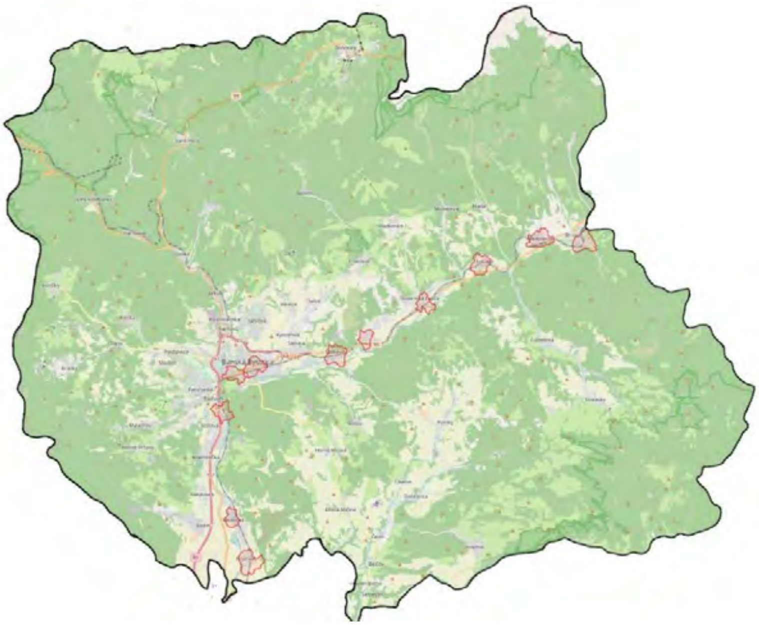

Fig. 3 Isochronic display of the commuting distance to railway stations by walk

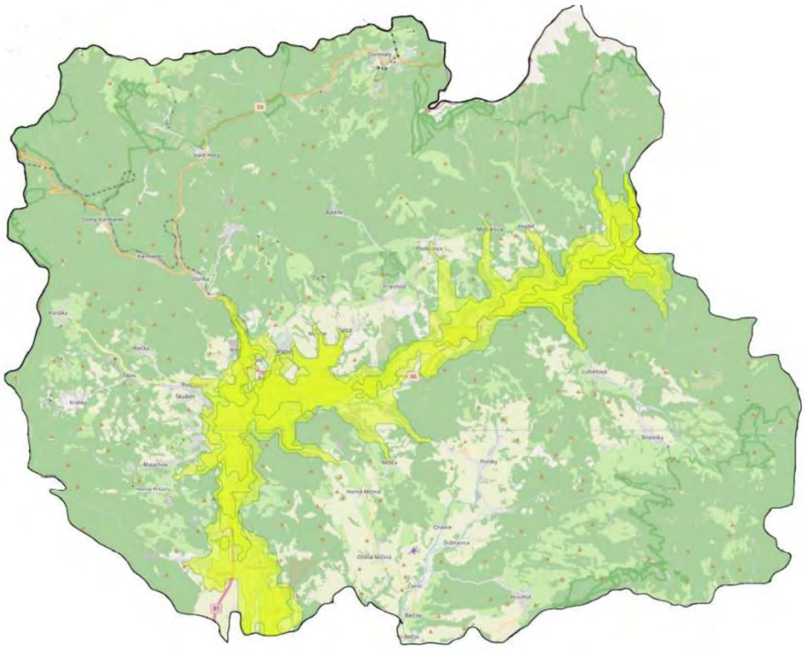

Fig. 4 Isochronic display of the commuting distance to railway stations by car

The Travel Companion app will help users to find a comprehensive door-to-door travel solution and will also allow them to use individual modes of transport (ride sharing), which will be linked to public transport (specially to cover the first and last mile) and this may increase the interest of the traveller to travel at least partly by public transport. From the isochrones shown in figures it was found that the use of the private car makes rail stations and stops much more accessible to the surrounding villages and their inhabitants compared to walking to the same public transport stops.

The general impacts of linking public transport with ride sharing and using of Travel Companion application are related to:

- Increased system efficiency - with sufficient information and route options, the overall efficiency of travel can be increased. This applies to route selection, but also to the choice of individual modes of transport [1];
- Congestion reduction - when reducing congestion, it is also important to bear in mind that there are financial savings, which consist mainly of time spent in congestion, increased transport costs and carbon charges [9];
- Improvement of air quality - reduction of CO2 emissions, which occurs with the reduction single occupied car rides [15];
- Increasing social cohesion - by transport users swapping the single car rides to public transport on at least part of the journey and by ride sharing the space for people to meet is created from different social backgrounds, which can have a positive impact on social cohesion in society [8],
- improving access to services for people with low incomes – the ride sharing opens the door for cost sharing, which can potentially improve the accessibility of transport services for these residents as well;
- Ride sharing as a part of integrated transport system [8, 9].

5. Conclusions

The disadvantage of public transport compared to individual modes of transport is less flexibility and reduced accessibility for users, since it is operationally and technologically limited. Travelers have to commute to public transport stations and stops by various means, whereas this problem does not arise when using individual transport and, in practice, travelers have the possibility to travel from any location [1] [2].

The ever-increasing trend of individual motorisation is having a negative impact on the lives of residents and the environment. The proposed solution states that private car journeys will allow users to become part of public transport through ride-sharing services, which will increase the range of services provided to public transport users [11]. In addition, ridesharing will bring many benefits to the whole system, such as reduced road congestion, savings from externalities, increased private car occupancy, increased availability of public transport for users, etc. The Travel Companion application allows travelers to use a co-modal approach, besides this it also includes other innovative functionalities and a comprehensive range of travel arrangements for passengers, from planning their journeys based on their preferences, it allows travelers to booking and purchasing travel tickets for a complete travel solution. Also, through Travel Companion application, travellers can track their chosen complex travel solution on a map base and travelers receive real time information and many more [3].

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A Reduction of the Running Resistance of a Tram Bogie

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Abstract

This contribution is aimed at investigating of the effect of selected properties of a tram bogie on the running resistance. It assesses the possibilities of a reduction of losses of mechanical energy in the wheel/rail contact while a bogie is running on a track. There are evaluated three designs of tram bogies differing by their wheelsets designs, or by their guidance in a bogie. There are three types of tram bogies, namely a bogie with a standard wheelset and a standard wheelset guidance, a bogie with a wheelset with a perspective wheel design including standard guidance and a bogie with standard wheel design and with a radial wheelset guidance. A perspective wheel design is typical by its independent rotating flange regarding to a wheel tread surface. The obtained results include a comparison of the energy efficiency of these designs in the wheel/rail contact for a particular motion route and the average dissipated power. Energy losses have been generated due to the slip in the wheel/rail contact. The performed research and evaluated results have shown, that a tram bogie with the perspective wheel design appears as the most suitable bogie variant in terms of energy efficiency.
KEY WORDS: *tram, bogie, running resistance, energy efficiency*

1. Introduction

In some European countries, trams operate not only in cities, but they can move on tracks of standard railways and they may transport passengers even 80 km suburban parts of cities. In cities without an underground, trams move in tunnels and this kind of public transport is still being developed [1].

Constantly increasing energy prices and requirements for reduction of environmental pollution force designers and researchers to a difficult task, how to improve the energetic efficiency of transport means including means of city public transport, such as trams. Based on the work presented in [2], the energetic efficiency increases, when one is able to use less amount of energy for the same goal. Regarding transport, when one is able to transport the same number of passengers for the same distance by means of less consumed energy. From the point of view of trams, the goal is to reduce the running resistance during their movement on a railway track [3]. Innovations in bogies design of trams are one of a possible way to improve their energetic efficiency [4, 5]

One of the most known way is the use of a system, which controls key components of a tram bogie during its running on a track [6, 7]. A disadvantage of these systems is their inaccuracy during running in curved sections of railway tracks. On the other hand, they work independently of profiles of rails and wheels. However, in the case of worn rails, this system for radial setting of wheelsets to a track leads to increased worn of railway wheels. The system for setting the wheelset to the radial position in a track is not possible to add to modernized trams [8].

As kinematic running resistance is the main component of the entire running resistance of a railway vehicle, there have been developed technical solutions for the reduction of this negative effect of railway vehicle running in a track. The most known of them are wheelsets with independently rotating wheels (IRW) on an axis [9, 10]. The IRW system also reduces wear of in a contact of a wheel and a rail [11-15]. Further, there is also invented a design of a railway wheel, which has two main independently rotating parts, i.e. a flange and a tread surface [16, 17] called as a perspective design scheme (PDS). Such a design of wheels can reduce the kinematic running resistance of a railway vehicle on a track.

2. Materials and Methods

The research comes from an important generalized factor of energy consumption. It is a total specific running resistance [18-20], which is given by the following formula:

$$w''_{T\,sr} = w''_{M\,sr} + w''_{A\,sr}\,, \tag{1}$$

where $w''_{M\,sr}$ is the main specific running resistance; $w''_{A\,sr}$ is the additional running resistance.

Astakhov [18] states, that the main components $w''_{M\,sr}$ of the specific running resistance are sum of partial resistances and it is given by the formula:

$$w''_{M\,sr} = w''_{B} + w''_{RW} + w''_{SRW} + w''_{AD} + w''_{EDT} + w''_{EDE}\,, \tag{2}$$

where w''_{B} is friction resistance in bearings; w''_{RW} is rolling resistance of rails and wheels; w''_{SRW} is sliding friction of rails and wheels; w''_{AD} is aerodynamic resistance; w''_{EDT} is resistance due to energy dissipation in transit; w''_{EDE} is resistance due to energy dissipation to environment.

Friction resistance of bearings depends on a type of a bearing. Current modern railway vehicles use bearings with rolling elements, which rolling coefficient is of 0.001 to 0.005. A value of aerodynamic resistance is given by design of a railway vehicle body, running speed and other factors. Resistance of rails and wheels influences the total vehicle resistance. Its values are determined by experiments [18, 21], therefore it is difficult to calculate it based on empiric formulations. Similarly, resistance due to energy dissipation in transit is difficult to express by means of an explicit formulation. Based on works presented in [22, 23], a value of this factor are given by comparative calculations. A value of sliding friction of rails and wheels is determined by calculation to specific values of absolute values of forces of running resistance [24]. Additional specific running resistance of a vehicle consists of running resistance in curves, specific resistance of rails cant and specific resistance due to wind and other loads, which can arise during railway vehicle running on a track [25, 26].

Kinematic running resistance is one of the most significant components of running resistance. It relates with slipping in a contact of a wheel and a rail and it causes dissipation of mechanical energy, when a railway vehicle runs on a track. Based on review of scientific literature, the kinematic running resistance depends on various factors, such as number of curves with small radii on a track, specific length of them, lubrication of friction surfaces in a contact, technical state of railway vehicles and others. It would be possible to get certain amount of energy, namely during braking of a railway vehicle [27-31], however, it can be applied only in some running regimes and special devices have to be mounted in vehicles.

Values of kinematic running resistance is affected by maintenance of a railway track in an appropriate technical conditions. However, the maintenance of a track in a proper technical conditions requires considerable costs. One of reasons is a discrepancy of geometric parameters of a track and parameters of wheels, which effect factors of wear and transport safety [32, 33].

The study of theoretical review has resulted to the findings, that existing methods do not take into account their dependence of structural properties of bogies. This fact does not allow to estimate these characteristics of in a design state. It is recommended to investigate and evaluate these characteristics by means of simulation computations.

Simulations of a railway vehicle have been performed. The main goal has been to assess possibilities to apply innovative technical solutions in tram bogies in order to investigate their influences to energetic effectivity during running on a railway track. A Tatra T3 tram bogie has been created in the multibody software Simpack. Simulations have been performed on a track model, which has corresponded to a real track section in Ukraine, namely Kharkov, Yuzhny Station – Lesopark. This track section includes straight sections and curves with various radii. The minimal curve radius is of 20 m.

As it has been found out, the main components of running resistance of a railway vehicle are caused by forces in a contact of a rail and a wheel due to slipping of a wheel along a rail on both straight sections and in curves. Therefore, an innovative technical solution of a tram bogie has been developed to investigate, whether it is possible to reach reduced these negative effects by means of it. This innovative bogie design includes an independent rotation of a flange against a tread surface of a wheel and a mechanism to set a wheelset in a radial position regarding to a track axis.

The research has taken into account three different design of a tram bogie:

a) a tram bogie with a standard design of a wheelset guidance system;
b) a tram bogie with a standard design of a wheelset guidance system and with the perspective wheel design;
c) a tram bogie car with a radial installation of wheelsets and with standard wheelsets.

Fig. 1 shows a multibody model of a tram bogie created in the Simpack software. This bogie is equipped with wheels with the perspective wheel design.

As it can be seen (Fig. 2), in a case of a wheel with the perspective wheel design, a flange rotates independently of the tread surface of the wheel. Thus, the flange is mounted to a wheelset axle. However, in contrast, a part of the wheel with the treat surface is rigidly mounted on a wheelset axle. This special design of a wheel leads to reduced kinematic slip in a contact of a wheel and a rail. Together with that, energy caused by a friction force is reduced too.

A tram bogie with a radial guidance of wheelsets has been presented in [34-36]. The main characteristics of this bogie is, that three axleboxes guide wheelsets and a special lever mechanism help to set wheelsets to a radial position in a curve. This bogie is shown in Fig. 3. The main advance of this system is, that suspension system works kinematic independently from an axis positioning system.

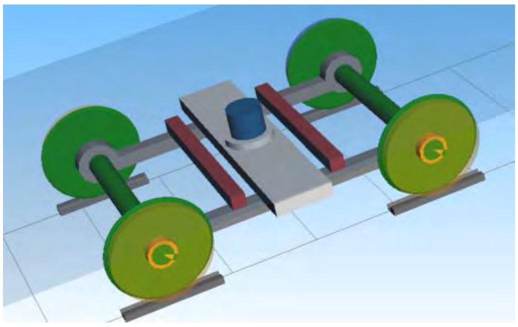

Fig. 1 A multibody model of a tram bogie with wheels with the perspective wheel design

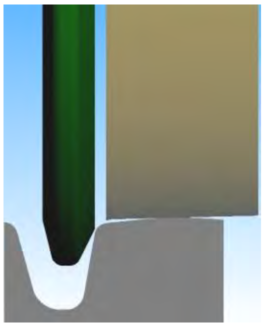

Fig. 2 A detail of a contact of a rail and a wheel with the perspective wheel design

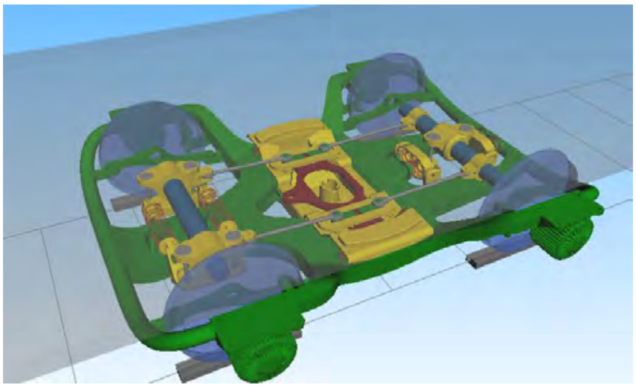

Fig. 3 A multibody model of a tram bogie with a special lever mechanism

3. Results and Discussion

The results of the research, which are focused on consumption of energy, come from calculation based on determination and summarization of mechanical work of friction forces in contacts of individual wheels with rails for a tram.

During a tram running on a track in curves, mechanical energy is dissipated due to slipping wheels on rails in wheel/rail contacts. Then, this mechanical energy is calculated based on a defined formulation. This formulation expresses the mechanical energy as a scalar product of a corresponding component of creep force in a contact point during wheel slipping on a rail in the given direction. Hence, mechanical energy is given by the formulation:

$$E_{M\ ab} = A_{M\ ab} = -\left(U_{M\ ab} \cdot s_{M\ ab}^{U} + V_{M\ ab} \cdot s_{M\ ab}^{V}\right), \tag{3}$$

where bottom indices *a* and *b* indicate a wheelset of a tram in the running direction and its position (right or left) in a bogie, respectively, further, $U_{M\ ab}$ and $V_{M\ ab}$ are longitudinal and lateral components of the creep force in the *i*-th contact of a wheel and a rail and $s_{M\ ab}^{U}$ and $s_{M\ ab}^{V}$ means sliding in the *i*-th contact of a wheel and a rail in a longitudinal and lateral directions, respectively.

When a quick change of a value of the force, which is in a contact of a wheel and a rail, taken into account, a certain value of frequency (called as a simulation frequency f_s) is also taken into account for a modelling process.

The slip in a wheel/rail contact is calculated based on the following formulation, which takes into account individual components of slip velocity in the wheel/rail contact:

$$\left.\begin{aligned} s_{M\ ab}^{U} &= v_{M\ ab}^{U} \cdot T_{f_s} \\ s_{M\ ab}^{V} &= v_{M\ ab}^{V} \cdot T_{f_s} \end{aligned}\right\}, \tag{4}$$

where $v_{M\ ab}^{U}$, $v_{M\ ab}^{V}$ are sliding speed components in each wheel/rail contact in a longitudinal and lateral directions, respectively; t_{f_s} is simulation time, or simulation period, regarding to the simulation frequency f_s and its value is calculated by a known ratio $T_{f_s} = \dfrac{1}{f_s}$.

The following formulation expresses an equation of equilibrium of total consumption of mechanical energy caused by sliding of a wheel on a rail in their contact during running of a tram and a sum of consumption of mechanical energy caused by sliding of individual wheel on a rail of a tram:

$$E_{M\ Total} = \sum_{a=1}^{4}\sum_{b=1}^{2}\sum_{i=1}^{2} E_{M\ abi}\ . \tag{5}$$

The next formulation gives a value of average power P_A, which is dissipated due to sliding the wheels on rails during running of a tram in a track:

$$P_A = \frac{E_{M\ Total}}{t}\ , \tag{6}$$

where t is time of a tram running on in a track.

During the research, values of total losses of mechanical energy due to sliding a wheel on a rail in their contact and average value of the dissipated power have been evaluated. In a case of the total losses of mechanical energy, it is a work of tangential forces in the contact of the wheel and the rail. The result values are as following:

- the value of 297.3 kJ for a tram equipped by the typical wheel design;
- the value of 178.6 kJ for a tram equipped by the standard wheel design and by the wheels with the perspective wheel design;
- the value of 168.1 kJ for a tram equipped by the standard wheels together with the mechanism for radial setting of wheels.

Further, the values of consumption of the average power, which overcomes the kinematic running resistance during a tram running on a track have been observed as following:

- the value of 0.083 kW for a tram equipped by the typical wheel design;
- the value of 0.05 kW for a tram equipped by the standard wheel design and by the wheels with the perspective wheel design;
- the value of 0.048 kW for a tram equipped by the standard wheels together with the mechanism for radial setting of wheels.

Fig. 4 shows the results of studies, which are aimed at the effectivity of application of the proposed technical solutions, which are used in a tram bogie in order to improve the energy effectivity. The results are for the running speed of 10 km/h.

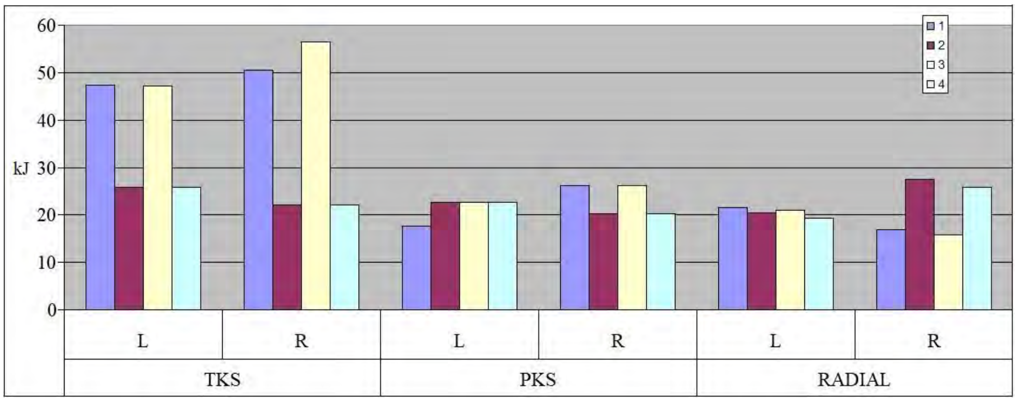

Fig. 4 The graph of distribution of the losses of the total mechanical energy due to the slippage of a wheel on a rail in their contact at the running speed of 10 km/h, numbers 1 to 4 indicate a wheel of a bogie, *L* is the left wheel, *R* is a right wheel

Fig. 5 depicts the average value of the power, which is dissipated during running of a tram on a track at the speed from the interval of 10 m/s to 30 m/s, which corresponds to the running speed of 36 km/h to 108 km/h.

The data obtained from the analyses allow to confirm, that the using of railway wheels with the perspective design scheme are able to reduce the mechanical energy consumption, which is needed for overcoming the running resistance of a railway vehicle (in our case, of a tram) and together with these findings, the results confirm, that a bogie equipped with wheels with the perspective design scheme can reduce the mechanical energy consumption in a comparable manner as a bogie equipped with the mechanism for setting wheels (or wheelsets) to the radial position regarding to a track axis.

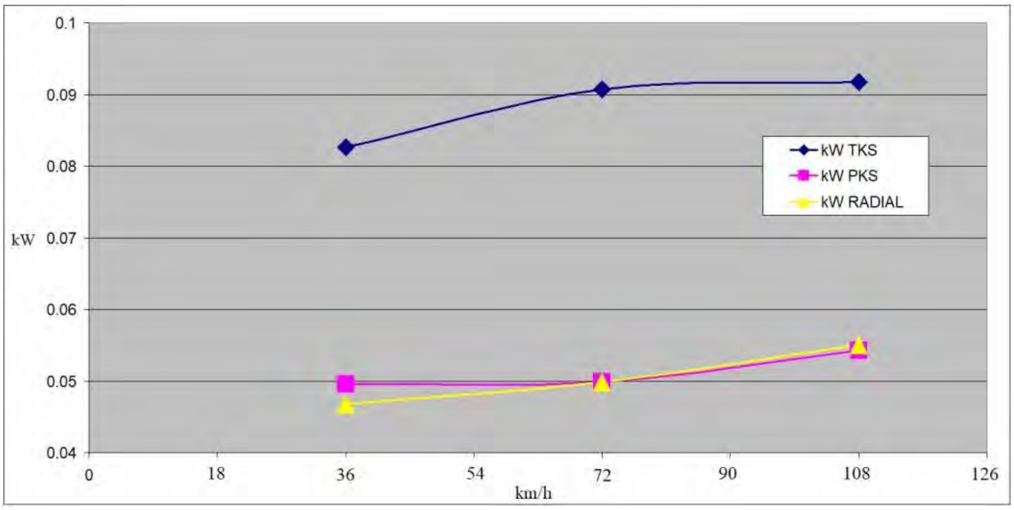

Fig. 5 The average value of the power, which is dissipated due to the sliding of wheels on a rails

4. Conclusions

The presented research has been focused on the analysis of properties of three various technical solutions of a tram bogie, namely a bogie equipped with a standard wheel's design and wheelset guidance, wheels with the perspective design scheme and a bogie with a mechanism allowing the wheelsets setting to the radial positon regarding a railway track. The main purpose has been to investigate the loss of mechanical energy during a tram running on a track. The achieved results have shown, that a bogie with the perspective design scheme wheels and a bogie with the setting mechanism have in principle similar properties regarding to the mechanical energy losses and they have reached similar values of it. Further, the analysis of energy efficiency has led to the findings, that also in this case, the setting mechanism of a bogie and the perspective design scheme of wheels reach similar values. Considering the advantages and disadvantages of these technical solutions, an application of the perspective design scheme of wheels seems to be the suitable technical solution of wheels for tram bogies for their efficient operation.

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Regulations towards Cryogenic Carbon Capture Implementation on the Marine Transport

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Abstract

Considering that the maritime industry emits roughly 3% of the global emissions within the outlook to increase in-between 50 and 250 percent by 2050 the forecast of the growth highlights the need to introduce measures against the negative maritime industry impact on the environment in order to comply with the International Maritime Organization (IMO) goal to minimize the total greenhouse gas emission generation at least 50% by 2050 towards Paris climate agreement policy. According to the established standard from the 01st of January 2023 all ships will be required to present their annual operational carbon intensity indicator (CII) and CII rating. The CII rating will be related to the total volume of cargo carried per distance and will classify vessels into categories of efficiency: A, B, C, E, D where category A will represent the most efficient class of vessels. The low class vessels accordingly will be encouraged by authorities to introduce action measures to improve cargo handling efficiency levels therefore the introduced grading will likewise force shipowners to revise technological availability to retrofit vessels into more efficient. LNG fuel serves as a transition fuel due to its beneficial properties for decarbonization and cryogenic carbon capture technologies implementation in marine transport.
KEY WORDS: *decarbonization, LNG, carbon capture, maritime*

1. Introduction

Greenhouse gases (GHG) is being described as the major issue to the environment as the impact of developing industrial activity level relevant to the shipping and transport sector. Due to GHG which contributes as a main cause to global warming in 2015 the United Nations have signed the Paris Agreement to determine goals towards the aim to limit the global warming down to 1.5°C as the increase in global warming. The countries and organizations have settled long-term measures to achieve a framework convention on climate change goals.

As transport plays an important role in the challenge to minimise global warming, it is being accounted that transport has the most engaged reliance on fossil fuels in comparison to any other sector and according to the International Energy Agency (IEA) in general accounts for 37% of CO2 emissions [1]. The marine transport sector which accounts roughly 3% of shipping emission has been impacted by the implemented measures by the International maritime organization (IMO). In order to reduce maritime sector negative impact to environment, IMO under its pollution prevention convention (MARPOL) have established an initial IMO GHG strategy within regulation on: consumable fuel quality – TIER emission standards, vessels' efficiency performance – the Energy Efficiency Design Index (EEDI), Carbon Intensity Indicator (CII). The regulations towards emission reduction have created an environment to boost and establish technological solutions to improve energy usage efficiency and, in the meantime, to reduce those processes' negative impact to the environment.

2. Regulations to Reduce Emissions from the Marine Transport Sector

The MARPOL Tier emission standards are focused to reduce nitrogen oxide (NO_x) emission and for a diesel engine in order to be compatible with standard the emission from engine must be reduced down by 70% from „Tier I" class to „Tier III". The Table 1 present the of implemented regulation on NO_x limits based on engine's build year. The „Tier II" emission class prescribes the limit for engines which were constructed on or after 1 January 2011, then a „Tier III" class as from 1 January 2016 implemented emission regulation engines of vessels operating in Emission Control Area (ECA). In the meantime, the engines build prior to 1 January 2000 are applied to follow „Tier I" class [2].

Table 1

MARPOL Annex VI NOx limitation

Tier	Date	NOx Limit, g/kWh		
		$n < 130$	$130 \le n < 2000$	$n \ge 2000$
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016	3.4	$9 \cdot n^{-0.2}$	1.96

Then from 2023 the CII classification will enter into force for all cargo, RoPax and cruise vessels above 5,000 GT and trading internationally [3]. The CII classifies vessels into categories of efficiency for amount of cargo carried and the distance travelled. The index indicates the grams of CO2 emission per transport work. A five different categories of vessel efficiency will classify them in following grades: A, B, C, D and E. The grade E is a lowest class, so the according to CII classification, a vessel rated at class D or E for three operation years are required to present an action plan in order to achieve ranking of higher class (C or other). Likewise, as a CII grading measure, the EEDI has been established to promote ships to use more energy efficient equipment and engines. The EEDI is an index that calculates grams of CO2 generated per voyage of cargo transportation – grams of carbon dioxide per vessel's capacity mile. Indexing strategy was adopted in July 2011. The indexation serves as a measure to account for CO2 emission generated from the vessel activity and in addition it serves as an emissions control and reduction tool. When a vessel is certified with the index category, every five years the index has to be revised, tightening it by 10%. Such regulation obligates ship owners to follow up with technological developments to improve the vessel's efficiency level. As per EEDI, the 5 years periodical reduction of emission has been established until the period of 2025 to 2030 when a 30% emission cut is achieved. The EEDI regulation was established before the IMO session in June 2021 when the organization adopted a goal aimed to cut greenhouse gas emissions from shipping by at least 40% by 2030 towards the 70% goal in 2050, compared to the 2008 baseline [3].

All of these international shipping regulations were put in place to compel technical support and technological collaboration with the marine industry. In May 2021, the International Energy Agency (IEA) released a flagship report called Net Zero by 2050: A road Map for the Global Energy sector. The released report determined that in order to achieve a settled goal by 2050, an unprecedented clean technology push to 2030 must be reached. The figure (Fig. 1) presents the scale of actions that must be adopted in the short and long term gap. Mainly, the asset to achieve goals relies on technologies availability to reduce GHG towards 2050.

Fig. 1 EUA Price outlook 2021-2030 period

However, one thing is tightening of regulations and other – direct tax liability. The European Union has established a regulation called Emission trading system for European Union emission allowance. The regulation was established under Directive of the EU Emissions Trading System – Directive 2003/87/EC. Following the directive, the industrial corporations such as manufacturers who are producing greenhouse gas emissions are obligated to pay for the generated emission. According to established trading system, one emission allowance unit covers one tonne of generated emission, when the price in marked these days for a unit fluctuates at 70 Euro and above, for a business owner whose emission seeks 50.000 t of CO2 per year the business activity generates direct liability to pay over 3 mln Euro tax. The Table 2 presents a top 10 companies in Lithuania which generates major amount of individual CO2 emission per company's activity and at the position No. 7 line up a company with operational activity of Floating Storage Regasification Unit (FSRU) which is classified as a vessel permanently allocated in port of Klaipeda. Following the forecasted price with the reference to Fig. 1 – in the future the one allowance can even reach a cost of more than 100 Euro. Considering that one unit price in a 5 year window was 20 Euro, nowadays for business owners it has become a headache to reduce emission and remain business activity at profitable level [4, 5].

In contrast, there are louder discussions that in the future the same annual tax regulation liability will be established for all transport sectors. In the frame of tax liability, in 2021 the Maersk Line which is largest containers shipping company in the world have proposed an ambitious decarbonization plan to apply carbon tax on ship fuel for at least \$450/mt fuel, or \$150/mt CO_2 [6].

Table 2
Top 10 companies in Lithuania with the most verified emissions

No.	Account Holder	Allocated EUA for 2020, tons	Verified emissions in 2019, tons
1	AB Achema	1,817,507	2,486,023
2	AB ORLEN Lietuva	1,253,382	1,599,384
3	AB Akmenės cementas	567,464	965,272
4	AB Vilniaus šilumos tinklai	105,023	265,149
5	UAB Fortum Klaipėda	31,892*	139,590
6	UAB Paroc	30,933	62,338
7	UAB Hoegh LNG Klaipėda	19,761*	49,720
8	UAB NEO Group	31,330	28,020
9	AB Nordic Sugar Kėdainiai	26,282	26,905
10	AB Ignitis gamyba	10,258	19,012

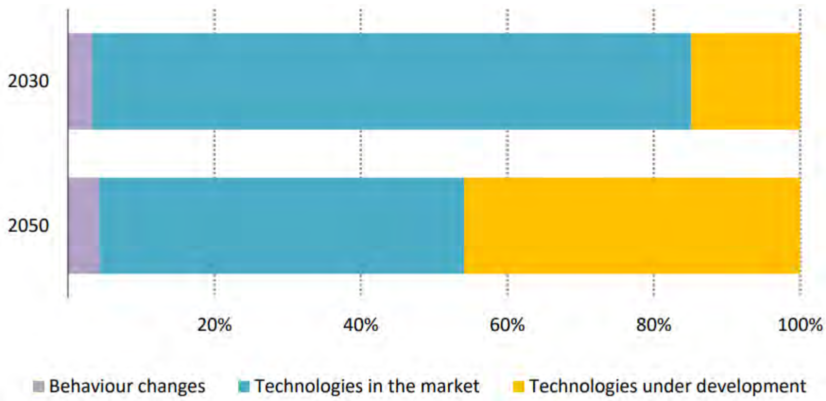

Fig. 2 Actions towards CO_2 emissions reduction [7]

According to the IEA released report currently only 1/3 of Government Research and development funding is being directed to essential technology development such as hydrogen infrastructure development, carbon capture and further disposal of captured carbon emissions (Fig. 2). Therefore, more attention must be highlighted towards green technology development. When technologies are at development stage, the implemented regulations on emission taxes and restrictions on emission from vessels have increased the LNG as a fuel demand. Because of the advantaged LNG fuel characteristics in comparison to standard low sulphur marine diesel oil (LS-MDO) properties, the LNG allows to cut NOx, SOx emissions by 90%, then to eliminate SO2 emissions and even to cut CO2 emissions by 25%. However, the percentage of CO2 emission cut its not sufficient enough to achieve the strategy goal set for 2050 but LNG is now globally being identified as a fuel source for transition to hydrogen fuel until sufficient infrastructure will be established. But in order to achieve the IMO's goals – which even allow for the capture of emissions before they are released into the atmosphere – new approaches must be put forth [7].

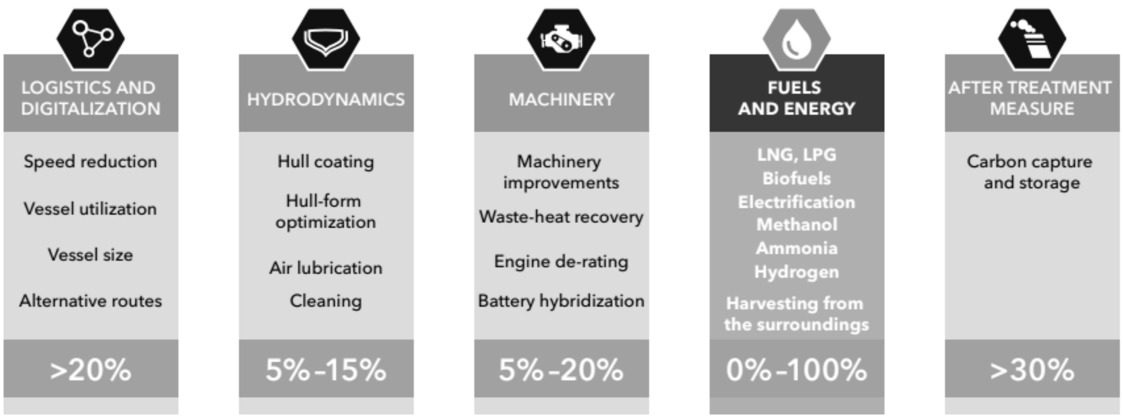

Fig. 3 Technological solutions to decarbonize shipping towards reduce of GHG emission [8]

According to DNV in the 2021 release report „Maritime Forecast to 2050“ decarbonization in shipping consists of a well-established vessel operational plan. The Figure 3 presents the main categories which must be considered and accordingly verified at vessel building or retrofit stage. A standout percentage towards decarbonization takes the fuel and energy category which allows in general to reduce CO2 emission in range from 0 to 100% within effectiveness relying on fuel type. According to the DNV statement in the report, the LNG and LPG are nowadays the main alternative fuels upon another, more beneficial fuel from EEDI and CII class perspective will be established considering long-distance shipping at sea [8]. Hence, align LNG implementation on ship other measures must be considered to achieve higher decarbonization rate and it can be noticed in Fig. 3 that after treatment measures of carbon capture and storage (CCS)stands out. According to DNV above 30% of GHG could be reduced with CCS technology. In addition, if technology would be introduced on the vessel powered by LNG fuel the percentage would increase above 55% due to LNG features. Furthermore, the LNG cold potential could be utilized by establishing a cryogenic carbon capture unit. In general, three principal carbon capture technologies exist: a) pre-combustion solution; b) post-combustion solution; c) oxyfuel solution. Pre-combustion and oxy fuel solutions are based on the fuel quality exchange prior combustion process; therefore such technology implementation would require vessel's propulsion system modification while the post-combustion technology is based on the CO2 capture from flue gas after combustion process is completed. Therefore, post-combustion technology does not require modification on the propulsion system and the capture unit installation has more wide flexibility [9].The CCS technology is at early development stage for a stationary emission source (manufactories and other industry units), same technology is being analysed to be implemented on mobile emission stations (vessels and other floating units). However, so far CCS technology has not been implemented on any commercial vessel although technology is being established on power plants at developing/testing stage. High cost, lack of financial support, space requirements were a reason of low technological progress and applicability. Moreover, the solutions to handle disposal of capture CO_2 must be established in advance. Nevertheless, the 2021 boosted an obvious progress on carbon capture, utilisation, and storage (CCUS) technologies development. During the year more than 100 new CCUS projects were announced to analyse technologies relevant to carbo capture infrastructure establishment [11].

For the captured carbon emission utilisation, the Carbon Capture and storage (CCS) projects are being developed. One of the latest project – „Stella Maris“ large scale CCS infrastructure where the goal is to create infrastructure as a logistic solution for captured CO2 from industrial sources transportation and injection into saline reservoir in offshore of North sea region [10]. The CCSO shall be able to handle different types of CO2 supplies:

– Type 1 CO2 : Compressed/dense phase CO2 for medium to long distance transportation. Further purification and liquefaction on the CCSO;

– Type 2 CO2 : Low pressure gaseous CO2 transported at low pressure from CC facilities close to the jetty for further purification and liquefaction onboard the CCSO;

– Type 3 CO2 : Medium pressure liquid CO2 typical for road or rail transportation;

– Type 4 CO2 : Low pressure liquid CO2 much similar as Type 3 CO2, but for larger batch volumes of liquid CO2 being brought to site, i.a.by river barges.

3. Cryogenic Carbon Capture Implementation on LNG Fuelled Ship

LNG is a cryogenic type of fuel which contains approx. temperature of -162°C. When the LNG is being used as fuel on marine transport either on stationary unit the LNG must be regasified via heater to more than 5°C, usually gas outlet temperature is regulated to 25°C. During LNG fuel supply cycle, the LNG is being sent to vaporizer via submerged pump. As well the vaporizer can be supplied with LNG vapor which is being discharged to vaporizer via compressor. The vaporizer the LNG is being heated up by water with an indirect contact where the heating agent (glycol, propane etc.) is heated by the sea water temperature and the heating agent transfers energy to the LNG by heating it up. Heater function in the fuel supply stage is to control the temperature of gas which is being sent to the plant for a combustion process (Fig. 4).

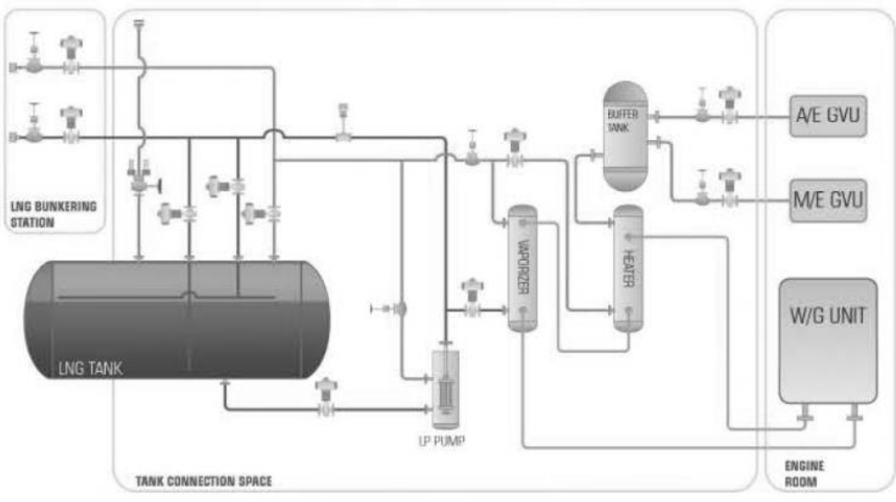

Fig. 4 Basic configuration of LNG fuel supply to combustion units [12]

During the heat transaction to LNG, the heat exchange agent is cooled down by LNG cold temperature and after the process must be heated up again by the sea water to achieve temperature for the LNG regasification stage. Therefore, during the process, the potential cold energy from LNG is being wasted. The cryogenic carbon capture technology allows during the LNG heating process to utilize heat exchange agent more efficiently. Technology combines two cycles: a) Organic Rankine cycle (ORC); b) CO2 capture cycle (CCC) (Fig. 5).

Instead of being delivered to vaporizer directly, the LNG passes several heat exchangers, the number of hear exchangers relies on capacity of machinery to be supplied with sufficient amount of fuel gas. First of all, the LNG passes Heat Exchanger No.1 as a cold for the ORC. Then LNG is being transferred by Turbine No. 1 to Heat Exchanger No. 2 where NG condensates the CO_2. By passing by through two steps of heat exchangers the LNG is being heated to sufficient temperature to perform combustion process. Two steps of LNG interaction with the heat exchangers in different cycles at firs cools down agent at ORC stage and then condensates CO_2 at CCS stage. After the combustion process the exhausted gasses are being sent to Heat exchanger No. 3 where exhaust gas is being utilized as heat source to heat up the agent which afterwards flows to the Heat exchanger No. 1 for the heat transfer to LNG. The CO_2 from the exhaust gas is condensed into liquid in the Heat exchanger No. 5. In the ORC process the temperature agent is heated up by exhaust gas twice at Heat exchanger No. 3 and Heat exchanger No. 4. For CCC, a portion of the carbon dioxide in the tail gas freezes in Heat Exchanger No. 4, and then totally condenses into liquid phase following an indirect heat exchange with natural gas [13].

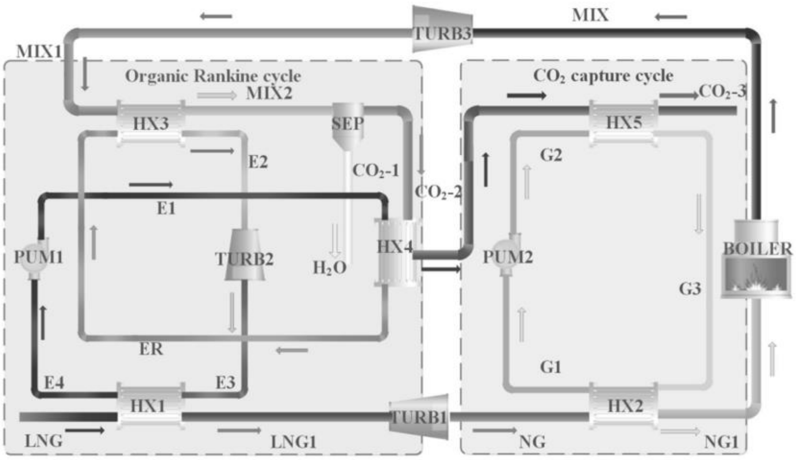

Fig. 5 LNG fueled power plant based on ORC and CO_2 capture systems [13]

When the CO2 is captured and converted into liquid or dry ice phase before further disposal it is temporarily stored. If carbon capture technology would be implemented on the vessel, the solution would require an additional storage tank arrangement to store captured emission. For example, if the vessel generates roughly 50.000 tonnes of CO2, this will require accommodating the same amount of volume in cubic meters of liquid or 31250 tonnes of emission in dry ice phase. Means in parallel additional infrastructure shall be established which would allow vessels to dispose CO2 at ports as regular wastes, in addition the solution likewise would require IMO actions to force seaports to develop infrastructures for CO2 collection and storage [14]. Considering that the vessel which generates 50.000 tonnes of emission per annum would discharge captured emission once a month – an additional 4200 m^3 capacity tank would have to be installed on the vessel to store captured emission. Therefore, in parallel to performed overview of CCC implementation, additional analysis must be carried out in order to verify proper way to dispose captured CO2 emission [15].

4. Conclusions

Controlling the harmful consequences of technology has received increasing attention in recent years. The maritime transport sector in the light of the decarbonization goal has established several regulations which are addressed to force shipowners to introduce an alternative fuel on their vessels: TIER emission standards, vessels' efficiency performance– the Energy Efficiency Design Index (EEDI), Carbon Intensity Indicator (CII). The tightened regulations have boosted technological evaluation to establish infrastructure for carbon capture and storage infrastructure. According to the DNV released report the LNG serves as a fuel for the transition period upon which another, more beneficial fuel from EEDI and CII class perspectives will be established. The LNG fuel aligned carbon capture technologies are compatible with cryogenic carbon capture solutions. During the LNG fuel combustion stage, a cold potential is being wasted during the LNG regasification stage to change warm LNG fuel from -162°C up to 25°C. With the application of Organic Rankine cycle and CO2 capture cycle exists theoretical feasibility to develop a solution based on heat exchangers based implementation in fuel gas regasification stage.

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Analysis of Problem Related to Experimental Data Processing in the Study of the Rolling Stock Influence on the Track

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Abstract

In paper discusses the problem of the correctness of the unification of experimental data by axes and points of measurement. The purpose of the study is to analyse experimental data in the study of the influence of the rolling stock on the railway track associated with the change of the nature and ratio of values of forces and stresses when combining data. Experimental data obtained from the study of the influence of Tulpar Talgo on the railway track were considered. The main feature is the construction of a trolley having one wheel instead of two, which makes it possible to show the nature of changes in stresses and forces when grouping data. This made it possible to assess the correctness of the unification in terms of the nature of the force ratio for the passage of rolling stock in the study area.
KEY WORDS: *rolling stock, track section, vertical forces, lateral forces, axle load*

1. Introduction

Any experimental measurements of dynamic processes, such as those related to the verification of models of interaction between the railway track [1-3, 5, 6, 8] and the rolling stock [4, 7, 9-11] or the state [12, 13] and design [14-17] issues rolling stock and tracks, as well as those related to climatic processes [18-20], provide continuous or either at specified or randomly determined time intervals on it data recording. The data obtained as a result of measurements are random variables. This is due to the influence of various factors of a probabilistic nature on the result of each experiment. For this reason, the experiments are organized according to the main scheme of (selective) statistical tests, where the number of both measurements and sensors varies. Data processing is carried out according to generally accepted statistical dependencies. However, increasing knowledge in understanding the physics of the measured processes requires a change in approaches to data processing. And the result of this study demonstrates the possibility of expanding knowledge on the issue under study, changing only the approach to the data processing.

2. Research Methodology

The determination of the stress-strain state of the track under the influence of the Tulpar Talgo rolling stock was the objective of these tests. During the tests, 172 runs were performed on 5 experimental sections of the route:
- curve with radius 320 m;
- curve with radius 685 m;
- rail switch 1/11 type P65;
- curve with radius 1842 m;
- straight.

As a result of deciphering the primary recorded data, about 250.000 experimental values of the indicators of the stress-strain state of the track and rail switch were obtained. The article analyses experimental data obtained for the direct section. Characteristics of the test section: straight, spurious track, type P65 rails, reinforced concrete sleepers, type W30 fastening with Skl12 terminal, reinforced concrete sleepers 1840 pieces per kilometer, crushed stone ballast, the thickness of ballast layer 0.60 m. On the basis of experimental data, the elastic modulus values in the test sites were determined. The modulus of elasticity in different sections: the test section was from 23 to 27 MPa. The accepted value for calculations is 25 MPa. Fig. 1 presents a schematic of sensors on the track and a schematic of rolling stock. All requirements for conducting experimental research are given in [21].

Table 1 presents the weighting data of rolling stock and characteristics of wagons:
A – technical wagon with diesel generator;
B – baggage wagon;
C – wagon with seats for tourist class;
D – buffet wagon, E - restaurant wagon;
F – sleeping coach wagon;
G – business class sleeping wagon;
I – sleeping first class wagon with disabled compartment.

The data obtained from the stress and force measurements are random variables. This is due to the impact of various probabilistic factors on the outcome of each experience. For this reason, experiments are organized according to the basic scheme of (selective) statistical tests. Indicators of the stress-strain state of the track are regarded as random variables that are subject to the law of normal distribution (Gauss law). According to the readings of each instrument, for each group of vehicle axles at the same speeds and directions of movement, a «primary» sample is drawn. These data are used to determine the parameters of the stress-strain state of the track at the assumed track strength level of probability not exceeding 0.994 according to the «Method of estimation of rolling stock impact on the track by conditions of ensuring its reliability» depending on the speed and direction of the experienced train.

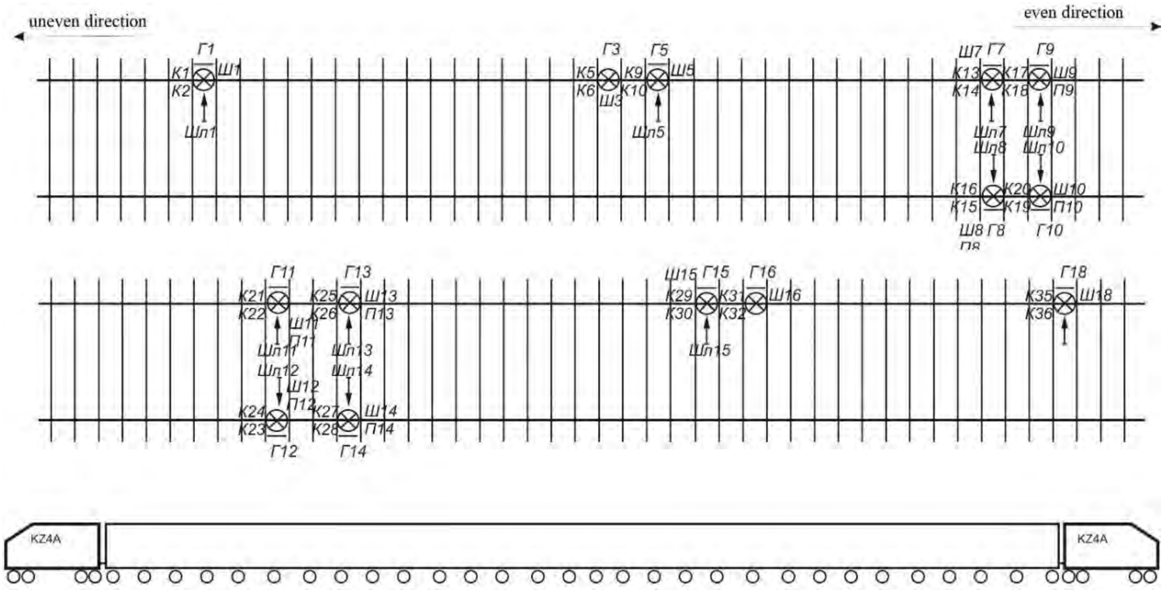

Fig. 1 Schematic sensors on the track and a diagram of rolling stock:
sensors for measuring stresses at the edges of the rail foot (K);
sensors for measuring vertical forces acting on (Ш);
sensors for measuring lateral (horizontal transverse) forces (Г)

Table 1

Rolling stock weighing data results

Axle	General axle load	Left wheel	Right wheel	Type of wagons	Axle mass, t
1	21.06	10.74	10.32	A	21.06
2	20.28	10.26	10.02	A	22.08
3	16.88	8.82	8.06	C	20.48
4	17.18	8.94	8.24	C	19.88
5	17.24	9.14	8.1	F	19.04
6	17.38	8.3	9.08	F	19.18
7	17.28	9.32	7.96	F	19.08
8	17.44	8.4	9.04	F	19.24
9	17.38	9.26	8.12	F	19.18
10	17.38	8.56	8.82	F	19.18
11	17.34	9.54	7.8	F	19.14
12	17.34	8.34	9	F	18.74
13	17.24	9.52	7.72	G	18.24
14	18	8.7	9.3	G	18.9
15	18.56	9.98	8.58	D	20.46
16	18.92	10.18	8.74	E	20.72
17	18.38	9.12	9.26	I	19.58
18	17.54	8.36	9.18	F	19.34
19	17.48	9.6	7.88	F	19.28
20	17.54	8.38	9.16	F	19.34
21	17.54	9.52	8.02	F	19.34
22	17.44	8.48	8.96	F	19.24
23	17.38	9.72	7.66	F	19.18
24	17.42	8.22	9.2	F	19.22
25	17.44	9.46	7.98	F	19.24
26	17.38	8.26	9.12	F	19.18
27	17.36	9.54	7.82	F	19.16
28	17.86	8.56	9.3	F	20.16
29	20.04	9.94	10.1	B	21.44
30	20.66	10.5	10.16	A	20.66

When planning the experiment, the sample size (number of trips) is determined based on the same requirements. After obtaining the «primary» selection the indicators under each axle and for each measuring device are analyzed. In estimating the values of the indicators, it is necessary to take into account the wide variation of track and rolling stock characteristics and to adopt a coefficient of variation at a level that ensures a sample according to the normal distribution law. If the coefficient of variation for a given indicator is exceeded, the indicator is removed from the «primary» sample because its values lie outside the confidence interval adopted for the law of normal distribution. Next, a «secondary» sample for the axles with the same nature of the impact on the track and direction of movement, with the same level of influence. Analysing the value of the coefficient of variation is made «united» sample from «primary» and «secondary» samples. For such «united» samples, the basic statistics of random quantity are determined according to the standard method: average value and standard deviation, and maximum likely value according to the formula:

$$X_{\max}^{вер} = \overline{X} + 2.5S, \tag{1}$$

where $\overline{X}$ – the average value of the indicator in the sample; S – mean square deviation of the sample.

3. Results of Investigation

The existing track impact assessment system is based on the definition of the first limit state, which determines the overall suitability of the facility to operate under certain conditions. According to this state, the strength and stability indicators are evaluated. They showed positive results. But a topical issue today is the issue of reliability, that is, the assessment of the risks of functional safety of any engineering facilities is related to the definition of the second limit state, which determines the suitability of objects to perform their functions safely (with certain levels of risk at all stages of the life cycle) and efficiently (with a certain level of cost) under specific operational parameters. Therefore, the following Tables 2 and 3 show data processing results at 180 km/h to analyse the correctness of using the existing data fusion algorithm to assess functional security.

Table 2

Results of vertical force values for various data combinations, kN

Axles	Quantity	Average	Maximum Likely	Maximum Observed
single passage / without uniting for Ш5				
1	1	101.9	101.9	101.9
2	1	97.65	97.65	97.65
3	1	96.26	96.26	96.26
4	1	107.2	107.2	107.2
5	1	96.66	96.66	96.66
6	1	100.8	100.8	100.8
7	1	98.05	98.05	98.05
8	1	93.77	93.77	93.77
9	1	96.06	96.06	96.06
10	1	88.21	88.21	88.21
11	1	92.78	92.78	92.78
12	1	88.71	88.71	88.71
13	1	93.18	93.18	93.18
14	1	84.54	84.54	84.54
15	1	109.5	109.5	109.5
16	1	80.76	80.76	80.76
17	1	95.86	95.86	95.86
18	1	83.05	83.05	83.05
19	1	97.75	97.75	97.75
20	1	101.6	101.6	101.6
21	1	89.7	89.7	89.7
22	1	88.31	88.31	88.31
23	1	94.97	94.97	94.97
24	1	86.03	86.03	86.03
25	1	96.85	96.85	96.85
26	1	86.03	86.03	86.03
27	1	93.08	93.08	93.08
28	1	88.01	88.01	88.01
29	1	91.59	91.59	91.59
30	1	85.93	85.93	85.93
Unification along the axles (1 - loaded axle. 2 - unloaded axle) measuring point Ш5				
1	16	91.91	106.5	102
2	16	82.89	96.59	95.46
Unification along the axles and measuring point (all sensors Ш)				
1	136	83.39	108	121.4
2	136	85.98	110.8	116.8

This speed was not chosen by accident. As is known in the straight section of the track, even in a perfectly straight section of the train moves along the sine wave and the higher the speed, the faster the train passes through it. In this case, the construction of the trolley also limits the transverse oscillations of the wagons. That is, the action of vertical forces at this speed tends to the maximum above each wheel, taking into account the position of the trolley relative to the axis of the track. For single passage, the force varies between 83.05... 109. 5 kN (difference 24.16%). The force value for the first axis union is less than the maximum observed in a single passage. However, in «secondary» samples, the maximum observed values of both loaded and unloaded axles are higher than in single passage. Thus, in order to assess the functional safety, it would be better to carry out the unification not on the loaded and unloaded axles, but on the position of the trolley relative to the axis of the track.

Table 3

Results of lateral force values/stresses at the edges of the rail foot for various data combinations, kN/MPa

Axles	Quantity	Average	Maximum Likely	Maximum Observed	Minimum Likely	Minimum Observed
single passage / without uniting for Г5/К9						
1	4	36.45/49.15	57.63/78.01	47.36/75.35	15.27/61.31	27.88/66.9
2	4	40.2/58.63	63.95/87.61	49.96/71.32	16.44/33.24	30.53/48.47
3	4	36.74/45.45	57.46/84.05	45.78/66.14	16.02/23.55	28.21/41.28
4	4	34.48/55.12	54.35/76.79	42.49/62.97	14.6/26.68	26.07/41.76
5	4	35.94/69.66	55.85/79.73	44.33/64.6	16.03/27.58	27.82/42.62
6	4	32.13/60.42	44.79/77.13	37.29/61.82	19.46/25.34	26.04/40.12
7	4	33.08/53.8	60.74/74.2	45.17/60.66	5.42/28.6	20.54/42.14
8	4	32.76/51.74	42.34/74.7	37.03/61.24	23.19/25.22	28.18/39.74
9	4	30.0/53.66	51.9/93.17	39.22/72.38	8.11/21.35	21.06/42.43
10	4	30.77/51.23	57.87/79.34	42.04/66.23	3.67/31.67	19.59/44.15
11	4	36.63/51.4	59.49/75.47	45.83/65.27	13.77/33.81	27.05/45.98
12	4	31.19/49.96	58.11/54.89	43.05/53.85	4.27/49.01	19.73/50.97
13	4	37.43/57.26	54.33/79.03	44.32/64.98	20.53/27.27	30.37/42.71
14	4	33.3/55.51	53.84/66.76	41.89/55.96	12.77/30.1	25.02/40.12
15	4	37.07/54.64	55.53/86.26	45.73/68.54	18.61/22.98	29.24/41.76
16	4	31.13/51.95	46.45/69.32	37.37/60.76	15.81/38.76	23.76/47.8
17	4	29.57/53.15	50.33/81.76	38.31/67.86	8.8/21.19	20.92/39.84
18	4	32.39/48.43	63.7/82.54	45.57/67.86	1.07/32.74	19.68/46.07
19	4	37.49/54.62	65.0/81.05	48.76/66.14	9.98/29.2	25.07/43.96
20	4	33.83/54.04	54.22/79.23	42.19/62.78	13.43/23.53	24.89/39.16
21	4	29.68/51.47	46.59/73.84	36.83/60.47	12.77/25.6	22.63/39.36
22	4	32.62/57.64	56.22/61.12	42.23/54.14	9.03/37.84	23.13/44.83
23	4	37.03/55.12	54.69/72.33	44.41/61.24	19.37/34.89	29.94/45.88
24	4	28.42/51.38	45.1/65.93	35.2/55.58	11.74/28.33	21.17/39.36
25	4	33.7/49.72	65.26/66.13	46.52/59.42	2.13/42.38	20.73/49.05
26	4	32.9/49.48	44.59/71.16	37.67/58.94	21.22/27.56	27.17/39.64
27	4	34.15/53.61	64.72/72.97	47.03/61.24	3.58/30.79	21.7/42.91
28	4	35.26/47.13	49.79/74.95	41.69/62.49	20.72/32.94	28.38/45.31
29	4	30.74/54.26	39.33/72.36	34.42/65.46	22.15/46.48	27.08/54.14
30	4	35.58/49.36	53.9/109.3	42.17/88.02	17.25/29.95	24.38/52.7
Unification along the axles measuring point Г5/ К9						
1	16	33.25/44.27	50.71/64.45	44.47/54.62	15.78/24.08	24.17/27.16
2	16	31.16/54.12	45.53/84.46	39.18/73.82	16.8/23.78	21.63/34.27
5	12	34.26/64.6	52.3/86.39	47.36/82.17	16.21/42.81	24.38/55.67
6	4	40.2/56.44	63.95/70.04	49.96/62.39	16.44/42.84	30.53/50.78
7	76	33.52/51.18	55.99/67.3	48.76/63.93	11.04/35.07	19.59/39.07
18	4	33.3/47.01	53.84/58.48	41.89/51.93	12.77/35.54	25.02/42.43
19	4	37.07/54.31	55.53/78.08	45.73/65.27	18.61/30.53	29.24/44.06
20	4	31.13/52.65	46.45/62.6	37.37/58.65	15.81/42.7	23.76/48.86
21	8	30.98/52.19	57.78/65.95	45.57/59.51	4.17/38.44	19.68/42.91
Unification along the axles and measuring point (all sensors Г/К)						
1	112/180	33.67/44.99	46.81/73.64	44.47/87.63	20.52/16.34	23.14/18.63
2	112/180	32.96/46.9	45.74/77.8	43.72/75.51	20.17/16.01	21.63/20.71
5	84/135	34.73/54.86	47.82/90.31	47.36/106.6	21.65/19.4	23.39/15.83
6	28/45	38.37/50.95	52.54/74.0	49.96/75.43	24.2/27.9	28.1/31.19
7	532/855	34.3/44.89	49.12/68.79	48.76/80.87	19.49/21.0	18.28/17.92
18	28/45	33.39/42.69	45.93/62	41.89/71.15	20.85/23.38	23.1/28.61
19	28/45	37.06/45.95	49.05/69.23	45.73/72.46	25.06/22.68	25.2/29.99
20	28/45	34.23/45.84	46.95/68.76	41.79/72.27	21.52/22.93	22.68/24.56
21	56/90	32.78/45.42	50.04/72.74	45.57/80.68	15.53/18.1	19.28/24.18

According to the Table 3, the values of the lateral forces determined in the experiment in a single passage can vary between 19. 59... 49.96 kN (difference 60.79%). The results of the calculations of the maximum likely values are in the range of 2.13...65.26 kN (difference 96.74%), but they significantly extend the range of the data and this trend is present in all unifications. The primary unification of lateral force values occurred in the unification of wagon types. In Table 1, for each axle, the characteristics of the wagon are shown, so the axle-by-axle unification has combined the effects of type A and F wagons, i.e., the same type of wagon. The load oscillation interval remained the same. For secondary unification, the lateral force interval was 18.28... 49.96 kN (difference 63.41%).

As can be seen from the results of Table 3, the combination of stress values was carried out similarly to the combination of lateral force values. It is very interested fact because two different kinds of values lateral force and stresses at the edges of the rail foot have not only the same unification, they have the same quantity for measuring point Г5 and К9. The reason of this is automatic unification on the position of the trolley relative to the axis of the track The difference between quantity of unification along the axles and measuring point (all sensors Г/К) is explained by different quantity of sensors utilizing for measuring values lateral force and stresses at the edges of the rail foot. The intervals of values for a single passage, the first and second combinations are respectively 39.16…88.02 MPa (difference 55.51%), 27.16…82.17 MPa (difference 66.95%), 15.83…106.6 MPa (difference 85.15%).

4. Conclusions

The existing statistical sampling system allows the variation of the number of cross-sections of track and passages of the rolling stock according to the number of sensors and the number of axles of the rolling stock to ensure an accepted coefficient of variation at the level providing a sample of the correct distribution. However, this approach excludes the study of the physics of the effect of rolling stock on the track depending on the position of the wheels relative to the track axis. The availability of statistics on vertical and lateral force ratios, for certain positions of the wheelset relative to the axis of the track, which is characterized by the wheel-rail contacts, would also make it possible to assess the functional safety of the interaction between the rolling stock and the track. Thus, the paper demonstrates the possibility of expanding knowledge on the issue under study, changing only the approach to data processing. This will allow:

– evaluate the correctness of the unification by the nature of the balance of forces for the passage of the rolling stock in the area under study;
– correctly plan the location of the sensors;
– use most of the primary recorded data.

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Artificial Intelligence and Its Use in Aviation

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Abstract

This paper analysing artificial intelligence and its application in aviation. Modern technologies have recently found extensive use in fields of robotics, engineering, healthcare, and information technology, aviation, maintenance, among others. The employment of such contemporary technology is prevalent in a number of industries, including aviation, where the main goal is to make work easier for individuals, increase the speed and efficiency of specific operations, or lower the risks of human mistakes. The main focus of this study is an analysis of the state of artificial intelligence applications in aviation today. The review focuses mostly on applications related to safety, security, maintenance air traffic control and airports. Based on previously available AI-enabled technologies, the advantages of employing AI are assessed in each of these fields. Finally, we evaluate the significance of the function artificial intelligence now plays in aviation by analysing the sources available and those used in our work using a mathematical model.
KEY WORDS: *Deep learning; Machine learning; Air transport; Airport; Aviation*

1. Introduction

Artificial intelligence is changing the way the world works today and is having a profound impact on the lives of ordinary people, while its development and improvement are accelerating rapidly. Society is using an ever-increasing amount of data, and with rapid advancement in computing and constantly improving algorithms, artificial intelligence will play a major role in all industries in the future, increasing competitiveness, productivity and, if used correctly, bringing huge economic and societal benefits [1].

However, the full potential of AI is far from being realised. Although there are many successful projects that are applying AI, understanding how AI can create business and societal value is still in its beginnings [1].

1.1. History of Artificial Intelligence

Many of the elementary methodological problems of artificial intelligence have been relevant to philosophy in ancient, medieval, and early modern times. Philosophers such as Aristotle, St. Thomas Aquinas, René Descartes, and many others addressed the questions, "What are cognitive processes?", "What are the conditions necessary for language to be an adequate tool for accurately and unambiguously describing the world?", or "Can reasoning be automated?" The first experiments that would help to answer the question "Is it possible to construct an artificial intelligence system?" could not be carried out until the 20th century. This changed with the construction of the first computers [2].

1) Turing test

The above-mentioned imitation game is in fact an operational test of artificial intelligence and can be described as follows. Three people are part of this game - a man (A), a woman (B) and an investigator (C) (Fig. 1).

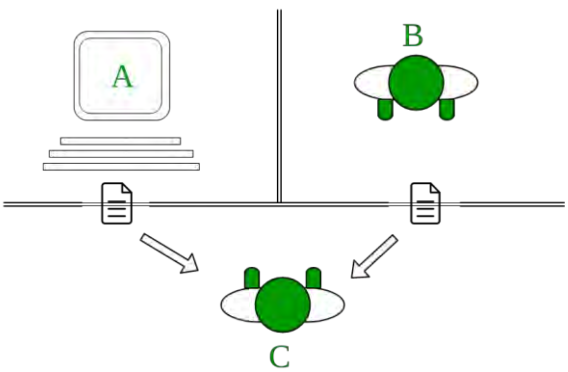

Fig. 1 Diagram of the Turing test [2]

The investigator is in a different room than the man and woman, and the investigator's goal is to determine which of the remaining two is the man and which is the woman. He knows them as X and Y. At the end of the game, the investigator assigns one of two possibilities - X is male and Y is female or Y is male and X is female. The investigator may ask questions such as, "Will X please tell me the length of his hair?" X must answer the investigator's question. Assume that X is in fact A. The object of the game for A is to try to confuse C and cause C to misidentify him. In this case, A's answer might be as follows: "My hair is long and the longest strands are up to 22 cm." To prevent secondary factors, such as tone of voice, from helping the interviewer, answers should be written on paper, but preferably on a typewriter or computer. The goal of the game for player B is to help C correctly identify the person. The best strategy for B is probably giving truthful information. He can help himself with statements such as: "I'm a woman, don't listen to him!" Player A can also make such claims. But what happens if the machine takes over Player A's role in this game? According to Turing, the artificial intelligence of a computer is the same as the intelligence of a human if the investigator cannot distinguish this change [2, 3]

2) ELIZA

The program simulated a conversation between a patient and a psychotherapist, using the person's response to shape its answer. The interaction occurred between the computer program and the user, who was seated at an electric typewriter, with the program responding to the user's answers. ELIZA convinced several people that it was an empathic psychotherapist with real insight. Users thus spent hours discussing their problems with the non-living program. It led creator Joseph Weizenbaum to reflect on the ethics and consequences of a relatively trivial program that deceives a naive user to expose his personal information. He admitted the possibility of developing an artificial intelligence program capable of understanding speech and natural languages in the future. In that case, theoretically, the program could listen to every important call, read emails, and collect users' private information. Possibly it could be used by the powerful to supress dissent and eliminate those who would threaten their existence. This raises the issue of how to teach a robot what is right and wrong. The answer lies in the three laws of robotics proposed in the book I, Robot. The first law states that a robot must not injure a human being either in its state of action or inaction. Likewise, the robot is required to obey orders (provided the order is not to cause harm to another human being), and finally, it must protect its existence as long as its future existence does not harm the human [4, 5].

3) Deep Blue

The next resurgence of artificial intelligence is coming with more advanced algorithms used by computers. One of them is the chess program Deep Blue from International Business Machines Corporation (IBM), which managed to defeat world chess champion, Garry Kasparov, in 1997. Deep Blue was supposedly able to process 200 million possible moves per second, thus determining the best move with respect to the next 20 moves ahead. He used a tree search method to process and evaluate the moves [5].

1.2. Defining Artificial Intelligence

In 1955, one of the early pioneers of artificial intelligence, John McCarthy, defined AI by saying that the goal of AI is to develop machines that behave as if they were intelligent. In order to test this definition, fifteen small robotic vehicles moving in an enclosed space of specific dimensions were used. Some of the vehicles moved slowly, others avoided collisions, and some drove aggressively. According to the previous definition, robots could be considered intelligent. However, seemingly complex behaviours can be created by simple electrical circuits. Braitenberg's vehicles have two wheels, each driven by an independent electric motor. The speed at which the motor rotates is influenced by a light sensor located at the front of the vehicle. The more the light hits the sensor, the faster it will move. Thus, the above definition is not sufficient as the main objective of AI is to solve complex problems [6].

According to the Encyclopaedia Britannica, AI can be defined as the ability of digital computers or computer-controlled robots to solve problems that are usually associated with the higher intellectual abilities of humans. Like the former, this definition is not ideal and has its shortcomings. If a computer with a large memory is capable of storing a long text and then displaying it on demand, such an action can be considered an intellectual ability, since memorizing long texts is one of the intellectual characteristics of humans. One such ability may be, for example, the rapid multiplication of two 20-digit numbers. According to this definition, then, every computer is an AI system [6].

Elaine Rich's definition can be used to resolve this dilemma, which is still relevant decades after its formation. Artificial intelligence is the research into how to force and teach computers to do things that humans are currently better at. It is a concise and accurate description of what many AI researchers have been trying to do for past 50 years. Among the strengths of digital computers, where they clearly outperform humans, is carrying out multiple and complex computations in a short amount of time. In many other areas, however, humans greatly exceed the capabilities of machines. For example, a person walking into an unfamiliar room can recognise the surroundings in minimal time and can make decisions and act quickly if necessary. According to the definition mentioned above, one of the roles of AI is learning how to cope with these situations [6].

From the perspective of air transport, three definitions immediately emerge. EASA has chosen a broad definition: AI is any technology that mimics human performance. IATA, on the other hand, in its study, refers to AI as computer programs that exhibit human intelligence, such as human reasoning, learning, and problem-solving. It can be found in both, digital (Apple's Siri, Google Now) and physical forms (robots). EUROCONTROL has used the complex definition of an AI system developed by the High-Level Expert Group on Artificial Intelligence (AI HLEG) as a starting point. Artificial Intelligence (AI) is a label for systems that exhibit intelligent behaviour by analysing and performing (to some extent autonomous) actions to achieve specific goals. AI hardware and software systems are designed by humans and operate in the physical or digital dimension by perceiving their environment through acquiring and interpreting structured or unstructured data, which they then process to perform the best action necessary to accomplish a given goal. AI systems can also adapt their behaviour based on an analysis of the environment that has been influenced by their previous actions. [7, 1, 8].

1.3. Classification of Artificial Intelligence

Artificial intelligence is usually divided into two categories according to its capabilities.

- Weak AI (also narrow AI): these are machines that simulate intelligence. They are usually designed for a specific task and therefore cannot be used outside that domain due to their limitations. They are often used to automate complex and repetitive tasks.
- Strong AI (also general AI): the main difference compared to weak AI is that machines have real intelligence. Such machines can adapt to different tasks, which they perform fully autonomously and as efficiently or even more efficiently than a human [9].

Fig. 2 shows applications of artificial intelligence.

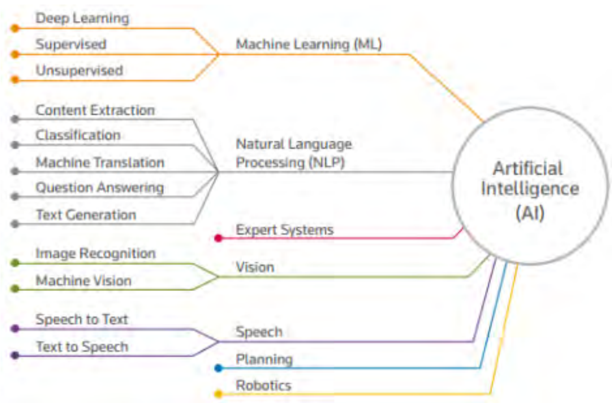

Fig. 2 Applications of artificial intelligence [7]

1) Machine learning

Machine learning (ML) refers to the ability of algorithms to learn. In relation to artificial intelligence, it is a subset of AI that includes algorithms. Machine learning algorithms require an initial, so-called training phase. In it, the parameters of a given model are optimised based on the data provided. The training algorithms are aimed at minimizing errors while satisfying certain requirements or constraints. Overfitting can occur in this phase - it occurs when the statistical model learns and memorizes data identical to the training data, thus negatively affecting the model's performance on the new data. In machine learning, we will generally be interested in three main learning methods [9] [10].

- Unsupervised: the dataset we used during the training phase does not contain output values.
- Supervised: In contrast to learning without a teacher, the model is provided a data set during training that incorporates not only inputs but also outputs.
- Reinforced: in this case, in the training phase, during each iteration, a random action is performed after evaluating the current situation, which is either rewarded or not rewarded based on the success achieved in the previous assumptions and goals.

2) Deep learning

Deep learning (DL) is a subset of machine learning and is based primarily on artificial neural networks. Similar to our human brain, deep learning uses computational cells, or neurons that interact with each other to perform simple operations. Deep neural networks consist of multiple hidden layers and are interconnected by nodes. Each layer builds on the previous one, seeking to refine and optimize the prediction [11].

The arrival of DL allows previously unsolvable problems to be solved with a precision exceeding that of humans. Image and voice recognition has become a typical example of deep learning applications. In identification, an image comes in form of an array of pixel values, and the first layer evaluates the presence or absence of edges at specific locations in the given image based on the learned features. The second layer can detect patterns by observing the arrangement of edges. The role of the third layer is to collect patterns in such a combination that it matches objects similar to the one identified. A key aspect of the whole process - and therefore of deep learning - is that the individual layers are not designed by human engineers, but learn on their own through the data they use [12].

2. The Application of AI in Aviation

The real world we live in is using more and more complex data. Even with the help of computer-aided analysis, humans identify and process such data with difficulty. It is because of its ability to identify data and its patterns that artificial intelligence seems particularly suited to the aviation sector, which is increasingly dependent on electronic data flows between ground and air systems.

2.1. EHang

The EHang autonomous vehicle technology design concept, which is superior to crew-controlled aircraft, is guided by three ideas. The first is to run as many backup systems as possible to ensure safety, the second talks about the use of autonomous pilots, and the last is about a centralized control center to manage the control of such vehicles [13].

With fully autonomous flight, human-induced failures or mistakes could be eliminated. Passengers would then be able to travel and enjoy the journey without any worries. The fact that there is no need for a large airport or runway is also considered an advantage of autonomous vehicles. EHang uses 4G and 5G wireless and high-speed transmission channel to communicate with the central control and guidance. Such transmission enables remote control of the aircraft and real-time flight data sharing. The concept also addresses the potential environmental impact. The use of electricity will significantly reduce the environmental damage caused by emissions. The aircraft takes two hours to charge, and the charging devices can communicate with the battery management system in real-time [13].

2.2. Stanley Robotics

Lyon Airport is expanding its automated parking service after a successful trial run. The airport is working with the Stanley Robotics company to increase its parking capacity. The service is to be operated by seven autonomous robots working simultaneously. Passengers can use 28 booths available 24 hours a day to park their motor vehicles. The main objective of this collaboration is to increase customer satisfaction and reduce the environmental impact of airport services. The efficiency of these services is also demonstrated by the fact that the airport was declared the best European airport in 2019 by the Airports Council International (ACI) in the category of 10 to 25 million passengers and received a carbon neutrality certificate based on automated parking [14].

In practice, the robotic parking system helps passengers find a parking space or easily locate their vehicle. If a passenger reserves a parking space through a service offered by Lyon Airport, he or she takes his or her vehicle to one of the booths. When transferring to the terminal with the help of a bus, the passenger is no longer interested in parking. That is where the robot comes in by parking the vehicle in a secure car park. When the passenger returns, the robot makes sure that the customer finds his vehicle in one of the available cabs. Using a robotic parking system is more environmentally friendly, as it creates 50% more spaces in the same area while reducing carbon dioxide emissions by eliminating the need for passengers to wander around a large area looking for a free parking space [15].

2.3. IRTOS 2.0.

IRTOS 2.0. represents the second generation of Indra's digital tower. Compared to the first generation, it is enhanced by several advanced computer vision applications that are displayed using augmented reality on a panoramic screen. All control and detection processes are performed autonomously, with alarms being triggered and air traffic controllers alerted when necessary. The aviation industry is very sensitive to the rate of false alarms that could distract attention from relevant ones. The main objective of this project is to achieve an accuracy rate of over 90% [16].

3. Methodology

In analysing the current status we have divided the use of AI into a number of areas to cover all the transport sectors in which it can be applied. In order to verify and compare the findings presented in each chapter, we decided to conduct a broader analysis of the use of AI. We have chosen aviation journals as the Source of the data, describing the use of AI in a simple non-detailed manner that will help the public understand the topic and the issue better [17].

The aim is to use research to analyse the trend in the use of AI, categorize its application in different sectors, and provide recommendations for the application of AI in the future based on a comparison of the data.

Based on the theoretical knowledge we have gained during our writing process, we set out two hypotheses.

H1 As a result of the COVID-19 pandemic, there is an increased use of artificial intelligence among airlines and at airports.

H2 AI is currently applied only on aircraft in the systems necessary for safe flight.

3.1. Procedure for Examining Questions

The process of examining the problems was designed and adapted to achieve the stated objectives of the thesis. Most important was the selection of the Sources from which we drew the data. There are many aeronautical Internet journals, so it was necessary to select the two most appropriate ones based on the relevant criteria. In making our selection, we ensured that the journal had sophisticated searching and sorting of individual articles into so-called "tags" and categories, which are extremely important in generating the input parameters needed to sort out relevant articles. The second key parameter for selecting a journal was the time horizon of its publication. As we want to assess the trend of AI usage in this thesis, it is essential that the aerospace journal archives articles from at least 2018 onwards.

The article analysis procedure consisted of the following steps:

- determining the research method - we used qualitative and quantitative methods in the analysis using statistical analysis;
- studying individual articles - we selected those articles that are relevant to our research;
- data collection, analysis and creation of statistics, interpretation of data - we recorded the data in tables, based on which we later created graphs;
- comparison of the current state with the findings, confirmation or refutation of hypotheses using t-test, drawing conclusions.

4. Analysis of the Application of AI in Aviation

Based on the presented analysis criteria, we narrowed the selection of aviation journals to two. The first one is called Aviation Today. The content of the articles in this magazine is diverse. We can find there the latest news not only from civil but also military aviation. In addition, it publishes articles in areas such as general aviation, regulation, avionics, air traffic management and futuristic concepts. The second magazine is called Future Travel Experience. Like the first magazine, it contains a diverse selection of articles. The articles are mainly focused on innovation in the field of aviation.

4.1. Defining Input Parameters

The input parameters of our analysis were chosen through keywords and tags. To select the most relevant articles from the first journal, we selected keywords that were frequently occurring in describing the current state and were closely related to the topic. We used the following keywords as a filter for the articles: "AI", "Artificial intelligence", and "Deep learning". We reached 238 results. Subsequently, it was necessary to study the articles and select those directly related to the use of AI in aviation. Out of these 238 articles, we ended up with 65. For the analysis of the second journal, Future Travel Experience, we used a tag called "Artificial intelligence" which was sufficient to determine the frequency of AI use in airlines and airports. After reviewing a total of 55 articles, we analysed 46 articles.

To observe and assess the trend of AI usage, we selected the date of publication as another parameter. The year was our guideline, as we are analysing the frequency of articles in the time interval 2017-2022.

4.2. Source Analysis, Mathematical Model Verification

As noted above, the source analysis relies on two online aviation magazines. In Aviation Today, we note two basic parameters. The first parameter is the sector in which artificial intelligence is used. This is used to allow us to statistically determine which sector is more and less interested in implementing AI. The second parameter is the year. Thanks to the frequency of occurrence of articles in a particular year, we can determine the trend of AI development in the period we have chosen (see Fig. 3).

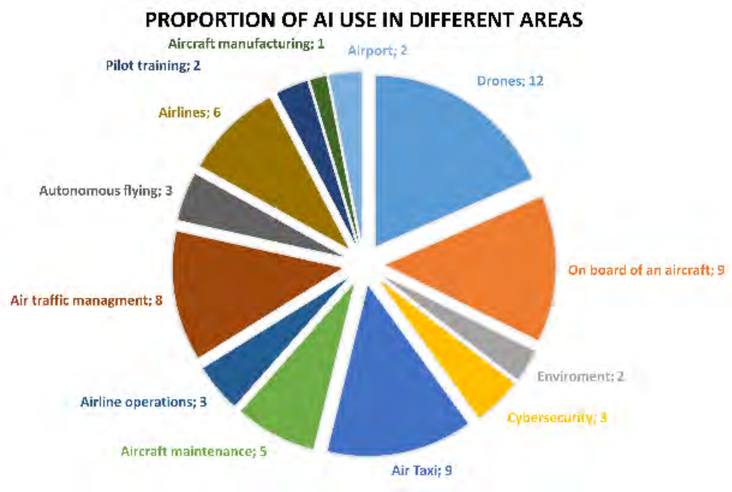

Fig. 3 Proportion of AI use in different areas

The largest number of articles was devoted to the area of drones (*12*). In second place was the application on board of an aircraft (*9*), together with the Air Taxi concept (*9*). Third place goes to air traffic management (*8*), followed by the use of AI in airline operations (*6*) and for aircraft maintenance (*5*). Equal shares are held by autonomous flying (*3*), cybersecurity (*3*) and aircraft operations (*3*). The last ranks belong to airports (*2*), environment (*2*), pilot training (*2*) and aircraft manufacturing (*1*).

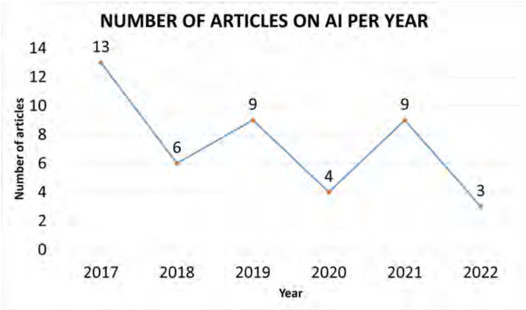

Fig. 4 Number of articles on AI per year

Based on Fig. 4, 4 articles were published in 2017. One year later, there is almost a doubling of the number of articles. Approximately the same increase occurs in 2019. The highest number of articles was seen in 2020 and only two articles less in 2021. By February 2022, 2 articles have been published.

We used the online magazine Future Travel Experience to analyse the share of AI usage in airports and airlines. The main reason we decided to analyse these two segments is that they are the most affected by the COVID-19 pandemic. The first parameter was related to the area of AI usage - airlines and airports. The second parameter was related to the specific use of AI.

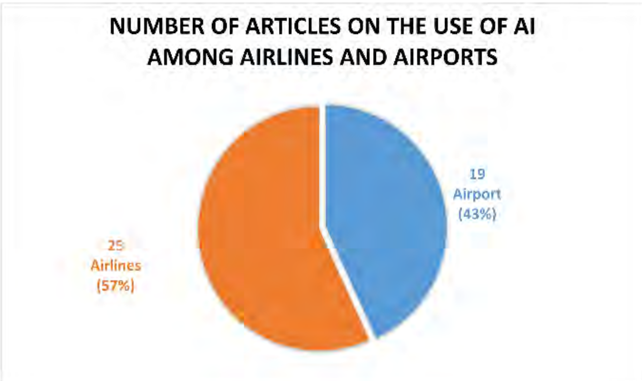

Fig. 5 Number of articles on the use of AI among airlines and airports

Of the 44 articles analysed, 25 articles (57%) discussed the use of AI in airlines. The remaining 19 articles (43%) dealt with the use of AI in the airport environment (see Fig. 5).

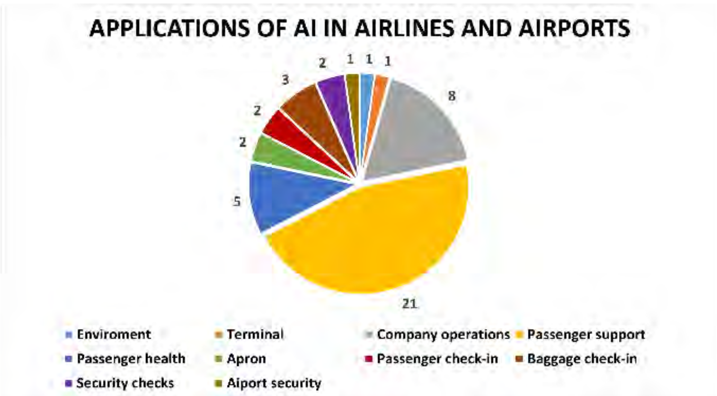

Fig. 6 Applications of AI in airlines and airports

Fig. 6 shows that AI is most used in the context of passenger support (*21*), followed by company operations (*8*) and passenger health (*5*). Smaller usage rates are observed in categories such as passenger check-in (*2*) and baggage (*3*) and security checks (*2*). The lowest usage is in the areas of airport security (*1*), terminal (*1*), environment (*1*) and apron (*1*).

Current AI research in aviation is moving towards the creation of new intelligent systems to assist humans. In relation to passengers, these include systems for recognising dangerous objects, automating baggage check-in, cleaning the airport environment, etc. Although it is not currently possible to talk about complete autonomy for these systems, many of them are capable of replacing certain human activities. In cooperation with humans, greater efficiency and accuracy of the task performed is achieved. The current state and development of AI can be described as an intermediate step towards achieving full autonomy, whether in the environment of airports, airlines or even urban air transport, which has also recently become popular.

5. Discussion

Thanks to the growing potential of artificial intelligence, there has been great room for the use of intelligent systems in recent years. With the advent of data digitization, the idea of a safer, more economical, and better environment in aviation is becoming more and more advanced. AI applications that seemed like science fiction a few years ago are now becoming a reality and an integral part of aviation infrastructure.

Hypothesis H1 asserted that the COVID-19 pandemic outbreak is leading to greater use of AI and a significant interest in AI in both airlines and airports. We assumed that during the COVID-19 pandemic there were strict anti-pandemic measures that significantly increased the workload of staff and had to be followed not only by airports but also by air carriers.

Table 1

Use of AI in airlines and airports

Sector of application	Number of articles	Arithmetic mean per year	Standard deviation	Statistical significance value
Before the COVID-19 pandemic (2017, 2018, 2019)				
Airlines	21	7,00	5,29	
Airports	7	2,33	2,081	
During the COVID-19 pandemic (2020, 2021, 2022)				
Airlines	4	1,33	1,53	0,25
Airports	12	4,00	1,73	0,34
Together	44	7,33	3,72	

Based on our analysis, we found a difference between the use of AI before and during the COVID-19 pandemic in airlines and airports. However, the question is to what extent how significant this difference is and what impact it has on the truth of hypothesis H1. Thus, we conducted a t-test, and the results showed that the results of the qualitative and quantitative analyses cannot be interpreted clearly. The value of statistical significance for the period before and during the pandemic is 0.25 for airlines and 0.34 for airports (Table 1). Both values are above 0.05, so based on these values, hypothesis H1 was not supported - we could not directly prove that the COVID-19 pandemic increased the incidence of AI in the selected sectors.

Whether AI has currently only applied onboard aircraft in systems essential for the safe flight was the content of hypothesis H2. To confirm or refute it, we again used the results of two research studies.

Table 2

Distribution of the number of articles in the sector on-board aircraft and drones

Area of application	Number of articles	Arithmetic mean per month	Standard deviation	Statistical significance value
Aircraft deck	9	0,75	0,62	0,62
Drones	12	1,00	1,28	
Together	21	1,75	1,45	

By analysing the frequency of selected articles on the use of artificial intelligence on board aircraft and in drones, we obtained a statistical significance value of 0.62 (Table 2). Hypothesis H2 was not confirmed as there is no significant statistical difference between the use of AI on board aircraft and in drones.

6. Conclusion

In the first part, we looked at the evolution of artificial intelligence. It is interesting to observe how a person with human intelligence was involved in ideas to create intelligent machines long before the first computers were created and later was able to transform these ideas into real applications.

The second part dealt with definitions of AI. As AI itself is not visible and in many cases is hidden behind complex processes with data that we do not normally perceive, it is difficult to imagine what AI actually means. Through a number of definitions from different sources we have tried to offer a general and easy to understand definition. In this part of the work, we have also characterized machine and deep learning.

In the third part, we looked at the sectors in which artificial intelligence can find its application. Companies involved in the production of various intelligent systems, autonomous vehicles and robots are responding quickly to the rapid progress in technology and computing power. By describing specific and practical examples of the use of AI in these segments, we have found that artificial intelligence can be helpful in any sector. An interesting finding in this section was that, compared to the past, artificial intelligence, together with algorithms, is improving much faster and achieving greater reliability and accuracy. By analysing the current state we have also discovered how much AI influences aviation processes and how important it is to implement it to ensure required standards, not only in terms of safety, but also in terms of environmental and ecological friendliness.

The fourth part was devoted to the analysis of journal articles. This was necessary to confirm or refute our hypotheses. After defining the input parameters, we chose two magazines - Aviation Today and Future Travel Experience. Recording the key data in tables allowed us to perform statistical analysis. The analysis led us to several findings. Airlines and airports recognize that AI progress cannot be stopped and needs to be used to its full potential in areas that will positively impact the aviation sector. Given the growing trend in the use of AI, which has not been halted even by the adverse circumstances of the pandemic, and the popularity it is receiving from the public, it is only a matter of time before AI becomes full-fledged support for humans and when it replaces human workers completely in some sectors of air transport.

Acknowledgement

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Substantiation of the Effectiveness of the Jet-Abrasive Impact on the Rails to Improve the Frictional Properties of the “Wheel-Rail” Contact

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Abstract

The article is devoted to the description of the results of an experimental test of the effectiveness of jet-abrasive impact on rails, as one of the possible ways to increase the efficiency of using sand to improve the frictional properties of the «wheel-rail» contact. Frictional properties mean the dependence of the sliding friction coefficient during rolling with sliding on the contact temperature. According to these dependencies, the clutch characteristics for selected friction compounds are con-structed.
KEY WORDS: *abrasive material, coefficient of adhesion, jet-abrasive effect, efficiency of friction transmission.*

1. Introduction

By today, a large amount of theoretical and experimental research has been carried out on various methods and devices for increasing the friction coefficient [1, 2, 3]. Most of the methods of active influence on the friction «wheel-rail» assembly provide a significant increase in the coefficient of adhesion. However, for various reasons, all of them (with the exception of the supply of quartz sand to the contact zone) are not widely used.

Considering the above, it can be argued that, in real operating conditions, the reliable operation of railway transport has been achieved solely through the use of quartz sand. This method is widely used all over the world, but along with undeniable advantages (high efficiency, ease of use, relative cheapness), it also has obvious disadvantages [4]. These shortcomings force scientists and engineers to look for methods of using sand (electrifying sand, supplying sand paste, using briquettes, etc.) that would reduce the negative consequences of its use.

One of the possible ways to increase the efficiency of sand use is the jet-abrasive impact (JAI) on the surface of the rail (or wheel and rail) [5, 6, 7]. In this case, the abrasive material (sand) under the action of compressed air is directed to the surface of the rail, affecting the frictional state of the «wheel-rail» contact, which consists in:

- removal of surface contaminants;
- formation of surface roughness, which, depending on the exposure mode, can provide a significant increase in the adhesion coefficient;
- the actual supply of sand to the contact of the wheel with the rail. In works [8, 9] it is shown that, from the point of view of traction, the best result is achieved when sand is supplied in one layer with a certain distance between the grains of sand (0,06 kg/m^2).

2. Research Results

This article is devoted to the description of the results of an experimental verification of the effectiveness of JAI on rails to improve the frictional properties of the wheel-forest-rail contact. The verification was carried out by examining the frictional properties of the «wheel-rail» contact before and after using the JAI. For comparison, the frictional characteristics of the contact were also studied when sand was applied to the surface of the rail in an amount corresponding to the normative supply of sand by the sand system of the locomotive (≈ 0,1-0,2 kg/m^2).

Friction properties here mean the dependence of the coefficient of sliding friction during rolling with sliding on the temperature in the contact.

The tests were carried out on the original friction machine, created at the Department of Railway Transport of the Higher Scientific Institution V. Dahl [10-12] (Fig. 1). Functionally, the friction machine consists of a trolley (Fig. 1) with an accelerating device (I), an orienting device (II) and a measuring unit (III) placed on it, as well as a microprocessor measuring unit (IV).

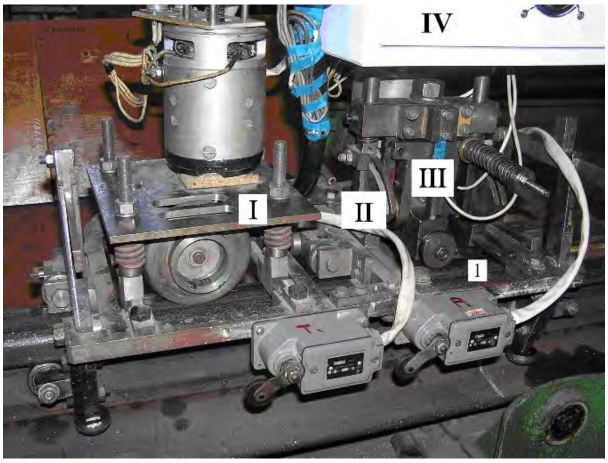

Fig. 1 Friction machine

The following were used as the initial frictional states of the rail surface: clean and dry surface; wet surface; surface covered with diesel fuel; surface coated with used M8 oil.

The experimental methodology included four series of trips with the following sequence of actions:

- the rail was brought into one of the listed frictional states, after which a series of measuring trips of the friction machine was carried out;
- further, 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 by the sand system at a locomotive speed of 5 km/h and determined by the characteristics of this modified friction state;
- after that, the rail was subjected to jet-abrasive action (Fig. 2) using the most efficient mode, and the friction characteristics were determined again.

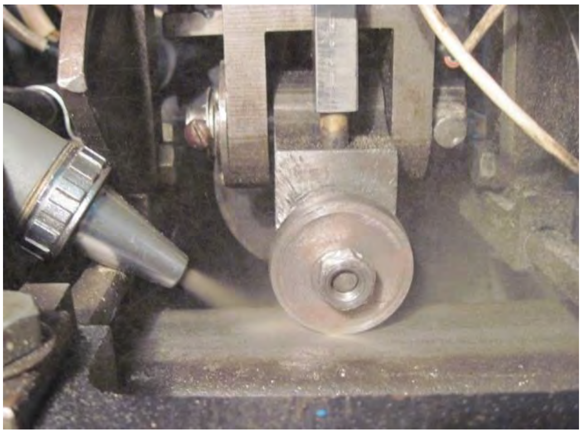
Fig. 2 Jet-abrasive impact on the bench installation

The results of the study are presented on Fig. 3-6.

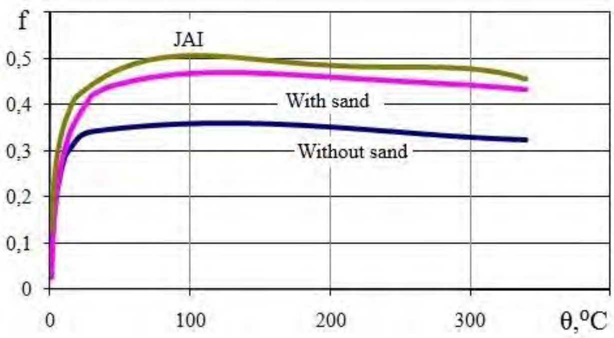

Fig. 3 The dependence of the coefficient of sliding friction during rolling with sliding on the temperature in the contact (clean, dry rail)

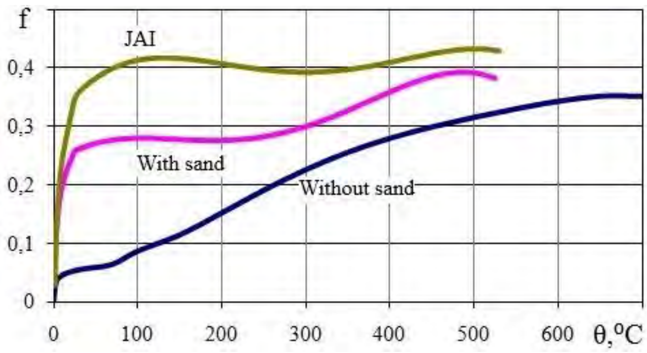

Fig. 4 The dependence of the coefficient of friction during rolling with sliding on the temperature in contact (rail covered with water)

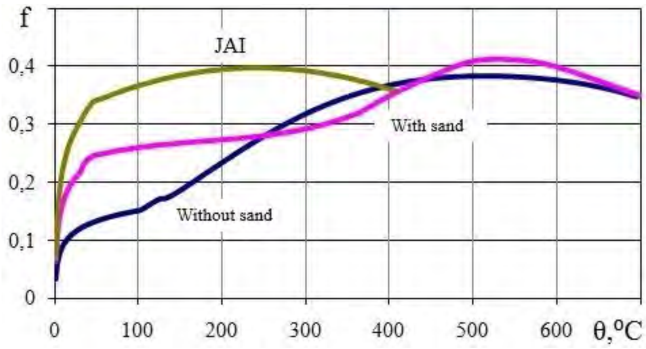

Fig. 5 The dependence of the coefficient of friction during rolling with sliding on the temperature in contact (rail covered with diesel fuel)

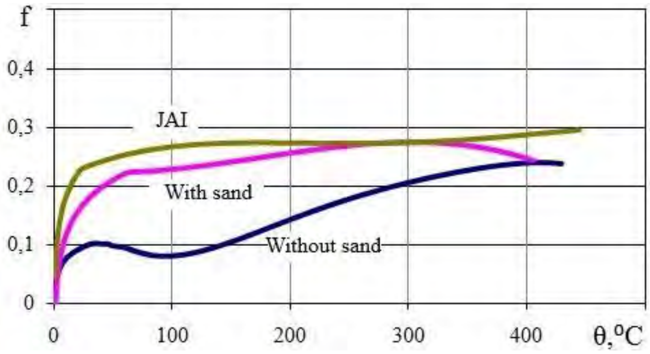

Fig. 6 The dependence of the coefficient of friction during rolling with sliding on the temperature in contact (rail covered with waste oil)

Using the results presented on Fig. 3-6, with the help of the VDEUNU CONTACT program [13], developed on the basis of a mathematical model of wheel-rail adhesion [13, 14], adhesion characteristics are constructed for the selected friction states. All calculations were carried out for the case of contact of new, unworn locomotive wheels (GOST 11018-2000) and R65 rails (GOST 51685-2000) with the central location of the wheel pair relative to the rail track. The vertical force from the side of the wheelset is assumed to be $P = 230$ kN. The calculation results are shown on Fig. 7-10.

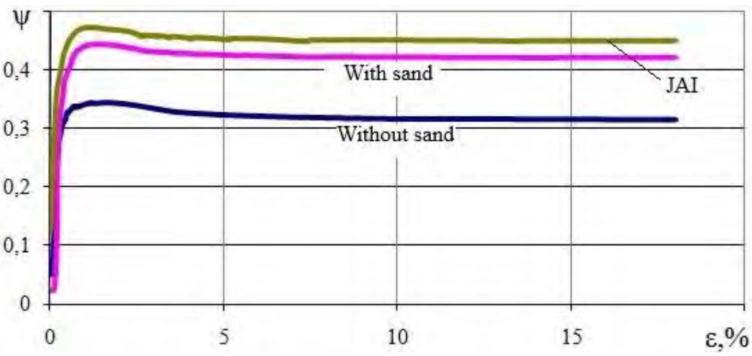

Fig. 7 Grip characteristics (clean, dry surfaces)

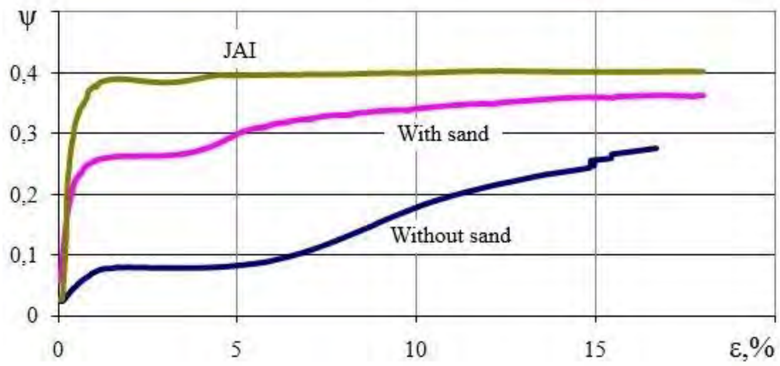

Fig. 8 Grip characteristics (wet surfaces)

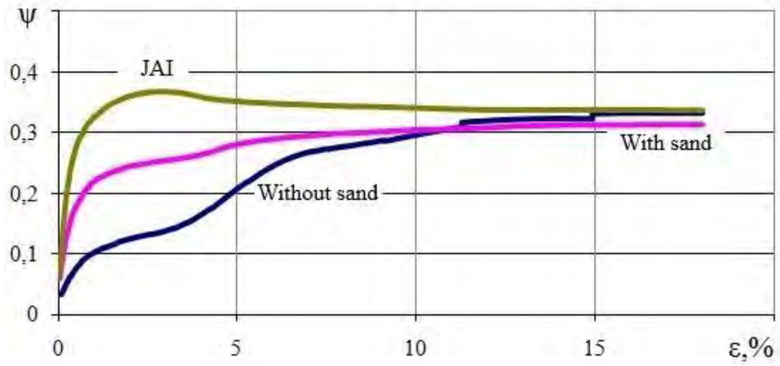

Fig. 9 Grip performance (surfaces coated with diesel)

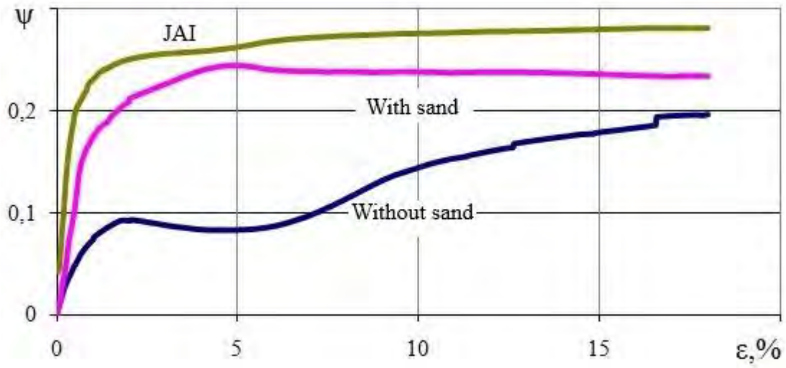

Fig. 10 Grip characteristics (surfaces coated with used oil)

The paper [15] considers the efficiency factor of friction transmission «wheel-rail». To calculate the efficiency, it is proposed to use the formula:

$$\eta = \frac{W_u}{W_g} = \frac{F_a \cdot V_л}{\left(F_a \cdot V_l + F_a \cdot V_s\right)} = \frac{1}{1 + \frac{V_s}{V_l}}, \tag{1}$$

where η – is the transmission efficiency; W_u – useful power; W_g – general power; F_a – the force of adhesion of the wheel to the rail; V_l – is the speed of the locomotive; V_s – is the sliding speed of the wheel relative to the rail.

Considering that V_s/V_l is relative slip ε, transform formula (1) to the form:

$$\eta = \frac{1}{1+\varepsilon}. \tag{2}$$

Using formula (2) according to the results presented in Fig. 7-10, the values of slip (ε) are determined and the efficiency of the wheel-rail friction transmission is calculated when implementing a traction force corresponding to a traction coefficient of 0,2. The calculation results are summarized in Table.

Table

Efficiency of friction gear «wheel-rail»

№	Friction state of the rail	Without sand		With sand		JAI	
		ε, %	Efficiency, %	ε, %	Efficiency, %	ε, %	Efficiency, %
1	Clean, dry	0,2	0,999	0,17	0,999	0,08	0,999
2	Covered with water	11,1	0,900	0,39	0,999	0,26	0,999
3	Covered with diesel fuel	4,8	0,954	0,75	0,999	0,25	0,999
4	Covered with used oil	17	0,854	1,7	0,983	0,53	0,999

3. Conclusions

Regardless of the initial frictional state of the JAI, it ensures the value of the friction coefficient not worse than 0,25.

The use of JAI in all investigated frictional states is more effective than the supply of sand.

When realizing a traction force corresponding to a friction coefficient of 0,2, the efficiency of the «wheel-rail» friction transmission at JAI exceeds 0,999, due to a decrease in the critical slip on the clutch characteristic.

Acknowledgement

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Application of Quality Management Methods in Railway Undertakings as a Support for the Competitiveness of Railway Transport in the Transport Market

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Abstract

In the transport market, railway undertakings face many of the competition challenges. The quality management methods used in various sectors and industries are a way of constantly improving the quality of services and thus the competitiveness of railway undertakings. At present, customers are increasingly demanding. The quality requirements grow. Nowadays, the majority of evaluation systems are only partial, limited to an assessment of certain factors, while many shortcomings remain hidden. New ways to seek more progressive approaches must exist accordingly for assessing the quality of services. It is difficult and costly to maintain quality in a long term. But it is the only way a railway undertaking may gain the trust of its customers in the transport market conditions. As a part of service provision, the undertaking has to make a great effort to make the customers feel like they received higher quality than expected. The authors would like to show the results of their research focused on the application of methods for the evaluation of transport service quality, such as the Quality function deployment method, Lynn Shostack method or Leonard Berry. As the author´s research showed, these advanced approaches to quality assessment would be a major milestone for railway undertakings for providing better services. The authors created a methodology that focused on the continuous improvement of processes, which lead to smarter communication between the transport company and customers. This focus brings the experience from the results of the improvement, interlinking of all improvement activities and systematic and coherent identification of quality.
KEY WORDS: *railway undertaking, quality management methods, competitiveness, transport market*

1. Introduction

The fourth railway package and authors say that strengthening of railway transport in the transport market will be able to achieve only if it provides efficient and attractive services [1-4]. Basic failures in regulation and market barriers, which undermine its effectiveness and competitiveness should be removed. It is essential for railway transport in the transport market to pay attention to the constant improvement of the quality of services. The large portfolio of services and the problems associated with their provision can be considered a demanding business environment. The expansion of services or the entry of new carriers into the market leads to enormous pressure on quality. An interesting question is which methods can be used in the environment of transport railway undertakings for continuous quality monitoring. The methods that the authors of this paper have applied in research also make a significant contribution to the correct monitoring of quality as a part of the Six Sigma philosophy. What contribution can the Six Sigma methods make to differentiate a company and its services from the competition? Do they help to create specific competitive advantages? Within the project, the authors of the research dealt with these contexts.

The decisive factor is not the introduction of a single concept, but the achievable level of increasing the value of the company's services through the overall fulfilment of customer requirements [5-7]. It is possible to achieve through the quality at the level of the zero defects and positive results concerning customers [8]. This makes it possible to meet the four central requirements of the competition, such as quality, cost, time and innovation [9].

2. Methodology Background - Quality Assessment of Transport Services

Quality evaluation in the area of services is a complex process that has to be carried out according to pre-established criteria by which quality can be assessed [10]. In general, quality can be assessed from two aspects, namely:

- technical quality - touches the process that created the service;
- functional quality - resulting from the interaction between the service provider and the customer, in this case the customer in addition to the technical quality (which may not understand) for example, assesses the behaviour of staff, comfort and so on [11].

The following methods for quality evaluation are defined in the literature [12-15]:

- objective and subjective measurement and evaluation according to evaluation criteria;
- measurement and evaluation oriented on supply and demand, including employees and company management;
- and methods according to differentiated and undifferentiated measurement and evaluation.

Unless we deal with the evaluation of the quality of transport services, there should be considered two points of this evaluation not made only by the side of carrier (service provider) but also in terms of passenger [16]. Based on these facts, the authors propose in extensive research approaches and the use of methods that were not originally intended for railway transport, but their application in railway conditions is beneficial [17].

2.1. Quality Assessment in Terms of Railway Undertaking and in Terms of Customer

Evaluation of the quality of services in terms of the railway undertaking (in other words carrier) can be done in several ways resp. processes. Based on the authors' research, the following systematic steps should be taken in the practical implementation of the correct quality assessment methodology. The key processes which justify the level of fulfilment defined quality requirements set by the carrier include:

- Management review - is one of the core processes that through its level and chosen methods may substantially affect the work of management and the company's future. The whole management review will be efficient and effective only if it is not done formally, so the output will not only finding the state, but the outcomes will be systematically addressed. The results obtained from the findings are valuable and important information for planning further activities in the process of improving and developing resources.
- Self-evaluation - is a broad and systematic review of activities and performance of the organization compared to the quality management system or a model of excellence (EFQM – European Foundation Quality Model). The basic objective of the self-evaluation is to reveal the strengths and opportunities for improvement.
- Quality audit - is currently the most effective tool to assess the functionality of the quality management system and serves as an identifier for process improvement initiatives. Quality audit provides objective evidence concerning the need to reduce non-compliance, remove them and above all to prevent them. The results of these audits can be used by management to improve the organization's activities [18].

Quality evaluation of transport services in terms of customer is largely done through a survey using a questionnaire method assessing the quality of services. Another way how to evaluate the quality of service in terms of customer may be an amount of written complaints, which directly point to customer dissatisfaction and the reasons for the discontent [19].

At present, however, does not regularly measure and assess quality in terms of customers but in the interests of the carrier should be just identifying their specific requirements [20]. Measurement and evaluation of satisfaction from customers should be carried out at regular intervals, but at least prior to entering into performance contracts in the public interest [21, 22]. While the duty to be measured and assessed should have both a public operator and a private carrier.

But as the authors' research shows, there are other ways to link quality assessment concerning the view of an undertaking and customers [23]. How can technical requirements for products be captured and combined with customer requirements? This is possible in the case of railway transport through the Quality Function Deployment method which is a structured method that uses the management and planning tools to identify and prioritize customers' expectations quickly and effectively [24].

At the same time within an excellent methodology for quality assessment, we can use event-oriented methods which are based on the belief that a customer notices certain standard or important events during the process of service provision. The essence of these methods is to measure quality of the contact between a customer and the employees. The sequential method, such as Lynn Shostack method, breaks down the process of service provision into more incremental steps, it is based on phase-oriented questionnaire, blueprinting of relations between the service provider and the customer, and it can be used in the evaluation of sub-processes [25].

Another method that the authors point out in a correct methodology for quality assessment in the railway transport is Leonard Berry model.

3. Quality Function Deployment Application in Railway Transport

According to QFD's ancestor, this method means targeted planning and development of product functions with regard to the features required by customers. In more detail, it is an integrated process of developing such services that will be adequately focused on customer needs and at the same time highly valuable in terms of quality [26]. Although this method can be time consuming, it is successful in the long run and we do not see its frequent applications in rail transport. This method accurately combines customer-tailored development, gathering the knowledge and skills of employees, their motivation, increasing the efficiency and effectiveness of processes These are the basic preconditions that a railway undertaking also needs in the market. The method also emphasizes the need to intensify cooperation, preventive service planning and comprehensible documentation by developing a QFD map in Fig. 1 (detailed parameters are shown). This method is the basis for the correct setting of the service parameters and also enables comparison with the competition within Benchmarking which deals with [27].

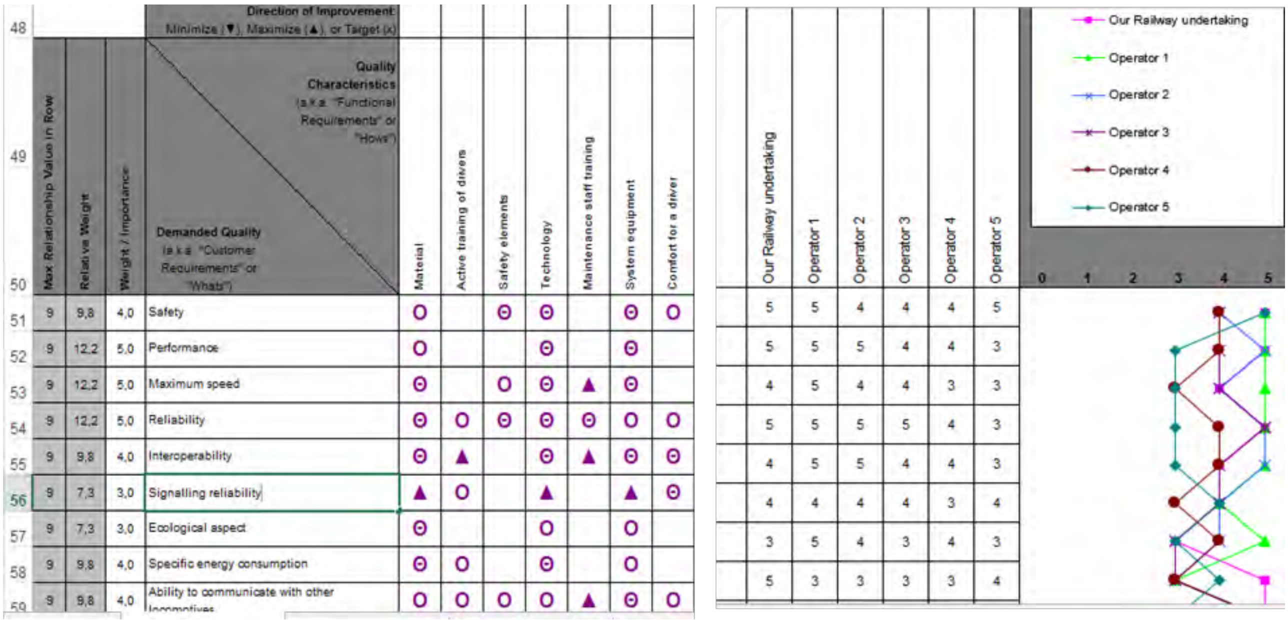

Fig. 1 A fragment of QFD method in a new locomotive design

4. Lynn Shostack Method in Railway Transport Services

The method considers the so-called line of visibility, a line of perception, when the limit is determined for visible components for the customer and invisible components (more in the description of the Lynn Shostack model). It is required that customers sum up the progress of the service provision process and their impressions in an open structured interview. The customer points of contact of a decisive significance are identified, when customer is in direct contact with the service provider.

The model uses the "blueprinting" method, which is often used in the preparation of studies about quality. It is a plan or a scheme, where a set of contact points is provided.

On the basis of the contact points the customer can assess the qualitative strengths and weaknesses. The contact points are separated by "lines of perception" from processes that are involved in the creation of performance towards services on the one hand, but are hidden from the customer and the customer cannot evaluate them, only insufficiently. However, these effects may become visible in a later contact or in an outcome of the performance. These dimensions are defined in more detail for the process of service performance creation in the transport sector in Fig. 2.

Even when a customer evaluates only the problems that he really remembers and considers appropriate to mention, this method proves to be advantageous because it can be used in the evaluation of service provision in the various phases of the carriage process as actually seen by the customer.

service provider	*COMPLAINTS - return of fare, non-compliance with selected standards*	customer
the contractual relationship between the carrier and the infrastructure manager on compensation for non-fault delays on the part of the carrier		passenger's stay in the train set - dissatisfaction with meeting and adhering to selected travel and hygiene standards
contractual relationship between the carrier and the customer - services for selected standards		passenger's stay at the railway station - waiting for a missed connection
contractual relationship between the carrier and the customer of services - scope of services		passenger's stay at the railway station - missed connection
tarifa/zmluvné prepravné podmienky dopravcu		visit to the personal cash desk - complaint request
		visit to the website - complaint request
internal guidelines and regulations for managing and handling complaints and claims		use of the contact center by the customer via the telephone set - complaint request
internal guidelines and rules of procedure for securing connection / on time connection		train crew confrontation - request for correction / complaint
		visit to the website - access to the carrier's tariff / contractual conditions of carriage
internal guidelines and regulations for dealing with breaches of selected standards		less reliability and negative perception of railway transport as a whole due to connection delays / connection delays
training of contact center staff / cashiers / train crew		
software, website		
Sufficient number of contact center staff / cashiers / train crew - possibility to respond promptly to customer requirements		

Fig. 2 A simplified diagram of the contact points for reservations and selling travel documents

In the model by Lynn Shostack, the service provision process must be mapped and reconstructed. A customer responds in an open interview about experiences, which can be critical or uncritical, positive or negative. An important result of using this method is that the railway undertaking is aware of the points of perception of the service and its quality from the customer's point of view.

5. Leonard Berry Model Application

Customer expectations with regard to a service provision programme are characterised by a routine dimension of quality under normal conditions or an extraordinary dimension, when there is a disturbance in the routine process of providing service [28]. The model can be used in the evaluation of the quality of the services rendered in normal operation, but also in the case of extraordinary events (emergency). It distinguishes two different dimensions of quality – the routine dimension and the emergency dimension. The characteristics of the routine dimension are typical of normal operation, when the service is provided under normal conditions. That is when the customer expects the course of the carriage to be in the way this process is known to the customer. The service provision process is a matter of routine for the employees, and is standardised. Fig. 3 shows a system of the model when extraordinary dimension occurs.

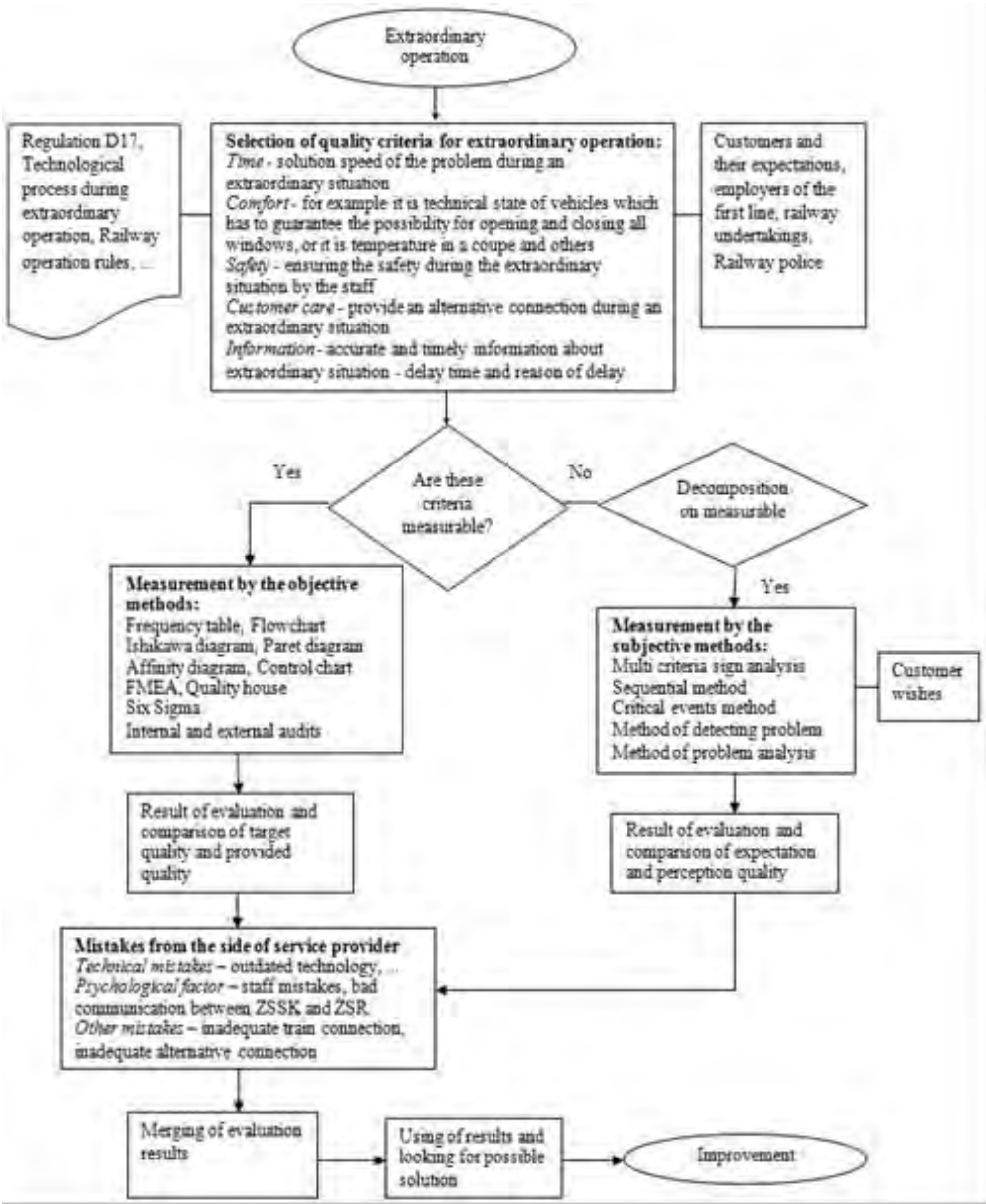

Fig. 3 Model Leonard Berry in application to the assessment of the extraordinary railway operation

The emergency dimension's characteristics are expected by the customer only in exceptional situations. They may be caused by the weaker performance, error on the part of the carrier, as well as the service provider, or the emergency occurs in connection with the necessity of an unusual approach to a customer who requires such an individuality. These characters also include additional performances in customer care, which are not expected by the customer, for example, after the end of the carriage.

In terms of the model it is essential to carry out a selection of characteristics for normal and emergency operation and then determine whether it is possible to measure those characteristics, that is to evaluate those using objective methods, or whether the characteristics are to be evaluated using subjective methods because they are difficult to quantify. To assess the resulting level of quality it is necessary to combine the results of measurement and evaluation of both types of the methods (perhaps using a combination of a number of methods). All of the above principles of the model must be based on clearly defined quality objectives of the railway undertaking as well as on the expectations and needs of customers.

The efforts of a transport enterprise to attain higher quality transport are identical with the efforts to achieve development and progress. The ability of a transport enterprise to develop is based on the ability to monitor independently the opportunities, changes, trends and risks of the external environment. The transport enterprise must also have an ability to learn, to change and to innovate, using effectively and efficiently managed harmonised processes according to the quality management principles.

6. Conclusions

The perfectionist concept is crucial in improving the quality of services. At the same time, continuous and fast implementation of certain know-how. This fact also applies to the application of the methods mentioned in the authors' research in railway transport. Railway undertakings often do not have experience in implementing management methods to improve quality. This is not only a continuous use of data and statistical analysis, but also a continuous measurement of the company's operational performance and subsequent improvement. Also achieving the quality of zero defects in practical operation, when it is important to maintain the safety and fluidity of traffic on the railways.

In order to properly understand the system, how the quality of railway transport services can be improved, research brings new practices that have not yet been identified in operation. They were applied to the national railway operator, which strengthened its position in the transport market by starting the implementation of methods, where in 2022 it achieved an increase in transport performance by 17.4% compared to the same period in 2021. At the same time it reduced the number of justified customer complaints by 11%. If it continues to improve quality through a set methodology, it is essential to monitor the results. It is important to connect the needs of customers with the railway undertaking's intentions, while communicating with employees and constantly maintain a positive motivational atmosphere in the provision of services.

These methods and their use may have their limits if their users are afraid of success or are not convinced of their suitability or their procedures have not been properly communicated. The methodology does not need to be understood as a quick program to reduce costs or job losses because we can provide services more efficiently and quickly and we do not need so many people. The new application of the methods seeks to increase customer satisfaction, increase economy and performance with less loss due to lower quality costs. The result is also an increase in competitiveness. It is a system of slower steps that really motivates the whole railway undertaking to make continuous changes, not leaps and bounds. The implementation of the methodology into the system of constantly improving the quality of services affects not only customer satisfaction, but also customer loyalty and the strategy of the railway undertaking leading to increased competitiveness.

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Resilience of Seaport Ecosystem: Theoretical Approach and Future Research

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Abstract

Authors provide a theoretical approach to enhancement of port ecosystems resilience. Resiliency as such is an important factor for the greater attractiveness of maritime services in the region. As the latter years' unforecastable events in geopolitics and pandemics revealed, the adaptability of different sectors of economy shows differently, yet it is important to ensure the logistics between countries in emergent conditions for the supply of required raw materials and products. Thus the authors attempt to theoretically justify the importance of said factor by adding the important parameter in the research of effective port governance and maritime transport attractiveness. The innovative approach of the study lies in the application of the term to managerial innovations in view of the resilience framework construction, since the effective governance usually is based on the changes in the overall port governance mode and management systems that altogether imply long processes and can not adapt for rapid responsiveness to critical situations; and the managerial interventions are more flexible way to react to the contingent externalities. The analysis of multiple studies on the adaptability of port business, business models evolution, managerial innovation and port governance found out that the resilience framework has to be based on the main unforecastable disruptions, and the enhancement of the resilience should be carried out through managerial interventions by placing them into clearly defined multilevel action plan. But as the seaport ecosystem is an immense interaction between port stakeholders and different business models, the resiliency enhancement framework becomes a complex multi-criterial task in port development, and given the identified low level investigation of this field it is resumed that these researches should be continued.
KEYWORDS: *seaport organizational ecosystem, managerial interventions, organizational resilience*.

1. Introduction

Research has proven that development of seaport governance passed strong evolutionary process throughout the last century of industrial and international trade development under intensifying globalisation process as the result of four industrial revolutions. According to seaports' evolution from the cargo handling node between foreland's and hinterland' vehicles (ports of first generation) toward the complex system working in the highly uncertain and emergent environment and taking into the market the whole package of wide area of services and added value for all stakeholders (ports of fifth generation) and implementing 90% of global trade. So, the seaport governance effectiveness and maritime transportation attractiveness have become one of the goals of the national transport policy's development in the context of formation of highly integrated and strongly connected global supply logistic chain geographically located on the national infrastructure. In this context the effectively managed seaports enable all other parameters of the whole maritime transport attractiveness.

Last three-year global emergencies with the global pandemic conditions and mobility restrictions, different geopolitical events in various regions had a big impact, including both- positive and negative, on the international trade processes and also on the global, regional and national economies. In these emergency conditions, the new parameters emerged in the private and public business models – such as standby preparedness for these emergencies, and simply being organizationally effective, sustainable and environmentally friendly and overall attractive turned out to be not enough. Subject to these changes, the scientific research focused in the domain of effective governance shifted the research object to analysis of the system resilience, because it was found that the potential of effective management system implemented in an organization could result in higher organizational resilience in different domains of externalities. Though resilience theme in maritime transport sector is not abundant, yet some research has been performed. A couple of newest findings were studied in detail and it was found out that research on resilience of maritime systems was fragmented and specific, but according to the newest analysis results, the buoyancy of seaports could be a denoting parameter when establishing ports position in the international market. Whereas the resilience of a port organizational ecosystem could be described as the result of effective managerial interventions in order to improve the implemented port governance model.

Based on these statements, the research object is the resilience enhancement possibilities in a seaport's organizational ecosystem, and the research goal is to theoretically investigate possible trend for future research in the area of strengthening seaport ecosystem's organizational resiliency. For implementation of this goal the following research objectives were identified: to describe the seaport's organizational ecosystem resilience; to substantiate the relationship between maritime transport attractiveness and seaport ecosystem's organizational adaptability; to construct a theoretical framework for future investigations into the seaport ecosystem's resilience enhancement potential, and also the relation between the widely discussed effective port governance and maritime transport sector attractiveness. To implement this theoretical approach the method of scientific sources investigation was applied which covered analysis of related conceptions in scientific sources as seaport ecosystem, organizational resilience, resilience enhancement methodology, managerial interventions and disruptions of port activities, further combining them into the construct of possible resilience enhancement framework, with further analysis of investigation level of a selected research field.

2. Analysis of Seaport Ecosystem's Organizational Resilience

Along with increasing possibilities of global emergencies and contingencies in the global trade the concept of business models also has changed and evolved to meet new needs and this evolution faced challenges for the whole maritime transport sector. Massa et al. (2017) defined business models as an illustration of organizational functions and moves to achieve their goals, such as value creation, value capture, and growth [1]. In this sense, seaport business models could be analysed as well as how organizations work and create value. Traditional business models have focused on value creation from the supply-side and value capture from the demand-side, while the newest seaport business models have placed more emphasis on business ecosystems and stakeholder interaction [2], so the scientific interest became more located on the investigations of the seaport ecosystem's business models (SEMB) and their management specifics.

It should be mentioned, that seaport ecosystem conception is not so new in the scientific researches in maritime transport sector. Previous research on the seaport governance effectiveness in the context of globalisation also payed attention on the development of specialised maritime networks and clusters especially in the container shipping field and these scientific findings influenced the research in the field of modelling effective port governance patterns based on the co-operational competitiveness [3] and path dependence [4, 5]. But the deeper analysis of port business ecosystem and stakeholders' interaction was described in the researches of R. Van Leeuwen [6] and K. Ibrahimi [7] where they presented seaports as the maritime clusters where a lot of relationships between stakeholders are placed in some triads of sub-networks [6] and the port governance performance were dependent on the effectiveness of management these relationships by applying the methodology of ecosystem-based management. These findings justified that the seaport clusters started to develop as the seaport ecosystem in the maritime transportation researches and the governmental aim started to be to facilitate the exchange of rules, data, services, actions and views to provide opportunities and value for related stakeholders by using appropriate SEBM [2].

It is important to note, that in the context of port governance these SEBM are placed as covered component in seaport governance model, which indicate main aspects of governance performance and maritime transport sector attractiveness, but rapid changes and emergent global events have raised the additional need for the stability of these SEBM by increasing their successful responsiveness for the contingency. And these needs enabled the new conception of organizational ecosystem and the management models of these models focus on social and economic interaction to create value by providing an infrastructure for stakeholders' communication and actions within the ecosystem [8]. And seaport as the central point of maritime transport sector are a good example of such ecosystems where many players interact with each other and these interactions should be managed in the most effective way and also, they should be responsive and fast recoverable in contingent conditions which are the main parts of the resilience conception.

The conception of the organizational ecosystem's resilience is rarely analysed in the context of attractiveness of maritime transport sector, but relation between effective governance and high system resiliency was justified in these researches. Generally, the organizational resilience comprises numerous and divergent themes. Researchers often use their own label for the concept (e.g., organizational resilience, resilience capacity, resilience potential, and resilient organization), and there are numerous independent, ambiguous, and partly inconsistent definitions of the construct [9] related with the resistance and recovery, adaptation, anticipation, but all of them have strong tendency toward the preparedness for the emergent externalities and are based on the modern management theories. Description of seaport organizational ecosystem conception is important in the widely analysed problem field of effective port governance and attractive maritime sector, but only some researches were oriented to the seaport organizational ecosystem analysis from the perspectives of port governance, mostly researches focus on the seaports' cauterization benefits and the competitive advantages of the national and regional economies. This is noteworthy.

These previous findings enabled the idea of importance of resilience enhancement in maritime affairs and also lets to justify the novelty of research in maritime scientific research by keeping high level of importance for the sustainable or profitable development of all organizational ecosystem of seaport with the creation of added value for all stakeholders. And the conception of seaport ecosystem's resilience could create the relationship between these researches for finding the values of the whole ecosystem resistance to the contingency. But at the moment the seaport ecosystems organizational resilience analyses are very fragmented and they could be divided into different categories where resilience phenomenon was investigated as it is presented in Table.

As it is seen in the Table scientific researches shifted the research object to the system resilience researches field because as it found out the result of implemented effective management system with the resilient business model in organization could be the higher as the higher will be the organizational resilience in different domains of externalities. And according to fragmentation and specialisation of researches has been done in port and maritime resilience research field it was defined that the global seaport ecosystem resilience framework was not elaborated yet and development of such type of framework could be realised by applying managerial interventions as improvements of existent governance models covered by business models and management systems.

In resuming it could be said that selected research field is not very deeply elaborated in previous researches on national and international level but the problem is actual for each country exploited seaports for the international trade purposes. And the idea of researches is allocated on the integral decision to find the possibilities to increase maritime transport sector attractiveness by including external stressors and the instrumentation to fight them into the improvement of seaport governance effectiveness for the ensuring the resilience of the whole organizational ecosystems.

Table

The resilience phenomena investigation in scientific maritime research

Domain	Analysis field
Digitization	It was found out that the port resilience depends on the information accessibility, and this point of view increasing in the importance according to intensifying of digitization processes in maritime transport sector. Interesting findings were done during port resilience analysis in the combination with Lean, Agile methodologies and greening conception. It is also crucial point of view because digitization of global supply chain is going to be more intensive in progress so digitization could be one of emergent factors in the development of environmentally friendly ports [10]
Climate changes	It was found out the port resilience investigation is important in the context of climate changes conditions and they applied the focus group interview methodology in their research, and this methodological idea was used in the construction of project research methodology. Also, the repercussions of the pandemic sent warnings to all the relevant actors in preparing plans and increasing their resilience for future risks and disruptions as well as to ensure that shipping, ports, and terminals function well along the global supply chain [11]
Pandemics	It was found out the resilience enhancement framework for the maritime transport sector should include the components nor only adaptability but also elements of creativity which is one of the most important factors facing the challenges of uncertainty [12]
Evolution of supply chains	It was discussed the resilience of maritime transport as an important factor for the ensuring supply logistic during the pandemics [12]. As the resilience of global supply chain also is under the influence of maritime transport sector resilience, some authors started to elaborate the optimal decision-making problem field on the global supply chain management level, and to look for the resilience ensuring possibilities on the maritime governance level in after pandemic conditions under the pressure of different possible restrictions [13].
Networking	Some research are in the field of port networks resilience which are relative but different from the port's organizational ecosystem resilience, but their applied methodology could be adopted in the construction of framework, because is based on the conjunction of reliability and resilience of port networks [3]. But the research was oriented to the path optimization solutions and imitational modelling of different scenarios of planned roots. [14] also made analysis of resilience of deep-water port but with the concentrating research into the port operations by excluding other externalities. Other researchers suggest that the organizational resilience could be dependent on the networking level of stakeholders and on the relationships between ecosystem members [15].
Port governance	The research on the EU policy formation level could justify the importance of selected topic, because the resilience became as additional very important domain in the formation of governance models in organizations which could assess the contingency and emergency of externalities [16]. But in addition, investigations on the managerial interventions as the extensions of governance practices could be found in this domain: they were more related with the human recourse management, so the adoption of managerial interventions on the governance improvement level could be as the innovation in the problem's scientific field [17, 18].
Connectivity	Other part of scientific researches is oriented to the investigation of resilience in the field of linear shipping including container shipping resilience conditions which ensure the supply of consuming product [19-23].
Port and city integration	Important researches also were done in the area on port and port cities integrational resilience, including the socio-economic impact on port cities' society [23-25].

3. Theoretical Modelling of Seaport Ecosystem's Resilience Enhancement Theoretical Framework

For the enhancement of the resilience it is important to identify all port governance parameters and as it is shown in Fig. 1, port governance on the highest level of management hierarchy controls the added value co-creation and covers port governance legislation as well as the strategical management level covers functions of port authority (Fig. 1).

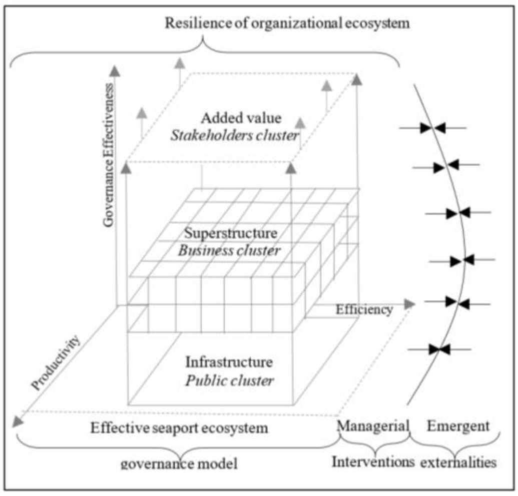

Fig. 1 Seaport ecosystem's organizational resilience model [26]

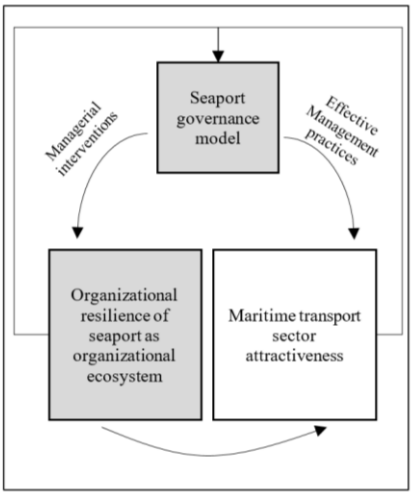

Fig. 2 Resilience impact on maritime transport attractiveness

But based on the theoretical findings, the changes in background governance models and/or in the implemented management systems could take a long time because law and other formal procedures required to be implemented. As it is presented in Fig. 1, all changes on the fundamental level of seaport ecosystem will enable a big amount of changes in all structure. But then we are talking about the resilience for contingent externalities we are talking about fast short-term operational processes, which could eliminate or minimise the effect of different type of disruptions which can influence the attractiveness of seaport and also maritime transport. And as it was found in previous researches on the effectiveness of port governance [5, 6, 26] higher effectiveness influences higher attractiveness of the whole maritime transport system, which is consisted of three dimensions of attractiveness parameters grouped in to the port authority and port performance and port logistical connectivity. For the managing and control this relationship between port governance effectiveness and maritime transport sector attractiveness, different management practices descripted in seaport business models are applied dependant on the patterns of seaport governance model. It means that maritime transport sector covers the conception of ecosystem and the effective port governance ensure the wellbeing of the whole ecosystem.

But as it was mentioned in the newest researches on seaport business models [1, 2] and port resilience [3, 28], some critical points of interconnections of ecosystem with the environment are not minimized by the governance models and patterns, so the additional managerial interventions should be applied for the creation of the ecosystem's resistant to these factors' dependant on their nature (Fig. 3) where visualised that the resilience should be enhanced not only in the relationship with the contingency in the outside environment, but also it should include important internal emergent parameters as it is presented [27]: external threats are political, economic social, technological environmental and legislator factors divided into the sub-groups, and internal treats are human, organizations, networking and access factors also divided into the sub-groups. All these disruptions can stem from a variety of factors: some are foreseeable, many are accidental and others are unanticipated. It is natural that maritime transportation is dependant on the weather conditions, but additional natural dangers to port ecosystems exists under the umbrella of multifaceted consequences of climate change, the biggest part of which are uncertain and difficult to quantify [28]. But, for example the human factors on the domain of decision making inside the ecosystem could influence not only internal accidents, but also external accidents and the level of contingency here is very high. These interdependencies including direct and indirect relationships between factors make the task more complicated for the solve the resilience enhancement questions. And it is obvious that implemented governance models and patterns including applied management systems and practices cannot enhance the resistance to these threats, but the additional tools in the kind of managerial interventions could be applied even they are more related with the specific field of threats and their contingency level even if they are more adopted for the field of human resources management.

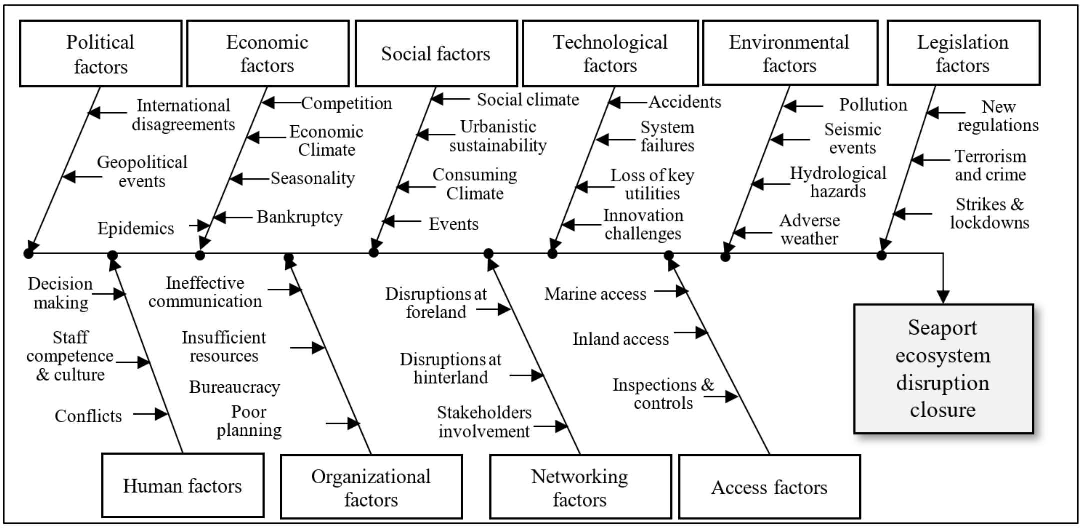

Fig. 3 Seaport ecosystem's threats illustrating the resilience enhancement framework multi-layered structure [27]

It should be mentioned that the conception of managerial interventions went out from psychology sciences' as educational interventions for the enhancement of mental resilience, but it was started be adopted in different fields or scientific expertise [17, 18] one of whom is the field of effective port governance for the finding special set of managerial principles and tools additionally to the existing business model [29]. As the existed implemented port governance model and legal regulation strongly influences not only on the attractiveness of the whole maritime sector, but also influences on the formation of good practices to develop the port organizational ecosystem which is also is the key element of attractiveness. But the existent threats and high level of contingency are not dependant and are not controlled by developed governance framework and the set of strategical management tools should be created for the reaction to these emergent and contingent disturbances and these tools in scientific researches are called managerial interventions as well as an additional working frameworks for the developing resistance of whole ecosystem to these critical points which could enable to stop functioning and wellbeing of the whole ecosystem. In addition, it is easier to be responsive to contingency challenges then you are the part of ecosystem instead you are alone organizational unit. So, the seaport ecosystem's organizational resilience enhancement framework could be described as the collection of managerial interventions expressed in different frameworks for the developing resilience in each category of threats as well as separate as well as multi collected. Based on these findings the resilience enhancement framework of seaport organizational ecosystem could be presented as the combination of managerial interventions placed in different domains representing these external and internal contingent disruptions and the specific action plan how to combine them according to implemented governance pattern and management system. And the construction of such multicriterial system require to additional deep prescientific researches in the field of fast identification of possible disruptions and their combinations and operative reaction through the innovative and on-time managerial interventions.

The full classification of possible and usable managerial interventions is presented in the research of T. C. Bednall and M. D. Henricks (2021). They found out that in the contingency of pandemics and geopolitical situations there is no single intervention that will ensure the adaptability of organization but exist complex frameworks of managerial interventions which should be applied according to the developed business model [18]. Big interest in managerial interventions could be found in the researches based on the adaptivity conditions which are important parameter in complex systems where also important role is dedicated for the knowledge-based management. As the K. K. Law and A. Chan (2017) found out that the modern organizations increase their resilience for the contingency through the creativity in knowledge-based management methodology which is one of the important tools for the resilience management [17]. They found out that in knowledge-based management style three types of managerial interventions should be identified: initiating intervention, reinforcing intervention and aligning intervention - which are particularly useful to promote resilience management among the organizational ecosystems.

As it was presented in Fig. 2, the managerial interventions are dedicated for the fast reaction to the externalities and contingencies, they should be also prepared for the reaction to the disruptions of port ecosystem's disruptions, so if the resilience enhancement framework could be constructed on the base o the multicriterial structure of different types of ecosystem's disruption, the managerial interventions for the increasing resilience should be placed in the clearly defined action plan according to the resilience enhancement framework. But as it was found the scientific researches on these structural modelling tasks is not enough and should be deeply elaborated, but the research field becomes the important part of maritime governance researches.

Also it is important to mention that interventions to improve general adaptability and recovering may be less useful when more specific characteristics are required to manage different types of disruption especially when the resilience of seaport ecosystem is analysed because researches of resilience called as adaptive performance is relatively small compared to the forms of performance and attractiveness, and also there is a lack of consistent researches on the antecedents of resilience which means that it is difficult to assess how universally effective specific managerial interventions are likely to be, as well as determine any relevant consequences that may limit their effectiveness. And this fact lets to justify that the researches on the managerial interventions are important for the developing the resilience enhancement frameworks in maritime ecosystems.

4. Conclusions

It was found out that the seaport ecosystem resilience firstly is related to the complexity of the maritime transport sector where a big number of interrelated stakeholders have big amount of interactions through operations and transactions. Literature analysis found out that the concept of seaport ecosystem was developed starting from port community network, port cluster conceptions, but the ecosystemic point of view includes the importance of the externalities and contingency. In this context the responsiveness and recovery, and adaptation to emergent factors of the seaport ecosystem is an important parameter when looking for the increase of the effectiveness of port governance.

Scientific research on the responsiveness, recovery and adaptation of port ecosystems found hat all these conceptions can be combined together into one conception of resilience, so the resilience enhancement framework for the seaport ecosystems should be constructed on the basis of the collection of possible contingent disruptions influencing the disruption of the seaport and whole ecosystem and this fact could decrease the attractiveness of seaport and maritime transportations strongly. It means that the maritime transport attractiveness depends not only on the effectiveness of seaport governance, but also on the level of resilience of seaport ecosystem.

As the scientific literature analysis found the resilience enhancement multi-layered framework could be constructed according to identified seaport ecosystem's unpredictable disruptions and the resilience enhancement could be realised on the base of managerial intervention. Usually researches on the increasing of maritime attractiveness or port governance effectiveness are looking for the changes in the background models of seaport governance and management system, but these changes require a lot of time for implementing the law and other formal procedures, whereas the managerial interventions are dedicated for the fast reaction to the emergencies and finding of these managerial interventions can help to enhance the resilience without long-term procedures on management systems. Also, the usage of managerial interventions allows to implementation of management innovations for the purposes of short-term fast-reaction actions. But the theoretical approach also identified the complexity of the task of resilience enhancement for the seaport ecosystem tasks because their multi-layered interconnected nature and multicriterial influence structure on the disruption of the seaport ecosystem. According to the identified low level investigations of this field it is resumed that these researches should be continued because they allow to find responses to emergencies and to keep systems in fast recovering adaptation. And these are important factors ensuring the attractiveness of the maritime transport sector.

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Communication Technologies Used in Intelligent Transportation Systems

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Abstract

Today's transportation systems are facing many significant challenges such as congestion, accidents, air pollution and noise. Intelligent Transport Systems (ITS), which include telecommunications and IT solutions, can help solve these problems. Advantages resulting from implementation of ITS solutions include obtaining safer, more efficient and more environmentally friendly transportation systems. This paper presents communication technologies used in ITS with reference to V2V, V2I and V2X models.
KEY WORDS: *intelligent transportation systems, communication technologies, V2V, V2I and V2X models*

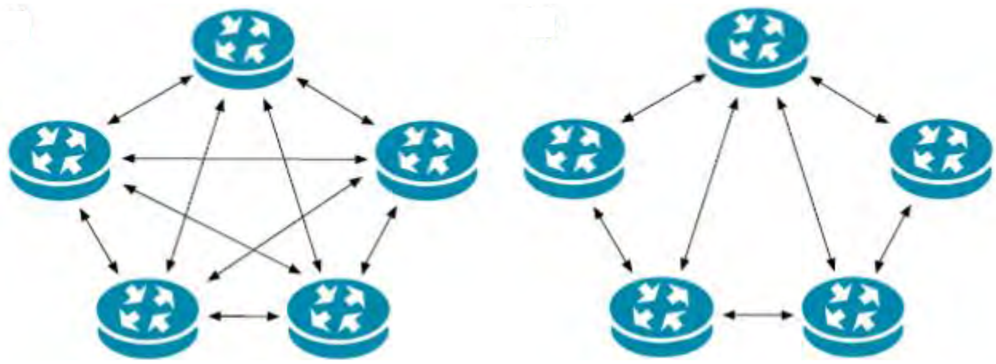
1. Introduction

Transportation systems are fundamental to society because they allow people and goods to move from one place to another. With the growing number of people and vehicles, the current transport systems must take into account the need to solve problems resulting from traffic congestion, accidents, air pollution and noise [6, 15]. Traditional solutions, such as extending the current transport systems by increasing the number of roads, are considered expensive, burdensome and cost-intensive. Instead, it is expected the telematics will be a better solution the telematics will be a better solution [9, 10]. Telematics and the associated intelligent transport systems (ITS) include telecommunications, IT, measurement and automatic control solutions adapted to the requirements of systems, transport infrastructure, organization, maintenance and management processes that are integrated with these systems [12, 17]. The advantages of implementing these solutions include obtaining a safer, more efficient and more environmentally friendly transport system by using the latest technologies. ITS are complex systems and function in many areas by intelligently sensing, analysing and distributing different types of traffic information. Vehicle networks that use advanced technologies to communicate with intelligent vehicles equipped with on-board units and intelligent road infrastructure perform the functions of distributing traffic information through communication between vehicles (V2V), between vehicles and infrastructure (V2I) and between vehicles and everything (V2X) - which is a kind of generalization. Therefore, telematics plays a key role in increasing road safety, reducing traffic congestion, increasing the comfort of drivers and reducing environmental pollution.

2. Communication Models Used in ITS

ITS takes into account various communication models, including V2V, V2I, V2X. The V2V model (Vehicle-To-Vehicle) is based on wireless data transmission between vehicles. This makes it possible to increase road safety as a result of vehicles communicating and informing each other about, for example, their speed and location. The primary purpose of this type of communication is to prevent possible accidents by allowing vehicles to transmit data on, for example, their position or speed. V2V uses a decentralized connection system (Fig. 1) that can provide either a Full-Mesh Topology or a Partial Mesh Topology. In Full-Mesh Topology, it is assumed that all nodes are interconnected which creates a redundant structure. Therefore, Partial Mesh Topology has been proposed, in which direct data exchange between selected nodes must be ensured, for example those that are most frequently connected to each other. In the first case it is referred to communication "one-hop" and in the second - about "multi-hop". The second topology also increases network reliability. In the case of a node failure or temporary outage, routes are recalculated using routing tables so that packets can reach all destinations.

V2V communication protocols are assumed to improve safety as it is believed that all vehicles in close proximity will communicate and thus react to an occurring hazard (e.g. driver's sleep, system failure, lane obstruction, etc.) by undertaking an effective solution to an emerging problem. Achieving this goal will be possible assuming that the primary goal of each node (vehicle) included in the V2V network will be to acquire data in order to ensure a specific own safety and the safety of neighbouring vehicles. It will also be necessary to adopt appropriate methods of data encoding and real-time access verification to ensure their adequate safety. The V2V technology integration with the existing vehicle safety systems, will allow to improve traffic management, enabling vehicles to communicate with each other and, in the case of the V2I, also between vehicles and the road infrastructure. Technologies proposed in the V2V model should become widely used, allowing the construction of more reliable vehicles. However, there are three main obstacles to the introduction of V2V communication and the Intelligent Transport System: the need for vehicle manufacturers to agree on the safe operation of this technology, to ensure the privacy and confidentiality of data transmitted over the V2V network and to ensure the financing of the development and deployment of this technology.



a b

Fig. 1 V2V network topologies: a) Full-Mesh Topology; b) Partial-Mesh Topology (own study)

V2I is another communication model, which takes into account the data exchange between vehicles and road infrastructure. Elements of this infrastructure can include traffic signs and lights, video recorders and other roadside equipment connected to the network. Typically, V2I communication is wireless, two-way and, like V2V, it uses DSRC (Dedicated Short-Range Communication) technology operating in the 5.9 GHz band, which has been dedicated to data exchange by ITS systems. Information is transmitted from vehicles to infrastructure and / or vice versa over ad-hoc wireless networks. In the V2I model, it is assumed that sensors can collect infrastructure data and advise drivers in real time They may relate to current road conditions, road closures, detours caused by repairs or accidents, as well as road toll rates, or allow viewing of camera images. Similarly, traffic surveillance and management systems can use data collected from infrastructure and vehicles to set variable speed limits in order to achieve fuel economy and a smooth traffic flow. The hardware and software that enable communication between vehicles and infrastructure possible will be the starting point for the development of autonomous vehicles in the future.

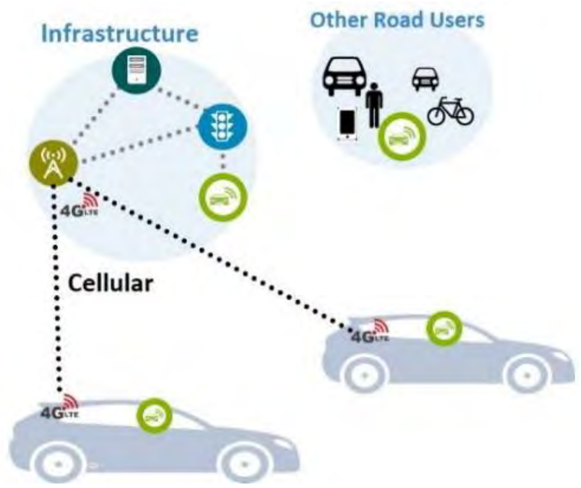
The V2V and V2I communication models can be generalized to V2X. This model takes into account the transfer of data from the vehicle to any object, for example vehicle-pedestrian (V2P) [13], vehicle-roadside (V2R) [17], between vehicle and device (V2D) [5] and between vehicle and grid (V2G) [2]. According to the report on global road safety, around 1.25 million people die each year from road accidents [16]. It is essential to develop V2X technology, as almost half of road casualties involve road users such as pedestrians, cyclists and motorcyclists [8].

3. ITS Network Safety

Despite the many benefits of ITS systems, it is necessary to consider safety issues in their development. Messaging in ITS communication networks is vulnerable to numerous hazards, such as interception, modification or fabrication of messages. These attacks have the potential to lead to catastrophic consequences such as traffic congestion, road accidents and even fatalities. Therefore, they pose a significant risk to transport systems which should be carefully examined before the transport networks are implemented. ITS communication network safety design should ensure authentication, and in the case of data transmission, should also ensure data integrity and confidentiality [11]. Conventional safety mechanisms, largely based on cryptography and key management, are designed to guarantee network authentication, but are not feasible in terms of protecting the integrity of the messages broadcast if there are attackers with valid certificates. The authenticity and integrity of the messages transmitted are of great importance to ensure network resilience to attacks. Unlike traditional safety settings, in ITS communication networks, the network topology is constantly changing, because the connections can appear randomly. The approach of building trust by monitoring object behaviour will be futile in ITS communication networks as maintaining the reputation of a vehicle that moves fast is very difficult. An additional safety challenge is ensuring that vehicles respond quickly to transmitted messages. In discussed cases, determining the true value of the messages broadcast is more important than detecting the hazardous vehicles. Despite the previously mentioned need for authentication, or control of data integrity and confidentiality, the vehicle can receive contradictory messages from various sources. Therefore, messages delivered by different sources need to be correlated, and the inclusion of basic topological information is essential in designing decision algorithms to verify data consistency. Based on the above-mentioned challenges, the exploration of topological approaches to secure message dissemination in ITS networks becomes a significant issue.

4. Communication Technologies Supporting ITS

Protocol, which is used in the automotive industry, called DSRC, is defined as one-way or two-way wireless communication channels for short- and medium-range [4]. In July 2003, the version of the E2213-03 (ASTM 2003) standard for DSRC was published, which is largely based on the 802.11a standard. After 2003, the DSRC protocol was developed by two IEEE working groups (WGs): P1609 WG and 802.11p. The first focuses on standards from higher media access control (MAC) layers to application layers, and has developed the P1690 protocol suite named Wireless Access in Vehicular Environment (WAVE). The second group focuses on the lower MAC and PHY (Physical Layer) layers. 802.11p standards drafts were developed on ASTM 2003 and finally approved in 2010. Therefore, DSRC includes both WAVE and 802.11p. Another technology that can be used in ITS is 4G LTE and 5G mobile telephony. Cellular technology is ideally suited for non-safety applications such as V2I communication where messages originate or are processed in the cloud. In V2I communication, the technical challenges are relatively minor compared to the requirements of the V2V model. The exchange of information between vehicles requires the mobile network to provide high-performance and high-quality services. Unfortunately, modern cellular networks do not take into account this type of needs, and thus further development research of this technology is necessary. The V2X 3GPP research group is developing the concept of separating tasks related to ITS service. For this purpose, it was proposed to use the D2D (Device-to-Device) protocol, which is a part of LTE version 12. The improvement of the cellular network performance is then achieved by assigning the required resources to the user, including the required bandwidth (Fig. 2).



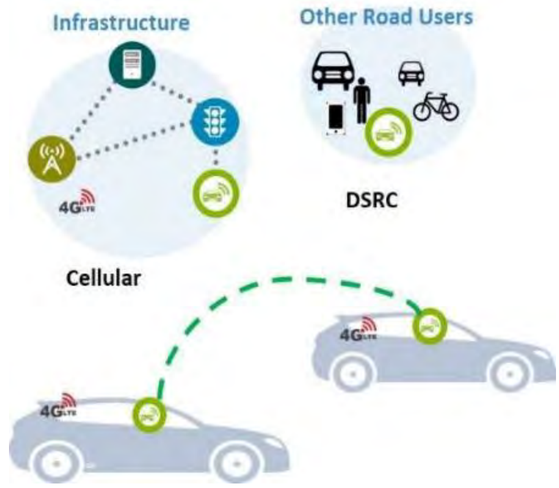


Fig. 2 Illustration of V2V communication using: a) V2V with LTE; b) V2V with DSRC [3]

The wireless technologies used in V2X communication are facing further challenges. They take into account the differences in relative speeds between network nodes (e.g. vehicles) and the high randomness of connections. As a result, the network has to handle very low latency (e.g. 50 ms for a "pre-crash warning message"). Dedicated ITS technologies must also be prepared for temporary heavy network traffic. Another aspect is the local nature of the messages, e. g. the collision warning is only relevant for vehicles that are close to a danger area and is not relevant for distant vehicles. The standard for V2X communication is the already mentioned DSRC technology, which is based on the IEEE 802.11p standard and the IEEE 1609.4 protocol. The IEEE 802.11p standard has been specifically designed to meet the stringent performance requirements that result from the V2X communication model. Among the cellular technologies that can be used for V2X communication are 4G LTE and 5G [1, 7, 14]. Unfortunately, this technology is not fully compatible with the requirements of the V2X model, for example with regard to the randomness of connections and the low transmission delay. Current versions of mobile phones can only send basic V2X messages because they do not take into account low latency and high mobility use cases, which are required for safety reasons. Fig. 3 shows the possibility of using 802.11p and cellular in V2X applications.

It is obvious, that safety is an important aspect to consider when applying these technologies. For cellular systems, safety is ensured by the use of subscriber identification modules (SIM) for network authentication. SIM cards can be used for network-assisted V2X communication, but a different type of security mechanism is required in the unavailability of the cellular network. Of course, IEEE 802.11p takes into account this important aspect of safety, and therefore mobile telephony should take a similar approach. By analysing the timeline of the development of the IEEE 802.11p standard and the cellular technology shown in Fig. 4, it can be certain that cellular telephony will find application in V2X communication.

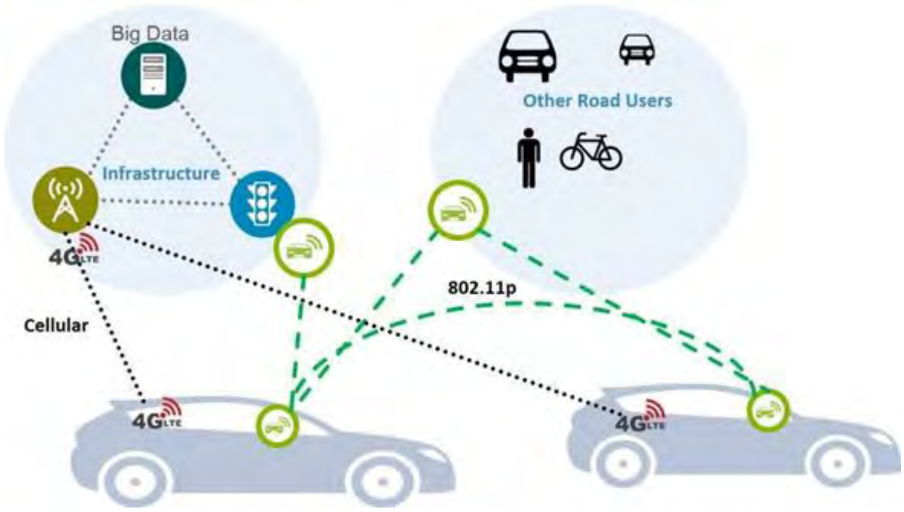


Fig. 3 Application of the 802.11p protocol and mobile telephony in V2X solutions [3]

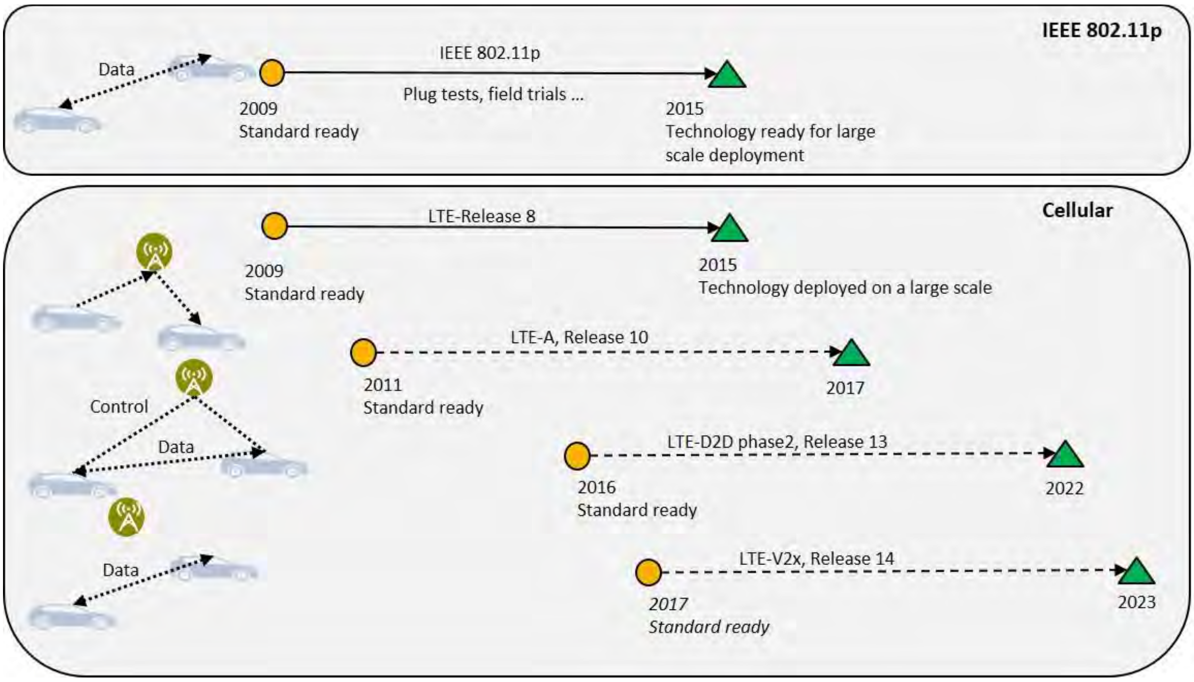


Fig. 4 Timeline for the development of the 802.11p standard and cellular telephony in V2X applications [3]

5. Conclusions

In the case of road transport, it is important to eliminate accidents and road congestion, which ultimately contributes to the improvement of traffic safety. In recent years, this sector has developed rapidly through the use of intelligent systems, replacing traditional transport solutions with telematics systems. The main goal of these activities is to increase road safety by anticipating the circumstances of a potential hazard. V2V, V2I and V2X technologies use transmission models ensuring communication between all road users and communication with selected elements of road infrastructure. It is also necessary to build the infrastructure such as the ad-hoc and mesh networks, whose nodes are all objects connected to the network using wireless modules, including the Internet of Things (IoT). The results of the analysis of communication technologies used in intelligent transportation systems indicate the future road safety benefits that can be obtained in this way.

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Traffic Safety as an Element of Children's Education in the Czech Republic

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Abstract

The paper focuses on the issue of training and education of children in the field of traffic safety. The topic of education in traffic safety for children is important from the point of view of protecting the life and health of both children and other road users. The main goal of the thesis is to find out under which system children are educated in primary schools in the Czech Republic in the field of traffic safety and how they are prepared for independent movement on roads. The secondary goal of this work is to characterize documents and basic approaches in the field of traffic safety education. Achieving the goals is realized by the method of literature search, analysis and synthesis of the obtained information and especially by the questionnaire survey. Education in the Czech Republic is covered by a basic document of the Ministry of Education, Youth and Sports, which is called the Framework Educational Program for Basic Education. Traffic education is enshrined in this document, where the student should learn to "perceive the traffic situation, evaluate it correctly and draw appropriate conclusions for his behavior as a pedestrian and cyclist. The possibilities of education in traffic safety are reflected from the point of view of the use of traffic playgrounds and available publications for children.
KEY WORDS: *Education, Society, Traffic education, Traffic playground, Traffic safety*

1. Introduction

It is necessary to educate and educate children in the field of traffic safety, to teach them to anticipate possible imminent dangers, to teach them the basic rules concerning normal road traffic, because they become participants in traffic almost every day. Teaching children the basic rules for safe movement on roads, sidewalks, bike paths, etc., so that they understand them as automatic, is important for their daily safety from preschool age [3, 6]. Children should first learn how to behave as safely as possible as a pedestrian as a participant in traffic. Know the rules for walking on the sidewalk, respectively on the pedestrian path, walking on the road, crossing the road at marked pedestrian crossings, crossing the road outside the marked pedestrian crossing, they should also know how to behave safely in the residential and pedestrian zone.

The main goal of the thesis is to find out under which system children are educated in primary schools in the Czech Republic in the field of traffic safety. The secondary goal of this work is to characterize documents and basic approaches in the field of traffic safety education.

Traffic education of children can be understood as the preparation of children for the safe use of sidewalks and roads in road transport [12]. Children should gradually acquire habits of safe behavior, be aware of the pitfalls and potential dangers. These habits must be built from an early age by their parents, when they are held by the hand and enter the road for the first time [4, 10].

2. Methodology

The work deals with the education of children in the field of traffic safety. It is aimed specifically at children in the 4th and 5th grade of the 1st grade of primary school, because at this age they can become road users themselves and it is essential that they know the basic rules of road traffic. Methods of literary research, content analysis of documents, synthesis, comparison are mainly used to meet the goal. Literary research together with content analysis serves to classify and gather relevant information sources. A questionnaire survey was used to find out the current state of education of primary school children and how children are informed about traffic safety in primary schools. The questionnaire survey is one of the techniques of field information collection, in which the necessary information is obtained from the surveyed persons in writing, through the printed questions contained in the questionnaire. In general, the questionnaire survey is characterized by the following features: it finds out the necessary data indirectly, through the subjective testimony of the surveyed persons; there is no direct interaction between the researcher and the respondent; it is a highly formalized and standardized technique. The final synthesis is to reveal possible shortcomings in general traffic safety education in the conditions of the Czech Republic.

Traffic safety has an impact on human behavior in the traffic environment, on respecting and adhering to the established rules, on responsibility, on being aware of one's possibilities with regard to one's experience. The concept of traffic safety can be understood as the prevention of threats to life, health or damage to property. These situations often occur in traffic accidents [1, 2].

3. Results and Discussion

Education in the Czech Republic is covered by a basic document of the Ministry of Education, Youth and Sports (hereinafter referred to as the Ministry of Education, Youth and Sports). This document is called the Framework Educational Program for Basic Education (hereinafter referred to as the FEP). Traffic education is enshrined in this document of the FEP, where the student should learn to "perceive the traffic situation, evaluate it correctly and draw appropriate conclusions for their behavior as a pedestrian and cyclist. It also applies the basic rules of road traffic for cyclists and correctly evaluates the simple traffic situation on the field." [8, 11].

The content of the FEP is a proposal for the distribution of curriculum for individual grades at primary school. The integration of traffic education into primary schools at the first stage of primary schools has the task of teaching pupils road safety, gaining knowledge, knowing and learning to follow the rules and anticipate possible dangers. The main goal of traffic education is to protect life and health, reduce accidents and not endanger any road users.

Traffic education at primary schools is taught either by the teachers themselves within the subject teacher, or in the case of cooperation with the school, traffic education can be presented by the city police, the Police of the Czech Republic, non-profit organizations or other external companies dealing with this issue. The Ministry of Education, Youth and Sports submitted materials for teaching the topics of education in primary schools. This material serves as a basis for teachers from the school year 2013/2014, according to which the curriculum for the 1st stage of primary school can be appropriately distributed [9].

3.1. Traffic Education at the First Stage of Primary Schools

The aim of traffic education at the 1st stage of primary school is to teach the pupil to apply safe principles and to observe the basic rules of the road user, which apply to pedestrians and cyclists. The basic rules that apply to pedestrians are to follow the vertical or horizontal traffic signs, which are used for safe crossing of the road, or compliance with the principles of safe walking on the sidewalk.

Another task is to teach children to use public transport independently and to follow the rules when transporting them. Take extra care when crossing the road after crossing the pedestrian, be aware that a public transport bus, tram or trolleybus have a longer braking distance than a car. One of the most important rules regarding public transport is to appeal to the rule of priority of the tram over the pedestrian at the pedestrian crossing. Know what to call for help in a traffic accident, how to keep yourself safe in this situation and at the same time be able to help. Know the telephone contacts for hotlines, know who to call in different situations and know [5].

Children aged 6-9 years should therefore know the theoretical knowledge of the rules of traffic on roads, it is mainly walking on the sidewalk, walking on the road, safe crossing of the road with automatic and thorough looking around in various situations. Furthermore, they should learn to perceive the location of traffic signs and recognize their meaning. Know where the safe places to play are, recognize the dangers involved when playing near the road. Be able to call for help in a traffic accident, know the telephone numbers for emergency lines. Be able to divide traffic signs according to their meaning into warning, prohibition, command and informative.

For children who attend 4th - 5th grade and are between the ages of 9 and 12, emphasis is placed on knowledge for the basic conditions for cycling in traffic on roads. According to the Road Traffic Act, it has been permitted to ride a bicycle independently in road traffic since the age of ten. For independent riding, it is important that children have the necessary knowledge of traffic regulations, know what is forbidden when cycling, such as dangerous driving in the form of driving without holding the handlebars, carrying objects on the handlebars or leading a dog while cycling. The basic rules for cycling also include giving a sign of a change of direction, which the cyclist gives with his arm. When riding a bicycle independently, cyclists cannot avoid intersections where it is necessary to know the advantages of riding. These are intersections that are marked with traffic signs, either vertical or light, or they can be intersections that are not modified by traffic signs. Recognize and adhere to the meaning of vertical traffic signs. Every cyclist must know the mandatory equipment of the bicycle, which is set out in the mandatory equipment of motor vehicles. It is important to teach children that the weather affects the safety of riding, the need to use the prescribed lights on the bicycle, choose suitable clothing, ideally with a variety of colors, pay attention to the condition of the road, where there may be gravel, mud, fallen leaves, puddles, etc. the associated risk of skidding.

3.2. Possibilities of Security Education - Case Studies

3.2.1. Traffic Playground

The skills and knowledge that children have learned from their parents or from school can best and safely verify on the children's traffic playground. One of the first children's traffic playgrounds was established in the Czechoslovak Republic in the mid-1960s. These playgrounds were not under the supervision of a lecturer, so the children drove around the playgrounds in an uncontrolled manner, they were more of a play attraction than of preparing the children for independent road traffic. The first permanent and mobile playgrounds, which already had set rules and had regulated training, were established in the late 1960s. Over time, the playgrounds improved, the efficiency of activities increased, there was a certain schedule, when the playgrounds began to contribute to increasing road safety. As of 2019, a total of 221 children's playgrounds are in operation in the Czech Republic, which are located in all regions of the Czech

Republic. At the traffic playground, children can try their theoretical knowledge, which they have learned during traffic education, and in the form of a game they practice active participation in traffic.

3.2.2. Educational Literature

Children can also learn the basics of safe behavior on the street, sidewalk but also on the road thanks to books. The authors of children's fairy tales are the least concerned, such as the book "Playful driving school" by the author Pospíšilová Zuzana, which explains to children the basic rules for pedestrians, explains traffic lights, teaches young cyclists how to ride a bike safely and what rules a cyclist must follow. In the book, the author deals in detail with the basic traffic signs that every cyclist should know.

Another interesting and informative book for children in the field of the science of traffic education are "Traffic Fairy Tales", written by Hlavatá Dana. In her book, this author focuses mainly on small pedestrians when crossing the road, the rules of good behavior in public transport or how children should behave in a residential area. He also mentions how children should behave when they hear an audible warning and there is a mention of emergency calls.

"Attention red!" Is the title of another book for children, the author is Primusová Hana, who focuses on the little ones. He practices with children the colours that appear at the traffic lights, further exercises the sides of the left and right hand, warns children where it is dangerous to play, explains the importance of reflective clothing for children's safety and also focuses on young cyclists. In each of the chapters, this book ends with playful exercises.

The book "Encyclopedia of Larousse to the Right" by the author Besson Agnés also deals with marginal traffic rules. In the form of pictures, the author describes bicycles, various means of transport, mentions emergency vehicles, explains the right of way and shows readers how to behave in various situations, which are regulated by traffic signs. There is a list of traffic signs that concern children the most, how to behave in public transport, how to properly prepare for walking in the dark so that the road is safe, contains a book entitled "My first rules of traffic" by Fournier Sophie. At the end of this book, an entertaining quiz is created to help children practice the knowledge they have learned from the book.

3.3. Survey

The aim of the questionnaire survey at selected primary schools is to find out how children are educated and how they are prepared for independent movement on roads. The selection of pupils in the 4th and 5th grades of primary schools was chosen because, according to the Road Traffic Act, children under the age of 10 are only allowed on the road accompanied by an older person 15 years. However, they may use the sidewalk, bike path or residential area with caution. Their age is approaching the age when they will decide for themselves how to behave in different situations and children should be sufficiently prepared for different situations. Questionnaires were distributed in selected primary schools in three regions of the country. All questionnaires were handed over to the schools in paper form.

a) The cities were differentiatedly selected so that the city with the largest concentration of inhabitants took part in the questionnaire survey, therefore Prague was chosen. It has several children's traffic playgrounds on its territory, various sports competitions are held and the field of traffic education is dedicated not only to schools, offices, but also to libraries, which create tests for young readers. The questionnaire survey took place at primary schools in the Prague 4 district. A total of 500 questionnaires were distributed to 16 primary schools, of which 436 were returned;

b) The medium-sized town of Kadaň from the Ústí nad Labem Region was also chosen. There are 18,000 inhabitants, they have a children's transport playground and there is a large number of bike paths. Children from this area are often led by their parents to cycle and should be sufficiently prepared for safe cycling. Here, 180 questionnaires were distributed to three primary schools, of which 143 returned;

c) The town of Týnec nad Sázavou in the Central Bohemian Region was chosen as the third town. It is a small town with less than 6,000 inhabitants. There is no children's playground, there are also bike paths leading to the larger town of Benešov, 10 km away, where, among other things, they have to commute to the children's playground. Here, the questionnaires were distributed to two primary schools. A total of 130 questionnaires were distributed, the return was 101 returned questionnaires.

The results of the questionnaire survey show that children are interested in road safety. They gain experience not only at school, but also from their parents, who are their greatest role model. Most of the children answered that they actively ride a bike or scooter and take part in road traffic, whether on the sidewalk or on the road. With a few exceptions, everyone is wearing a helmet when riding a bike and is aware that they can be seen better on the road in reflective and light colors. In the cities, there are children's traffic playgrounds, which children visit, with few exceptions, only compulsorily within the school. As for the rules in road traffic, the vast majority of students answered the basic traffic signs correctly. The biggest problem in the test was the intersections, which even half of the respondents did not answer correctly. It is important to mention that more complex intersections were chosen in the questionnaire, where in one case the pupil had to focus on an additional table and in the other case to realize that the intersection was not modified by traffic signs and children had to apply the right hand rule. These intersections are usually located on children's traffic playgrounds, which are freely accessible.

As for the knowledge of important emergency numbers, the students know the connection to the fire brigade and the Czech police very well. In the case of the telephone number for the integrated rescue system, a number was mostly written for incorrect answers, which had jumbled numbers as for the IRS emergency line. Children know this number subconsciously, but they could not remember it. This may have been due to a lack of time to complete the questionnaire survey, as this was the last question. The least known number for children is the emergency line to the city police. In the wrong answers, they entered either a completely different number or a number from the Police of the Czech Republic.

The correct answers in individual cities do not differ extremely. In most cases, they have a similar percentage of correct answers. Pupils had the biggest problems with intersections, when they could not determine the correct order in which drivers pass through the intersection. The most bad answers regarding the issue of intersections were from the town of Týnec nad Sázavou. In the other two cities, the success rate was less than half. Pupils from the town of Kadaň won the imaginary priority of the largest number of correct answers.

In the questions that were evaluated according to the correct answers of individual cities, the city of Kadaň answered 10 times with the largest number of correct answers out of a total of 12 measurable questions. The percentage of the same number of pupils as from the town of Týnec nad Sázavou answered one question. Pupils from this city answered 3 times with the largest number of correct answers. Pupils from the Prague 4 district did not win any imaginary first place. However, it should be noted that the total percentages of correct answers are calculated from a larger number of selected questionnaires, 436 students answered. A total of 7 questions answered with the lowest percentage of correct answers. In most cases.

4. Conclusions

The main cause of traffic accidents is usually a human error, after which the technical condition of the vehicle or the condition of the road. Anyone can become a participant in a traffic accident, and pedestrians tend to be the most prone to injury compared to other road users. Due to the lack of intellectual understanding, children are among the most endangered pedestrians who participate in road traffic [7, 13]. Great emphasis must be placed on children aged 5-8 when they enter school, and there may be situations where their first independent journey awaits them.

Anyone who directly participates in road traffic is a participant in road traffic. This means that a pedestrian, a driver of a motor or non-motor vehicle, a person being transported, or, for example, a guide to guided animals, if the animals move on the road, are considered to be road users. Undoubtedly, the most endangered road users are children, who are just learning the basic rules they encounter. Children are dependent on adults whom they trust and from whom they learn even the most basic rules in order to reach their destination safely [16]. An adult or older escort should set an example for the child and, in the event of any possible danger to the child in operation, warn him or her of the possible risk in order to avoid possible danger. An important element in the process of traffic education is also school teaching, which ideally builds on the basics that the child has acquired from parents.

Inserting foresight into a child reduces the likelihood of the child being at risk. These are, for example, the rules for crossing the road at or outside the crossing, to keep in mind for children that after each crossing they must stop and look around, that the tram has priority over pedestrians, that at the pedestrian crossing it is not allowed to ride a bike or scooter that both the bike and the scooter must be transferred across the pedestrian crossing. Explain to the child why this is the case [14, 15]. Therefore, it is necessary to emphasize the topic of traffic education in the education system, which must be continuously updated in connection with the needs of society.

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Modeling of the Heat Transfer Process for Steam Condensation inside the Tubes of Diesel Locomotive Radiator Sections

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Abstract

The results of mathematical modeling of the heat transfer process at steam condensation inside the tubes of diesel engine radiator sections are presented. The obtained regression equations, created by the results of physical experiments, derived the criterial equation of the heat transfer process at steam condensation inside the tubes of plane-oval section. The obtained criterial equation will allow to calculate more accurately the heat transfer of radiator sections in the mode of steam condensers, which will greatly realize the economic advantages of diesel cooling systems with phase transitions of coolant, which is one of the most promising ways to increase the efficiency of diesel locomotives.
KEY WORDS: *steam, condensation, radiator section, heat transfer, criterial equation*

1. Introduction

One of the most promising ways to increase the efficiency factor of the diesel locomotive is to reduce power costs for its own needs, which is 8-12% of the diesel power [1, 2]. The main consumer of this power is a diesel engine cooling system: oil coolers, charge air coolers, cooling water units of the diesel body, cooling chamber ventilators, blowing radiator sections.

Theoretical and experimental research [3-5] has shown that the application of coolant boiling in heat exchangers with subsequent removal and condensation of generated steam in the diesel cooling system has an obvious advantage over heating and cooling processes of constantly circulating liquid. The use of phase transitions of a rationally selected coolant allows saving up to 30% of the power to the pump and ventilator drive.

One has found out that it is most viable to use standard diesel locomotive radiator sections for steam condensation, as a plane-oval form of tube section substantially surpasses a round form in the intensity of heat transfer from walls to the air and aerodynamic resistance. Besides, the plane-oval form of tube section quite positively affects the steam condensation process.

This work aims to derive the criterial equation of the heat transfer process at steam condensation inside the tubes of diesel engine radiator sections.

2. Research Analysis

Heat transfer inside the tubes is revealed in numerous works by such well-known scientists as W. Nusselt, H. Wong, H. Hartmann, W. Black, V.P. Isachenko, S.S. Kutateladze, F. Kreith, etc. However, the given mathematical models are focused only on the tubes of round section, and the range of theoretical calculations is frequently replaced with experimental coefficients. Thus, it was necessary to create a mathematical model of the heat transfer process from condensing steam to the plane-oval tube wall. Similar to H. Hartmann's mathematical model [6], we examined the heat and mass balance, conditionally divided the plane-oval section into a rectangle and two semicircles, and conducted a range of mathematical transformations [3], which resulted in two systems of equations:

$$\begin{cases} \dfrac{\lambda_c \cdot \Delta t}{r\rho_c} \cdot \dfrac{R-\delta_1}{\delta_1} = \dfrac{d}{dz} \cdot \displaystyle\int_{y=0}^{y=\delta_1(z)} (R-y) w_{c1}(y) dy; \\ w_{s1} = \dfrac{R^2 w_{s0}}{(R-\delta_1)^2} - \dfrac{2\rho_c}{(R-\delta_1)^2 \rho_s} \cdot \displaystyle\int_{y=0}^{y=\delta_1(z)} (R-y) w_{c1}(y) dy; \end{cases} \tag{1}$$

$$\begin{cases} \dfrac{\lambda_c \cdot \Delta t}{r\rho_c \delta_2} = \dfrac{d}{dz} \cdot \displaystyle\int_{0}^{\delta_2(z)} (R-y) w_{c2}(y) dy; \\ w_{s2} = \dfrac{w_{s0} R}{(R-\delta_2)} - \dfrac{\rho_c}{\rho_s (R-\delta_2)} \displaystyle\int_{0}^{\delta_2(z)} (R-y) w_{c2}(y) dy, \end{cases} \tag{2}$$

where: λ – heat transfer coefficient; r – specific condensation heat; ρ – density; z – coordinate along the tube length; δ – condensate film thickness; y – coordinate normal to the wall; R – radius of the round part of the plane-oval tube; w – speed; indices s, c denote the belonging of the parameter to steam and condensate; indices 1, 2 are round and plane section areas; index 0 is a parameter at the tube inlet; $w_c(y)$ – condensate flow speed changing when moving away from the wall; Δt – difference between the temperature of steam and tube wall (determined at each elementary layer by solving Fourier (3) and Fourier-Kirchhoff (4) equations for laminar and turbulent flow modes [7]):

$$T_{(y,t)} = \frac{q r_0}{\lambda} \int_0^\infty \frac{J_0\left((y-R)\cdot r / r_0\right) J_1 (y-R)}{y-R} \times erf\left(\frac{y-R}{r_0}\sqrt{\Psi t}\right) dy; \tag{3}$$

$$T_{(y,t)} = \int_0^\infty \frac{J_0\left((y-R)\cdot r / r_0\right)}{2\cdot \Psi \cdot \sqrt{\pi \cdot t}} \cdot \left(\exp\left(-\frac{\left((y-R)-(y-R)\cdot r / r_0\right)^2}{4\cdot \Psi^2 \cdot t}\right) - \exp\left(-\frac{\left((y-R)+(y-R)\cdot r / r_0\right)^2}{4\cdot \Psi^2 \cdot t}\right)\right) dy, \tag{4}$$

where $\Psi = \lambda / (c \cdot \rho)$ is a diffusivity coefficient; $\vec{q} = -\lambda \cdot grad(T) = \lambda \cdot \dfrac{dT}{dy}$ is the heat flux; $J_0(...)$ and $J_1(...)$ are Bessel formulas; $erf\left(\dfrac{y-R}{r_0}\sqrt{\Psi t}\right) = \dfrac{2}{\sqrt{\pi}} \displaystyle\int_{-R}^{y-R} \exp(-t^2) dt$ is the error function (Gaussian integral).

Distribution of the condensate flow speed $w_c(y)$ in formulas (1) and (2) is presented as a cubic parabola:

$$w_c(y) = a + by + cy^2 + dy^3, \tag{5}$$

where coefficients a, b, c, d are determined by the boundary conditions.

As a result, $w_c(y)$ is the $f(\delta)$ function and is determined by the equation:

$$w_c(y) = \frac{\tau_w}{\mu_c} y + \frac{1}{2\mu_c}\left(\frac{dp}{dz} - g\rho_c\right) y^2 + \frac{\tau_\delta - \tau_w - \delta\left(\dfrac{dp}{dz} - g\rho_c\right)}{3\delta^2 \cdot \mu_c} y^3, \tag{6}$$

where τ_w is friction tension at the edge of the condensate and wall; τ_δ is tension on the film surface caused by steam friction; dp/dz is pressure drop towards steam flow; μ_c is dynamic condensate viscosity.

The Eqs. (1), (2), (6) and solutions of Fourier and Fourier-Kirchhoff Eqs. (3), (4) allowed us to calculate values $wd_1 \cdot \delta_1$ and $wd_2 \cdot \delta_2$ for round and plane areas of tube section using initial and boundary conditions [3, 4], as well as determine mass expenditures and heat transfer coefficient according to the transferred amount of heat.

The obtained mathematical expressions are solved numerically in specially developed software.

To check the results of the mathematical model, we carried out physical experiments with a full-scale sample of a serial radiator section BC-0.5. The deviation of the results was within 17%.

The experiments resulted in the following regression equations:

$$\begin{aligned} \alpha_a = {} & 3729 - 7{,}372 \cdot z - 5101 \cdot \Delta t + 1056 \cdot w_{s0} + 4258 \cdot z^2 - 20940 \cdot \Delta t^2 - 11{,}259 \cdot w_{s0}{}^2 - \\ & - 58{,}89 \cdot z \cdot \Delta t - 36{,}9 \cdot z \cdot w_{s0} - 333{,}06 \cdot \Delta t \cdot w_{s0}; \end{aligned} \tag{7}$$

$$\alpha_a = 5437 - 5,6\cdot10^3\cdot z - 23\cdot10^3\cdot\Delta t + 956,46\cdot w_{s0} - 1,53\cdot10^6\cdot\mu_c + 3369\cdot z^2 + \\ +14570\cdot\Delta t^2 - 5,278\cdot w_{s0}{}^2 - 3,135\cdot10^9\,\mu_c{}^2 - 3834\cdot z\cdot\Delta t - 65,288\cdot z\cdot w_{s0} + 1,9\cdot10^6\cdot z\cdot\mu_c - \\ -367,438\cdot\Delta t\cdot w_{s0} + 1,938\cdot10^7\cdot\Delta t\cdot\mu_c - 1,842\cdot10^5\cdot w_{s0}\cdot\mu_c, \tag{8}$$

(note: for water, $\mu_c = 2,994\cdot10^{-4}$ Pa·s; it is –4 degree that causes high degrees in the regression equation)

where α_a – heat transfer coefficient of the average length from steam to walls during condensation; w_{s0} – inlet steam speed; z – tube length; Δt – difference between the temperature of condensation and the wall.

The Eq. (7) allows us to calculate α_a during condensation of water steam only, the Eq. (8) is valid for azeotropic aqueous solutions and steams of other substances that substantially differ from water only in viscosity.

It is obvious that the overwhelming amount of substances differ from each other and from water in all physical and chemical parameters at the same time. In this case, the regression equation fails to cover the full range of substances. Therefore, we should use the above-mentioned software or obtain the criterial equation.

3. Research Results

To derive the criterial equation of the heat transfer process at steam condensation inside the plane-oval tube, we used the first and second similarity theorems [8], which allowed determining the equation structure:

$$Nu_a = A\cdot\mathrm{Re}_{s0}{}^B\cdot\left(\frac{r}{c_c\cdot\Delta t}\right)^C\times\left(\mathrm{Pr}_c\cdot\frac{\rho_s}{\rho_c}\cdot\left(\frac{\mu_s/\rho_s}{\mu_c/\rho_c}\right)^2\right)^D\cdot\left(\frac{d_e}{z}\right)^E, \tag{9}$$

where Nu_a – average Nusselt criterion along the tube length; $\mathrm{Re}_{s0} = \left(\rho_s\cdot w_{s0}\cdot d_e\right)/\mu_s$ – Reynolds criterion for steam at the tube inlet; $\mathrm{Pr}_c = \left(\mu_c\cdot c_c\right)/\lambda_c$ – Prandtl criterion; A, B, C, D, E – required values; c_c – specific condensate heat capacity; d_e – equivalent diameter.

Multipliers in the Eq (9) are grouped in this manner not accidentally: the equation structure completely coincides with H. Hartmann's equation [6]:

$$Nu_a = 0,085\cdot\mathrm{Re}_{s0}{}^{0,6}\cdot\left[\left(\frac{r}{c_c\cdot\Delta t}\right)\times\left(\mathrm{Pr}_c\cdot\frac{\rho_s}{\rho_c}\cdot\left(\frac{\mu_s/\rho_s}{\mu_c/\rho_c}\right)^2\right)\cdot\left(\frac{d_e}{z}\right)\right]^{0,333}. \tag{10}$$

Redefining the variables in the Eq. (9), we obtain:

$$y = A\cdot x_1^B\cdot x_2^C\cdot x_3^D\cdot x_4^E, \tag{11}$$

where 1, 2, 3, 4 are serial indices.

Finding the logarithm of the Eq. (11), we obtain:

$$ln\,y = ln\,A + B\cdot ln\,x_1 + C\cdot ln\,x_2 + D\cdot ln\,x_3 + E\cdot ln\,x_4. \tag{12}$$

Redefining the variables, let's reduce the Eq. (12) to the generally accepted form:

$$Y = b_0 + b_1\cdot X_1 + b_2\cdot X_2 + b_3\cdot X_3 + b_4\cdot X_4. \tag{13}$$

All b_i coefficients are calculated by the method of least squares; to conduct the calculations, we used the calculation data of the mathematical model in the developed computer program, as its adequacy was proved experimentally. After obtaining b_i values, we made inverse transformations and definitions, allowing the criterial equation of the heat transfer process at steam condensation inside the plane-oval tube to take the final form:

$$Nu_a = 0,0071\cdot Re_{s0}{}^{0,883}\cdot\left(\frac{r}{c_c\cdot\Delta t}\right)^{0,282}\times\left(Pr_c\cdot\frac{\rho_s}{\rho_c}\cdot\left(\frac{\mu_s/\rho_s}{\mu_c/\rho_c}\right)^2\right)^{0,333}\cdot\left(\frac{d_e}{z}\right)^{0,141}. \tag{14}$$

4. Conclusions

We obtained the criterial equation of the heat transfer process at steam condensation inside the plane-oval tubes of diesel locomotive radiator sections. The derived equation uses a range of dimensionless similarity criteria, which allows making calculations for a large spectrum of substances with different physical and chemical properties.

The obtained criterial equation will allow calculating more accurately the heat transfer of radiator sections in the mode of steam condensers, which will greatly realize the economic advantages of diesel cooling systems with phase transitions of coolant.

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Pedestrian Target Systems for Active Vehicle Safety Testing

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Abstract

Vehicles currently have several safety features, active and passive safety systems. However, despite advanced developments in this area, serious accidents and fatalities occur in vehicle and pedestrian accidents. The pedestrian does not have any safety protection, so vehicles must provide this kind of protection. Considerable attention needs to be paid to research and continuous development, as a matter of priority, of active vehicle safety. During simulations and subsequent tests of these elements, they use various systems whose task is to simulate the movement of a pedestrian, cyclist or motorcyclist. These pedestrian simulation systems may have different operating principles to simulate different traffic situations. In this article, we will analyse these systems, describe their principle of operation and describe the advantages and disadvantages of each type of equipment. This exercise will point out the importance of these simulation systems for further research and development of active vehicle safety systems, because simulations and tests of active safety systems help us to find better solutions and reveal the shortcomings and errors of active safety elements.
KEY WORDS: *pedestrian; system; test*

1. Introduction

To increase the safety of road traffic and their most vulnerable participants (pedestrians and cyclists), it is necessary to constantly test the safety systems of active safety of automated road vehicles. Euro NCAP uses accident scenarios for pedestrian detection. These scenarios include a pedestrian crossing directly in front of the vehicle track; a pedestrian walking in the same direction as the direction of the vehicle; a pedestrian crossing the road where the vehicle turns; a pedestrian passing behind a reversing vehicle. All of these scenarios represent risk situations where fatal pedestrian injuries could occur. Testing of automated road vehicles, their behaviour and decision-making in critical situations is therefore essential for the further development of autonomous technologies in transport. When testing these systems and equipment, soft manikins are used, which are placed on propulsion systems that allow precise control of the speed and position of the manikin. It is this propulsion system that we will address in the next article [1].

2. Test Systems

Systems used to test the active safety features of automated road vehicles must meet some stringent criteria. 4Activesafety and AB Dynamics are also among the most frequently used test systems for pedestrian accident tests. These companies also produce belt test systems, the principle of which we will use in our project. Of course, there are other test systems and companies that address this issue, such as the 6D manipulator system from Messring, which will also be described in this article

2.1. Soft Pedestrian Target (SPT)

It is a portable tracked drive that uses patented Synchro technology to ensure accurate and consistent playback of test scenarios. This system uses the standard drive of the AB Dynamics controller drive unit and the motor of the control robot (Fig. 1). There are also built-in engines capable of reaching speeds of up to 40 km / h (SPT40 Standalone variant) and are designed for a weight of 15 kg. The accuracy of the platform on which the pedestrian manikin is placed achieves an accuracy in space and time of ± 2 cm and the height of this platform reaches a height of 25 mm, which does not degrade the sensed field of the vehicle by this mechanism.

In the case of the system from 4activeSystems, this is a similar principle of operation. The speed of the platform reaches a speed of 20 km / h and the height of the platform is also 25 mm. As these are systems used to test the same scenarios and their operating principle is similar, there are not major differences between the two manufacturers' systems.

The advantage of this system is the fluidity of movement. Tearing movements are eliminated thanks to the closed-loop. The only disadvantage is the straight movement of the pedestrian [3-5].

Fig. 1 Soft Pedestrian Target (SPT) – AB Dynamics [3]

2.2. Ultra-Flat Overrunable Platform – UFO

This robotic platform provides versatile, low-maintenance solutions for active safety testing (Fig. 2). It is a remote-controlled platform on which the manikin is placed. It is a low-profile platform with high stability and repeatability of tests. It allows the performance of fully autonomous testing of the latest safety features with maximum accuracy without the risk of damage to vehicles or injury to the driver.

The UFO platform enables Euro NCAP ADAS testing and allows a high degree of flexibility with some optional accessories.

The advantage is the low number of components and space requirements compared to the SPT system, as it is a separate platform. Another advantage is the modularity of the platform and a wide range of different tests. The disadvantage is the jerky movements during acceleration and deceleration or the oscillation of the manikin [7].

Fig. 2 Ultra-Flat Overrunable platform – UFO (Humanetics) [7]

2.3. 6D Target Mover

This system enables a consistently reproducible and technically perfect implementation of predefined trajectories based on the specifications of the test scenario used in the individual tests. 6D Target Mover allows a wide variability of pedestrian movement for different AEB scenarios for pedestrians, including changes in direction of movement, speed, level (from sidewalk to road) and in combination with realistic pedestrian manikin Fig. 3 can test advanced pedestrian detection systems, including functions such as prediction routes and detection of preliminary indicators. From Fig. 3 we can see that this is a technically demanding device.

Fig. 3 6D Target Mover [2]

Undoubtedly, the advantages of this device include the natural movement of the manikin, which is highly realistic compared to previous devices. This device also allows the simulation of height differences (pavement height and road/curb height). We could consider the space and construction complexity to be a disadvantage (Table) [2, 6].

Table

Basic parameters of individual types of test equipment [2-7]

Parameter	SPT	UFO	6D Target Mover
Power	12V/115V/230V	Batteries	-
Max. speed	40 km/h	80 km/h	36 km/h
Hight platform	25 mm	98 mm	-
synchronized with control robots and GNSS systems	Yes	Yes	Yes
ADAS testing	Yes	Yes	Yes
Cycling test	Yes	Yes	Yes

3. Design of a Belt Device

The goal of our belt device design is to expand the measuring system, which is currently used primarily for crash tests. Expanding the possibility of testing active safety features, will help us to better understand the principles of operation and decision-making of these active vehicle safety systems. It will be a device with the possibility of repeatability of selected tests (scenarios).

After a previous analysis of the individual types of equipment mentioned above, we decided to use the type of belt mechanism to test the active safety features of vehicles in the event of a collision with a pedestrian. The belt mechanism, in terms of construction, hardware and software, seems sufficient for us to achieve our goals.

Several basic devices are required to design a functional mechanism, such as a pressure switch, light gates, a control unit, a drive unit, a platform, and the like. Some of the mentioned devices are described in more detail in the article below.

3.1. Belt Mechanism Devices

As mentioned, several basic components are needed for the whole mechanism to work. The task of these components is to synchronize the movement of the pedestrian into the path of the vehicle. The aim is to achieve the right direction and especially the speed of movement of the pedestrian dummy, including the right timing. To perform such synchronization, it is necessary to design the correct procedure and timing. The pressure switch, light gates and control unit will be used for the correct functionality of the entire device

3.1.1. Pressure Switch

The pressure switch is used to activate or deactivate another device. Their properties allow pressure to be applied to any place and represent a basic, simple and reliable component of the belt device. The variability of the switches and their versatile use in various cases and conditions represent an ideal choice for us to use the lowering of the platform to the point of collision with the vehicle. In our equipment, we will use pressure switches of the type "Tapeswitch 101-B Ribbon Switch", which is shown in Fig. 4 [8].

Fig. 4 Tapeswitch 101-B Ribbon Switch [8]

3.1.2. Light Gates

Another component of the whole system is light gates, whose primary task is to measure time and then calculate the speed of the vehicle. The light gates themselves shall be located at a sufficient distance in front of the point of impact to ensure the smooth movement of the manikin and sufficient space for it to accelerate to the required speed. The "Minimeter HL440" light gate system from TAG HEUER will be used in our measuring system (Fig. 5). We will also use the device "HL2-31 Reflective Infrared Detector" (Fig. 5), whose task will be to record the passage of the vehicle by interrupting the signal. The interruption of the signal is recorded and, thanks to the use of a pair of light gates and based on the distance between them, it will be possible to calculate the speed of the vehicle [9].

Fig. 5 Minimeter HL440 (right side) and HL2-31 Reflective Infrared Detector (left side) [9]

3.1.3. Controller

It is the most complex component of the whole device, whose task is to control the course of the whole test based on defined input data. This control unit consists of a frequency converter; PLC (Programmable logic controller) unit; control (HMI) panel, with which we can read the values of measured data; and connectors for connecting electrical and voltage sensors (Fig. 6).

The main task of the frequency converter is to change the direct current to alternating current and vice versa. Another feature of this frequency converter is the possibility to convert a single-phase or three-phase source with a constant voltage and frequency to a three-phase voltage source. Frequency and voltage are variable and the subsequent control of the frequency voltage allows a smooth change in the speed of three-phase motors.

A PLC unit is a miniature computer that can, thanks to its hardware and software, perform control functions such as machine control. This unit consists of two components, the central processing unit (CPU) and digital and analogue modules. The processor unit (CPU) receives and processes data from the input modules and, after processing, sends signals to the output modules. Based on these processes, the PLC system can check the device´s status, which it adjusts according to its programming [10].

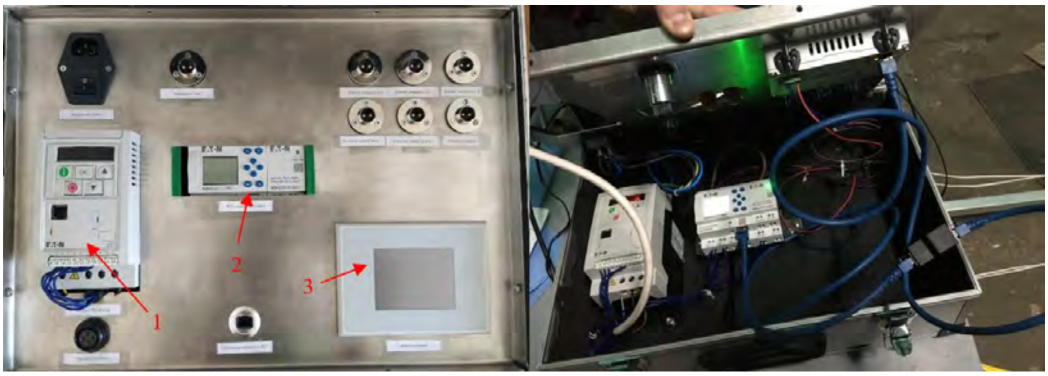

Fig. 6 Controller unit – close (left side), open (right side); *1* – frequency converter, *2* – PLC unit, *3* – controller HMI panel

4. Procedure and Diagram of the Whole Device

The basis is to set the goals we want to achieve with this device. Our goal is to construct a belt mechanism consisting of the basic elements mentioned above and technical elements such as pulleys, ropes, platforms, anchoring methods and the like. The main elements used for our equipment were described in more detail in the previous chapter. As far as the technical elements are concerned, some parts will be continuously tested and, if necessary, the problems encountered will be eliminated. The emergence of potential problems and their subsequent solution will take place during physical tests.

A total of 5 pulleys will be used in the construction of the belt device due to the formation of a closed-loop. Thanks to the closed-loop, the jerky movements of the manikin when accelerating to the required walking speed (4 km/h) are significantly reduced. The pulleys themselves will be placed on a metal base in the shape of a triangle for greater stability. Subsequently, they will be loaded or anchored directly to the ground for stability. Furthermore, a tow rope will be tensioned between the pulleys, which will be tensioned at both ends by springs to prevent damage to the movement mechanism due to a sudden stop of the rope when passing/braking the vehicle. The platform on which the soft mannequin will be placed will be made of glued wooden plywood. This is so that in the event of damage or destruction, the platforms can be easily replaced and also reduce the risk of damage to the vehicle as it passes. The already mentioned light gates and pressure switches will be placed in front of the crash site for the correct timing of the pedestrian's movement to the crash site. Their operating principles have already been described. Furthermore, experimental testing will be performed due to the settings of synchronization, calibration and resistance of individual elements of the device. After correct setting, test tests shall be performed with a vehicle equipped with an autonomous emergency braking (AEB) system and the correct functioning of the entire device shall be verified. By performing repeated tests, output data will be obtained, which will be used for further research and the development of active safety systems.

The diagram of the whole device including individual elements is shown in Fig.7.

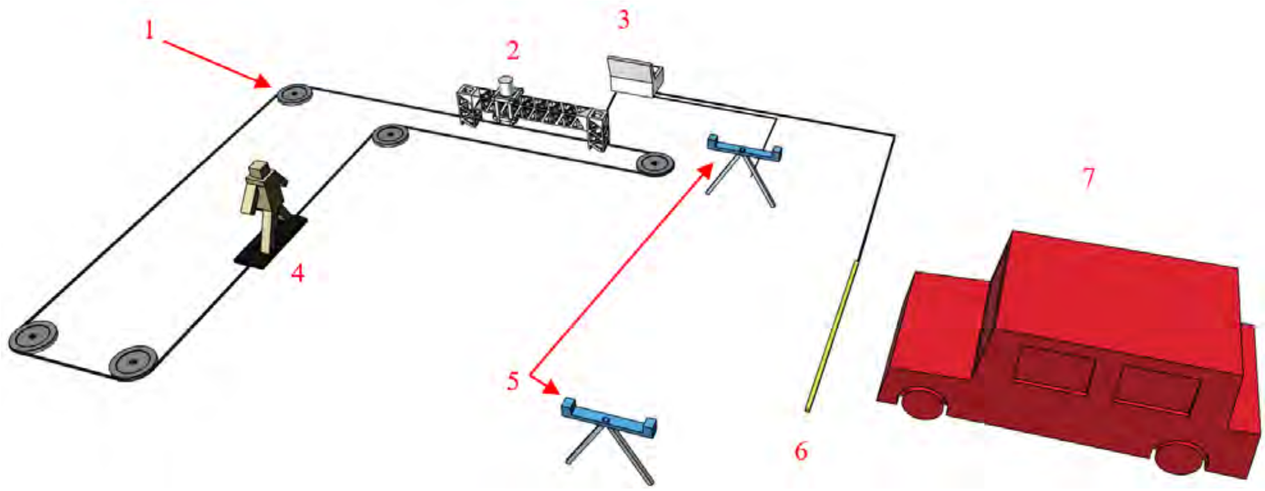

Fig. 7 Design of the proposed equipment: *1* – pulley; *2* – engine; *3* – controller unit; *4* – platform with mannequin; *5* – light gates; *6* – tapeswitch; *7* – vehicle

5. Conclusions

The development of active safety systems and pedestrian protection are important for the introduction of vehicles with full automation. The number of accidents and injuries in road accidents is still high. The goal of the car industry as well as the European Union is to reduce the number of accidents as well as injuries in road accidents and to eliminate fatal injuries. That is why it is necessary to constantly improve active safety systems, to which the test equipment, systems and systems themselves contribute. For this reason, we decided to focus on the track system to help improve the active safety features of vehicles, provide space for other researchers to perform test tests and help them understand the principles of decision-making and how these features work in the vehicle. The role of the devices for testing these elements is to imitate human movement as reliably as possible.

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Review of Green Practices in the Czech Republic Challenges and Implementation of Lean Supply Chain Management System

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Abstract

This paper is focused on the review of the lean supply chain management system in the automobile industry of the Czech Republic. The green practices that are integral to the supply chain management in the automotive industry of the Czech Republic will also be assessed. The main result of the research is focused on assessing the challenges encountered during the implementation of a lean supply chain management system in the automobile industry of the Czech Republic. The implementation of the lean concept appears to be more advanced in the automotive industry with a focus on the efficiency of the procurement process, therefore lean is the first rational step undertaken by these companies to reduce cost-saving. The choice of the automobile industry for this paper can be attributed to the fact that the automobile industry in the Czech Republic is globally interconnected and automotive production is vertically integrated into supply chains. As the Czech Republic is an integral part of V4 countries, the V4 region in Europe is a focus of the car manufacturing sector in Europe. Moreover, the Czech Republic is ranked second among V4, the first ranking is held by Slovakia. Nonetheless, the selection of the Republic can be justified for this work as it is an association of the automotive industry, wherein almost 66% of all automotive employees are employed in the supplier companies. Large suppliers of the Czech market also source to the local and global markets. The study will integrate the two diverse approaches of lean and green. So that the green practices associated with the Czech automobile sector can be reviewed, and the challenges faced by the Czech automotive industry can be analysed for the implementation of the lean approach.
KEY WORDS: *supply chain management, lean supply chain management, green practices, automobile industry, Czech Republic, integration*

1. Introduction

The selection of the automotive industry for this work can be attributed to the fact that this industry is probably one of the largest and most powerful global industries. The industry comprises of diverse firms involved in the marketing and sales of automobiles and spare parts, these firms are engaged in the design, production, and sales of automobiles and spare parts. The turnover of this industry almost corresponds to the sixth-largest economy in the world, confirming that the automotive industry contributes significantly to the economy of the world and is one of the most vital revenue-generating industries in the world. As per global standards, the turnover of this industry was more than 809 billion euros, only in the first half of 2021 [7] almost similar to the GDP of Turkey [36].

The automobile industry is one of the largest and dominant industries in the world, contributes not only to the economy but impacts the safety of people and the society thereby affecting the quality of life of individuals [37] at global level. The industry is growing at a very rapid pace as the revenue of this industry has increased by almost 28% in the first quarter from 2012 to 2021 [7]. This immense growth of the industry in the last decade or so has resulted in increased production of automobiles as the number of vehicles has increased significantly on the road thereby creating a diverse set of complications for the society. Moreover, during the complete manufacturing process automobiles go through different phases in their life cycle, and each phase might have a significant impact on the environment. Every automobile before it is ready for roll-on into wagons for shipment consumes a number of items like steel, aluminium, plastic, rubber and glass to name a few, and the most relevant problem is that most of these items are integral to the manufacturing of automobiles are either very tough or expensive to dispose of. Additionally, the consumption of fuel by automobiles leads to air pollution thereby increasing air pollution and adding significantly to climate change and resulting in global warming. Thereby considering the effect of the automotive industry on the environment, the automotive sector has adopted sustainability in operations [24].

The sustainability methods and performance procedures adopted in the automotive industry have been reviewed in the literature, the pragmatic environmental methods are ecologically designed vehicles, use of clean fuels, methods adopted for reduction of waste and recycling of materials [10]. The automobile industry emphasises the planning of the resources and the objective is to improve the process of production so that they can satisfy their customers. Nonetheless, the distribution process follows the global trends, this can have a direct effect on the performance and cost of the products, eventually affecting the customer relationship and services. To avoid such challenges lean approach can be adopted thereby improving the flexibility of the distribution, as this will reduce the dependence of the companies on estimates, as a result, the companies can implement improved strategies to attain better results in the performance related to SCM [38].

In addition to the lean practices, improvised methods are adopted at the end of the supply chain regarding the assessment of the environmental elements based on their impact on the automotive sector, wherein the green activities associated with manufacturing and operations were recognised [5]. The structure of suppliers plays a vital role in the management of energy and conservation of the environment. Supplier chain management involves numerous companies that operate mutually in manufacturing, production, acquiring information and financial flow. The most integral part of the supply chain (SC) in the automotive sector includes suppliers, warehouses, and original equipment manufacturers (OEMs) and extends to the centre for distribution covering dealers and terminates with customers. Sustainable environment management can be initiated with a complete supply chain, incorporating both suppliers and the original equipment manufacturers. Few energy-linked aspects, especially the use of fuels and renewable energy sources should be taken into account for the design and procedures related to a sustainable supply chain [2]. As per norms of the supply chain [4] affirmed that green supply chain management (GSCM) can be stated as the driver of the business performance in the automobile sector. Green supply chain management [30] focuses on a sustainable environment.

The most important aspect is that the SCM approaches like lean and green have been globally adopted by the manufacturing industries [16]. This integration of lean and green has led to the creation of environmental, social and economic benefits. The study of both paradigms can help in improving the environmental and financial performance [18]. The lean and green practices can be adopted by the manufacturing companies to attain sustainable development in a balanced manner and this integration can be adopted by the companies to improve the environmental and financial performance [3]. Nonetheless, the effect of GSCM on green innovation is considerable for the firms that implemented a green supply chain [1]. The companies had to adopt GSCM and green innovation due to external pressure from the stakeholders, as it improves the performance of the companies [6].

This paper will adopt the integration of the lean and green characteristics, evaluate challenges in the implementation of lean supply chain management and review green practices in the Czech automotive industry. The selection of the Czech automotive industry can be attributed to the presence of various global brands in the region. The Czech companies in the automotive industry can be categorised broadly into assemblers and original equipment manufacturers (OEM). Large suppliers source the car manufacturers like "Skoda Auto, Hyundai Motor Manufacturing Czech and Toyota Peugeot Citroën Automobile in the Czech Republic" [25].

2. Review of Green SCM and Evaluation of Challenges Faced by the Automotive Industry of the Czech Republic During the Implementation of Lean SCM

The integration of both lean and green paradigms based on the work of Jasiulewicz – Kaczmarek [17] and Sharma, Singhi, & Mittal [28] is considered for the study, as mentioned in Fig. 1. The integration of both lean and green paradigms will be implemented, and the evaluation of lean and green practices will be performed as per economic and environmental performance. The green practices will be reviewed as per sustainable development management, green purchase and eco-design and life-cycle evaluation of the products. The challenges in the implementation of the lean will be evaluated as per cost-reduction, elimination of non-value waste, minimization of inventory, supplier attributes like quality and cost and last but not the least problems related to maximising performance and minimising cost.

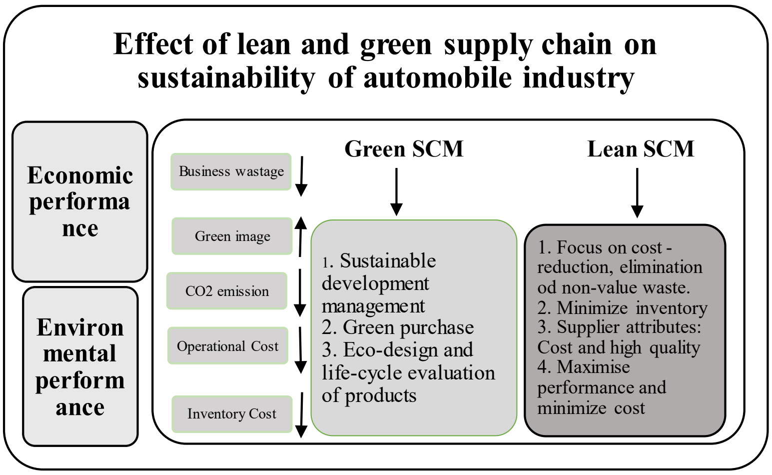

Fig. 1 Effect of lean and green un automotive industry [17, 28]

Lean practices have been followed and are one of the most established and acclaimed approaches in the automobile industry (Fig. 1); however, the approach of green supply management is relatively new as the companies are struggling with incorporating both these paradigms in their supply chain. As per the existing environmental situation, there is immense pressure on the automobile industry to adopt both lean and green processes beneficial for a sustainable environment. Even though the green supply chain is the approach, it needs to be linked with lean practices so as to attain a competitive advantage beneficial for the organisation and sustainable for the environment. This paper aims to assess the challenges in the implementation of lean and review the key practices of a green supply chain. The structured approach will be adopted by integrating both lean and green strategies, the Czech automotive industry was selected for the study.

Lean and green can be stated as the vital paradigms of the SCM, which are significant elements that contribute to the competitiveness and success of the supply chain. Lean practices are adopted across companies to improvise the quality of the products and services along with reduced costs, nonetheless, the environmental effect is not integral to lean. Although lean and green have diverse approaches, they are congruent in the creation of collaborative systems [14]. Value can be added to the green efforts by the adoption of the lean paradigm, wherein adverse impact on the environment can be reduced. Eventually, the green practices can act as a financial driver and improve the efficiency associated with the green procedures, lean practices on the contrary are focused on reducing the elimination of the waste [33]. Most of the studies have catered to either lean or green paradigms of SCM, even though very few studies have been conducted on the integration of lean and green paradigms, this integration can be effective in making supply chains more effective, efficient and sustainable [8].

2.1. Lean SCM and Challenges in the Implementation of Lean in the Czech Automotive Industry

Lean management underscores the timely delivery of the products at the exact location at minimum cost by eliminating waste and avoiding avoidable inventories [20]. Lean management can be defined as the supply chain management based on transaction SCM in the automobile industry with emphasis on information and flow of materials [35]. Effective use of SCM using lean management can help in attaining sustainability from three perspectives: economic, environmental and social as well [32]. Most of the studies have emphasised the operational aspects of the LM and not much has been studied from the perspective of the association between LM and its effect on the performance of the supply chain [34]. Therefore, it can be stated that in contrast to the conventional SCM model with too much inventory and relatively more ineffectiveness, the lean culture helps maximise the value, by reducing the waste and minimising the cost [15].

The Czech Republic is a country with a strong history of production and manufacturing, as such the industry is aware of the concept of lean. However, the global industry is putting significant pressure on the supply chain of the Automobile industry for the implementation of lean. As per a report conducted on the Czech industry, it could be proposed that "automotive supply chains that do not fully comply to the six sigma performance specifications throughout all tier ranks" [26]. Even though the Czech companies the downstream did apply lean measures like six-sigma, the upstream companies on the contrary did not show much trust in lean measures. The discrepancy in downstream and upstream companies in the application of the lean measures can be attributed to various factors. These factors include lack of understanding in the identification of the lean approach and inadequate planning and can be stated as a key challenge for the adoption of the lean approach by the Czech automotive companies, as proposed by [26] in their work.

2.2. Review of Green SCM in the Czech Automotive Industry

The GSCM has significant in improvising the performance of the firm, even though the adoption of the green supply chain is economically challenging, as it involves a huge cost [13]. The significant impact of GSCM on the performance of firms cannot be substantiated as not many firms have implemented green supply chain management [21]. The implementation of the green supply chain requires cooperation with suppliers, which is not a typical strategy, this is despite the fact that the companies that cooperate with the suppliers and have an intensive partner in supply chain management have significantly more rate of development when it comes to development in GSCM. Affirming that information sharing plays a vital role in the green supply chain as information sharing is of great relevance in the automotive sector, wherein regularly the notifications need to be sent based on changing requirements and consultations [31].

The analysis of the green SCM confirms that many automotive companies in the Czech Republic have invested in green initiatives to save the conservation of energy. The alternative is to rely on alternative technology, rather than using conventional fossil-fuel-based technology and work on renewable equipment so that the industry can overcome the burden. The most challenging task is to overcome the barriers between stakeholders as initially the companies need to seek permission and help from the government for the green design based on the legal requirements and the standards. In case the automotive companies can overcome the financial constraints, they can be in a competitive position to offer sustainable and eco-friendly green products [25].

The case of Skoda can be applied to understand the manner in which the integrated approach to the supply chain might be influenced by the existing SC and other regulatory frameworks. As already mentioned the automotive supply chain is integrated and very complex, as a conventional car uses more than 30,000 individual components [9]. Taking the example of Skoda, this global company as per reports published in January 2022, rolls out almost 1200 cars a day, at the company's main plant located in Mladá Boleslav, the city in the Central Bohemian Region of the Czech Republic [29]. The assembly of cars requires various components as already mentioned, and during manufacturing the automotive parts such as fuel injection components and even spark plugs can be sourced to various manufacturing sites across the world. In case the Carbon Border Adjustment Mechanism (CBAM) is used at each stage of manufacturing, this can help in saving the cost associated with the manufacturing of the fuel injection components and spark plugs. CBAM had been proposed by the European Commission (EC) in July 2021, wherein the levy on carbon-intensive products is proposed to be implemented on the products that were imported specifically to Europe. The use of CBAM can help Skoda to prepare for the future by reducing CO2 emissions and using sustainable and renewable sources like cotton, cellulose and flax. Skoda by becoming sustainable will not only7 cut CO2 emissions but save significantly due to the rising prices of carbon-based products in the market [22].

3. Conclusions

The GSCM is the established term in the procedural literature pertaining to the concept of SCM that incorporates the characteristics of the environment. The scholars of the GSM approach this topic from two perspectives. Aligning as a group of scholars [27] define the GSCM from the perspective of lean management (minimization of waste by the production of environmentally friendly products), the other determines the activities within GSCM like green design, green manufacturing and reverse logistics [19]. Nonetheless, the demand of the twenty-first century is finding a competitive approach regarding the SCM for the industries involved in manufacturing. Adoption of both lean and green approaches can be proposed to attain sustainability in the competitive market, but then again the challenge is the integration of both lean and green approaches and evaluating the impact of these approaches on each other, this paper has integrated the two paradigms and evaluated the Czech automotive industry.

The automotive industry of Europe is of great relevance as it is one of the largest manufacturing sectors of the European Union. The automotive value chain in the European Union (EU) is very extensive as various activities are integral to the automotive industry, all automotive engineering related activities like production, maintenance, repair along with end-of-life handling of the vehicles are integral to the value chain, thereby reducing waste and contributing to best environmental practices. The best environmental management practices incorporate procedures and activities that are executed by the organisations within the automotive industry, these practices are most advanced in terms of energy and resource management, and productivity emissions are integral to the automotive supply chain management of this industry. These environmental practices provide an encouraging pattern for the organisation within the automotive sector to improvise the environment.

The Czech Republic was chosen for this study as it has a long tradition of association with manufacturing industries, this applies explicitly to the automobile manufacturing industry. By the year 2014 Czech Republic became the world leader in the production of light vehicles. Since, the last twenty-five years Central Europe have evolved as the main automotive cluster, with the leading automotive brands and a huge supplier network covering the Czech Republic. The analysis of the challenges faced by the Czech automotive industry in the implementation of the lean supply chain management affirmed that despite being aware of the lean approaches, the Czech automobile companies do not comply with the lean approaches like six sigma. The adoption of lean for more downstream companies than the upstream ones can be attributed to the lack of understanding of the approach behind lean supply chain management and insufficient planning. The review of the green practices in the Czech industry affirms that the companies need to adopt renewable energy-based technology, should open communication with the suppliers, maintain transparency as per the legal system and share information with the distributers regarding green design and green purchases to avoid waste and maximise profits by reducing cost. The case of Skoda confirms that the adoption of CBAM by the global car manufacturer will prove to be sustainable, by reducing CO2. Adoption of CBAM and the use of renewable products instead of carbon can help the company in saving huge costs associated with imports of carbon-based car components like fuel injection components and even spark plugs.

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Competitive Advantages Assessment for the Railway Industry of Ukraine

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Abstract

The railway is a backbone of the country's economy and ensures its viability, resilience and safety even in critical situations. The railway has become a life pathway for Ukrainians in 2022. Railway network diversification has proved to be a practical competitive advantage for the transport system and the country as a whole. The purpose of the study: is to assess the competitive advantages of the Ukrainian railway industry in terms of EU integration. Methods: Porter's Diamond Model. Results of the research: factor conditions, demand conditions, related and supporting industries, firm strategy, structure and rivalry have been analysed; competitive advantages along with problems of their maintenance have been established; the ways of revealing the potential of the Ukrainian railway industry have been offered.
KEY WORDS: *railway industry, competitive advantage, Porter's Diamond model.*

1. Introduction

Given all the challenges nowadays, a firm and stable European integration course are being considered even more relevant for Ukraine than before. Ukraine's ability to make the most of existing potential and new opportunities is likely to determine its future role and place in the European Union.

Undoubtedly, the railway is the country's economic basis and ensures its viability, sustainability and safety even in critical situations. The railway in Ukraine became a road of life in 2022. Ukraine has launched a process of railway market liberalization aiming at increasing Ukrainian railway's competitiveness, integrating them into the EU's single transport space, and solving a number of critical problems complicated even further by russia's military aggression against Ukraine. Direct infrastructure damage caused through bridges, roads and housing destruction is estimated to be about $ 120 billion [1]. Experts emphasize the figures to continue rising daily. If destroyed military infrastructure and other civilian casualties are taken into account, the figure is more than 270 billion dollars [1]. Russian occupiers destroyed 6.3 thousand km of main tracks in Ukraine, as well as damaged 23,573 km of roads, 289 roads and 41 railway bridges [2]. A railway network loss of about 23% has been recorded [2].

2. Main Material Presentation

A tool to explain countries competitive advantages, as well as reason some industries becoming world leaders, was proposed by M. Porter in a form of competitive advantage diamond. He had defined four main indicators: factor conditions; demand conditions; related and supporting industries; firm strategy, structure and rivalry. Conclusions over those four components, based on the study of railway industry of Ukraine are presented at Fig. 1.

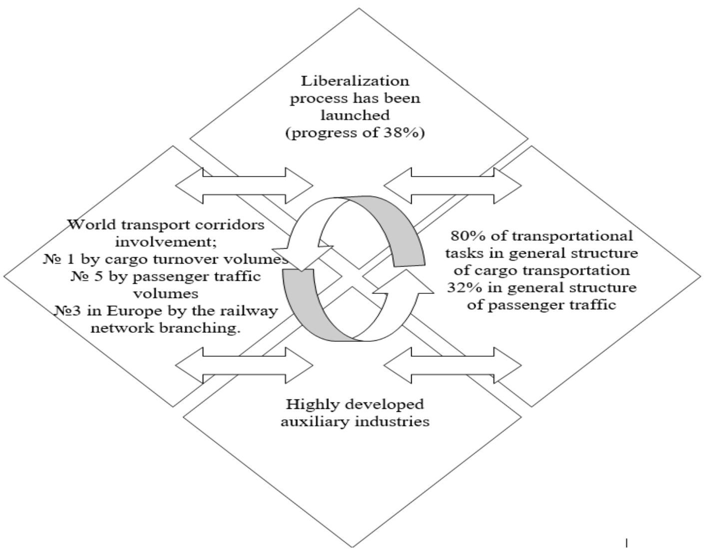


Fig. 1 Railway industry of Ukraine competitive advantages Rhombus. Source: authors own elaboration based on [3]

Below a detailed assessment is provided for the railway industry of Ukraine competitive advantages:

1. Factor conditions reflecting ability to transform natural resources and infrastructure into competitive advantages.

Following typical for the railway industry of Ukraine:

– favourable geopolitical position of Ukraine; it is located at the crossroads of trade routes between Europe and Asia, the Baltic and the Black Sea regions;

– the world transport space involvement (Pan-European transport corridors №№ 3, 5, 7, 9, as well as Railway Cooperation Organization (RAO) corridors №№ 3, 4, 5, 7, 8, 10 pass through the territory of Ukraine);

– an extensive railway network is the third largest in Europe (the railways of Ukraine operational network is almost 19.8 thousand km without taking into account the occupied territories, where network is not currently operated).

– international logistics opportunities – there was a decrease in the volume of rail freight in 2020 compared to previous year: import (-6,7 million tons, or -15,4%) – accounted 36,5 million tons; export (-2,8 million tons, or -2,5%) – accounted 113 million tons; transit (-1,9 million tons, or -12,8%) – accounted 12,5 million tons (Table 1).

Table 1

International railways markets 2017-2021 years. Source: grouped on the basis of [9-13]

Indicator	Years				
	2017	2018	2019	2020	2021
Transported, million tons, in particular	339,6	322,3	312,94	305,48	314,3
transit	19,6	16,3	14,39	12,54	11,5
import	43,9	43,6	43,16	36,51	40,6
export	116,1	107,4	115,83	112,99	112,4
Freight turnover, million t-km, in particular	191 914,1	186 344,1	181 844,7	175 587,1	180 361,0
transit	20 272,6	17 452,8	15 216,2	14 276,4	13 016,6
import	22 873,7	23 846,0	23 673,5	20 225,5	21 016,1
export	79 817,3	76 664,9	80 855,8	77 838,8	80 196,9

A downward trend is being observed currently due to a number of objective reasons, including crisises caused by the coronavirus pandemic and the war. Significant reduction in transit traffic. This trend can be explained by russian goods railway transit share decrease caused by aggravation of relations between Ukraine and russia.

As per previously provided arguments, factor conditions are quite favorable and form competitive advantages, but the biggest challenge for their maintenance is interoperability. The track width in Europe is 1435 mm (excluding Baltics, Finland, Ireland, Spain and Portugal). 1520 mm wide tracks are operated in Ukraine. There are about 15 docking stations in Ukraine (on the border with Poland, Slovakia, Hungary and Romania). Tracks of European width of 1435 mm are used at several regions of Ukraine: Zakarpattia region (Chop-Mukacheve, Chop-Korolevo-Dyakovo), Lviv region (Starzhava-Khyriv-Nyzhankovychi) and at some border stations (Yagodyn, Rava-Ruska, Mostyska-2, Vadul- Siret).

Ukraine and the United States signed a Memorandum on Transport Cooperation during the Summit of the International Transport Forum 2022 providing for modernization of Ukrainian infrastructure [6]. The expected key results of this cooperation: entire locomotives and wagons fleet renewal by 2030; high-speed railway connections between large cities creation; railway infrastructure improval, especially in large cities; existing roads modernization and automatic weighing stations installation on them; track width 1435 mm. This will primarily contribute to country's transport potential development and its involvement in globalization processes. Networks standardization helps to increase internal market efficiency; increase economic and social cohesion; helps to raise logistics standards; implement sustainable development through the use of a wider range of more environmentally friendly and highly efficient safe transport regimes.

The main problems of maintaining competitive advantages also include the infrastructure quality needing repair and recovery from hostilities caused by the russian-Ukrainian war.

2. Domestic demand terms.

The railway provides 80.1% of transportational tasks in the overall structure of freight traffic among all transport types and 32.1% in the overall structure of passenger traffic [12].

Railway is universal transport type and provides transportation of a large number of goods. Rail freight commodity nomenclature reflects structural changes in the economy of Ukraine. There was an increase in the transportation volume for the following categories: construction materials (+8,7 million tons), iron and manganese ore (+5,2 million tons), colored ore (+0,1 million tons). Decrease: coal (-10,2 million tons), cereals (-5,3 million tons), ferrous metals (-0,9 million tons).

There is possibility to maintain your competitive advantages in the domestic market by increasing the level of service. However, the results of rail freight market study state the following: 37% respondents rated the service as "good", 50% - "satisfactory" and 13% - "unsatisfactory" [4]. The most common problems customers are facing: cars serving delays, faulty equipment, insufficient number of equipment / workers to provide services during peak periods, incompetence of workers. 75.5% of respondents consider alternative modes of transport. This situation leads to a gradual market share loss for rail transport and requires rail transport market model introduction developed on the basis of liberalization policy.

3. Related and ancillary industries trying to gain a leading position in international markets, needing support of world-class suppliers and being able provide an accelerated process of innovation.

Rail transport is an important part of the logistics chain and therefore has an impact and interacts with a number of economy sectors. For the railway market being logistics chain participant, it is important to provide quality services ensuring modern technical and technological, digital, environmental, socially responsible solutions introduction along with improved safety. In line with global trends, the challenge for rail transport is to ensure smart, integrated, environmentally friendly and safe transport. Integration into global supply chains force all the logistics chain participants to be committed to stepping up cooperation to reduce time (planning, responding to requests, reducing delivery time, minimizing delays), provide the necessary flexibility, provide access to up-to-date and reliable information.

The main related industry is agriculture. Russian invasion of Ukraine and blockade of Black Sea-Azov ports have had a significant negative impact on world food markets. Over the past few years, Ukrainian seaports have processed more than 40 million tons of grain cargo for export. Currently, opportunities for agricultural products export shipments are concentrated in the western railway crossings and Danube ports in the south of Odessa region, partly - by road. Thus, during 4 months since the beginning of the year about 7.5 million tons of cargo were transported by rail in the export service. At certain transitions, the queues for goods transfer can reach 40 days. Before the war Ukraine exported about 50 million tons of grain annually. Ukraine's further export potential depends on the railway, so the reorientation of exports to the EU and Bessarabia, where there are two ports, is considered a priority. Ukrainian Railways are ready to reorient traffic from the ports of southern Ukraine to the western crossings with EU countries. Unfortunately, neighbouring countries were not ready for such volumes, but this work is on-going and volumes are prognosed to increase.

Related and ancillary industries ensuring the sphere of passenger and cargo transportation development and operation are determined by following enterprises:

– specializing in the repair and maintenance of rolling stock (Dnipropetrovsk Diesel Locomotive Repair Plant; Zaporizhia Electric Locomotive Repair Plant; Lviv Locomotive Repair Plant; Kyiv Electric Car Repair Plant; Darnytsia Car Repair Plant; Panyutyn Car Repair Plant; Stryi Car Repair Plant; Kryukiv Carriage Building Plant); In addition, cars repair and maintenance is carried out by the UZ car service at more than 20 depots (Drohobych, Zdolbuniv, Kolomyia and others);

– specializing in infrastructure, tracks and equipment construction, reconstruction and modernization (Korosten plant of reinforced concrete sleepers; Gnivan Special Reinforced Concrete Plant; Center for track construction and repair; Center for construction and repair of civil engineering). Center for track construction and repair is a branch of UZ including 27 track machine stations and six rail welding trains. The key function is construction, reconstruction, technical re-equipment and repair of railways, switches, crossings and their components. Center for Construction and Repair of Engineering Structures - a branch of UZ including track machine stations for repairing the earthworks and bridge building trains. The key functions are repair, reconstruction and construction of bridges, tunnels, earthworks and its components;

– providing communication services, materials production and supply, security, research and development;

– educational, scientific and health institutions.

Historically, they were created on the basis of a state-owned enterprise and were managed by JSC Ukrzaliznytsia. Now they are in the process of privatization. The biggest problem is the reduction of technical equipment level, out-dated production base, the need for investment, dependence on a key customer, staff turnover.

Related and ancillary enterprises include those producing goods that have a competitive advantage on the global market. Manufacturers of rolling stock are among them. For example, DMZ "Karpaty", Kryukiv Car-Building Plant.

There are more than 100 ancillary enterprises in total being involved in the railway transport sector, but many end up in the russian-occupied territories. As of May 25, 2022, Russia occupied about 20% of Ukrainian territory accounting to 125 thousand km^2 [5].

4. Companies' strategy and structure, competition.

The main purpose for railway transport reforming is to develop competition in the railway market and increase the industry's efficiency. Ukraine is on the European path of liberalization being based on the principle of infrastructure management and transport process separation.

Ukraine has launched a process of railway market liberalization aiming at Ukrainian railways competitiveness increase, its integration into the single transport space of the EU. European integration of Ukraine agreement defines liberalization as the main point to be implemented in the railway market. Currently progress at a level of 38% is being reported [7].

Authors' Empirical research in this direction was aimed at a group of major market participants - carriers merging into the Association of Ukrainian Railway Carriers (created by the first private railway carriers) [8]. A survey / questionnaire was conducted considering current progress of liberalization during April 2020. Generalized partial results are presented at Fig. 2.

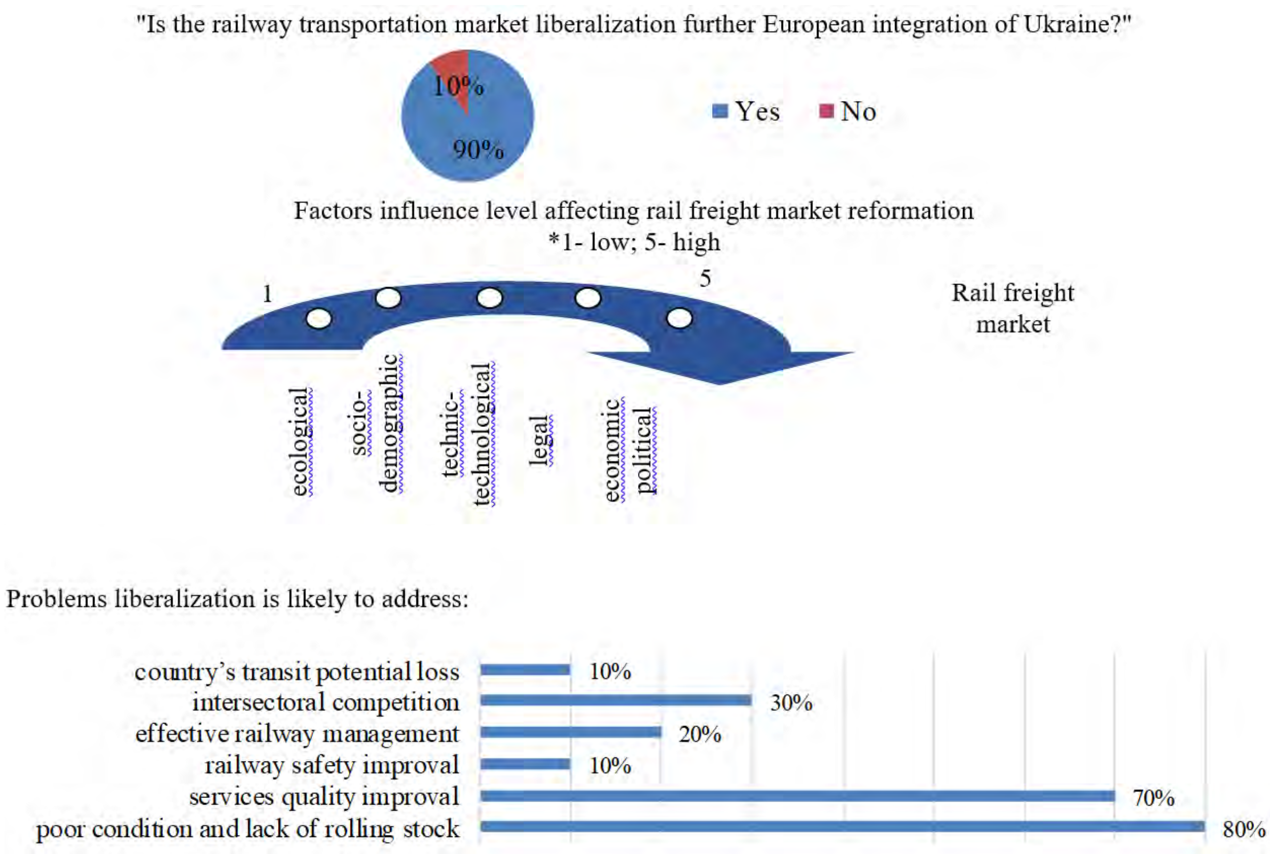


Fig. 2 Domestic rail freight market study results. Source: authors marketing research

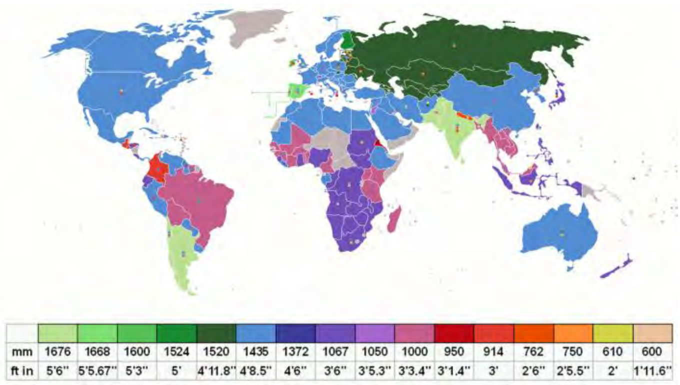
The vast majority of respondents express support for liberalization. According to respondents, liberalization introduction is likely to help solving following critical problems in the industry: poor condition and lack of rolling stock – 80%; services quality improval – 70%; intersectoral competition – 30%; effective railway management – 20%; railway safety improval – 10%; country's transit potential loss – 10% (problem being indicated as national scale one).

Resistance forces opposing competition start in the industry include: out-dated legislation, limited access to infrastructure, non-admission for private traction. Therefore, respondents described reforming factors influence level in the following sequence (starting with the most influential): political – economic – legal – technic-technological – socio-demographic – ecological. 90% of respondents support railway transportation market liberalization as an important element of Ukraine's further European integration.

Liberalization will help strengthen and maintain Ukraine's railway industry competitive advantages (Table 2).

Table 2

Problems of maintaining Ukrainian railways competitive advantages. Source: authors own elaboration

Competitive advantage	**Problems of competitive advantage maintaining**
Pan-European Transport Corridors №№ 3, 5, 9 involvement 	interoperability 
№ 1 By cargo turnover volumes (Ukraine - 187 billion km, Germany - 116 billion km)	russian-Ukrainian war consequences **Destroyed** 6,3 thousand km of main tracks

<table>
<tr>
<td>№5
By passenger traffic volumes
(Great Britain - 51 billion pkm, Italy - 51 billion pkm, Ukraine - 37 billion pkm)
№3
By railway lined used (Germany – 39 thousand km, France - 29 thousand km, Ukraine - 20 thousand km)</td>
<td>Damaged
23 573 km of roads,
289 automotive,
41 railway bridges.
Lost
23% of railway network.</td>
</tr>
<tr>
<td>80%
transportational tasks in general structure of cargo transportation</td>
<td>Low service quality
Estimate the general quality level of freight transportation services:

</td>
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3. Conclusions

With a number of leading positions, Ukrainian railway is capable of turning them into its competitive advantages by concentrating on priority problems resolution lying in the area of:

1. Railway liberalization program implementation acceleration. Issues being completely unresolved and needing immediate action include regulatory framework development ensuring equal access to railway infrastructure, restructuring in accordance with EU legislation incorporating separation of infrastructure management and transportation, an effective tariffs formation system development for railway infrastructure usage, infrastructure access licensing, a rail transport safety management system implementation, Ukrainian legislation amendment in order to update conditions for issuing certificates to train drivers, improve rail passenger services (implementation rates 0-30%).
2. Infrastructure quality being in need of repair and reconstruction due to hostilities caused by the russian-Ukrainian war.

Currently, the enemy is deliberately destroying railway infrastructure. The United States plans to allocate $ 40 billion to assist Ukraine. It is unknown at this point in time what is going to be included into land-lease package. Results expected by the railway transport industry are: renewal of locomotives and wagons fleet; high-speed railway system creation; railway infrastructure improvement; track width of 1435 mm. The EU also proposes expanding TEN-T corridors in Ukraine to improve connections with the EU through the development of standard European track (1435 mm) railways in Ukraine and Moldova. In particular, the conclusion of an agreement with Ukraine is being considered regarding the revision of TEN-T cards. This should be physically reflected through cross-border services modernization between the EU and Ukraine, as well as transport flows optimization in terms of infrastructure capacity, compatibility and efficiency of relevant services, including additional border crossings resumption.

3. Railway interoperability involves the ability to operate smoothly in the single world transport space and to ensure the safe and uninterrupted trains movement. This capability is determined by a combination of technical (track gauge, dimensions), regulatory (guidance through common regulations and directives) and operational requirements (integrated transport).

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Review of Researches Tendency in the Future of the Road Transport

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Abstract

The economic growth in the last years lead land vehicles to become an irreplaceable meaning of cargo transportation and people's travel. The massive increase in using personal vehicles and increasing the number of cargo transportation vehicles led to raising the different research needs in driving towards better vehicle structures and road transport systems. The aim of the current review research is to analyse, according to the world's scientific activities, the possible evolution of the road transport sector and personal mobility in the few future decades. The research includes a detailed review of developed and planning for implementation technologies and methods in the transport sector from energy use and emissions direction to safety and automation in transport. The reviewed trends in the research describe the effect of the part of the overall transport system linked to road urban area transport. In the final review analyses were founded four major directions for a new research tendency in the transport sector future: decarbonisation; automation; connectivity, and sharing. The research established the essential to address the road transport externalities in order to reach an efficient, safe, sustainable and inclusive multimodal transport system in the future.
KEY WORDS: *transport; research tendency; infrastructure; road; vehicle*

1. Introduction

Personal mobility, as well as cargo transportation each year, plays more and more important roles in society's life. The economic growth in the last years lead for land vehicles to become an irreplaceable meaning of cargo transportation and peoples travel. The massive increasing of using personal vehicles and increasing a number of cargo transportation vehicles led to raising the different research needs in driving towards better vehicle structures and road transport systems. The transport sector is – and will continue to be – increasingly driven by technology. According to [1], the main current research in the transport sector is directed in order to reach an efficient, safe, sustainable and inclusive multimodal transport system in the future.

To indicate the present and future challenges for research, firstly, should be provided actuality. Sustainable and universal mobility – is always at the centre of European Union (EU) transport policy, since it plays a vital role in the competitiveness of EU industry and services to meet citizens' needs. From 2005 to 2017, the total number of passenger kilometers (pkm) increased by 23.8%, according to information provided by European Commission [2], the vast majority of which were covered by passenger cars (Fig. 1). At the same time, expected that EU transport sector activity will grow, even more, in the coming decades, with road transport maintaining its dominant role, according to [3]. Specifically, growth is visible for two-wheels and private (passenger and cargo) transport and estimated at 16 % during 2010-2030 and at 30% for 2010-2050 (Fig. 1). From another side, for indicate especial trends in transport sector, additional researches is investigated age and urbanization factors in people mobility. This can be achieved during a detail review of [4], where is displayed that public transport is more pronounced for using in urban and in non-urban areas its prefer to use the private transport (Fig. 2), additional presented a preferences by age factor. This statistics make insure that researchers is plan to active in a trend transport direction for their research. Additional, just with information presented above, exist a limitation. That`s why in current review also provided a main challenges facing to road transport sector: safety; urbanization, commuting times and congestion; environment influence; demography.

According to United National Economic Commission statistics [5] – the trends in road traffic accidents and fatalities' in period 2009-2019 years is slowly decrease. Between 2009 and 2019, the total number of fatalities in road traffic accidents decreased by ~20% in the EU region. At the same time, World Health Organization [6] statistic shown that the road traffic accidents is on the leading place of deaths for a children and young people up to 29 years old. According to [7] research, between the 2015 and 2030 years expected an up to $1.8 trillion losses costs (hospitalization, combined societal losses of labour etc.) due to collisions from road traffic accidents. This all make a relevant a first challenges for a transport sector – safety.

United Nations (UN) each five years presented statistics about urbanization processes in the World, which also important challenge for a transport sector. According to [8], in 2019, globally more than 50% of people is live in urban areas, for Europe it's even more charactering up to 75%. At the same time, by UN prognoses [9] the urbanisation will continue to grow and will reaching 84% in Europe and 68% globally by 2050. Generally, the growing urban population, already mean, that the global challenge faced to mobility and transport more and more intensified. The more activities challenges connected with urbanisation for transport sector, from one side consist by commuting times (daily in/out city traveling for a working people), from another side, in larger cities, private car ownership tends to be lower and lower, since people in cities prefer alternative variation of transport (public, cycling, scooters etc.), according to [10] information. All mention above, lead to large amount of congestion in the urban areas. According to INRIX report [11], the productivity losses, achieved by different vehicle traffic congestion, around 2% from all gross domestic product in the EU country. In final, it can be pointed that urbanisation and congestion make a relevant a second challenges for a transport sector.

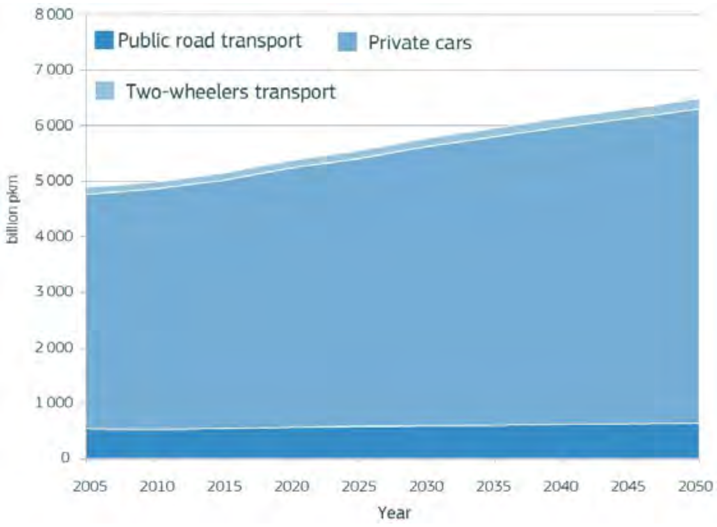

Fig. 1 Road passenger transport activity evolution since 2005 and up to 2050 (in pkm) by [2]

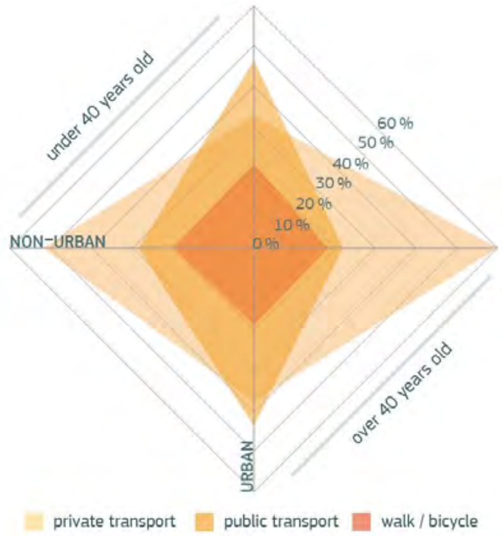

Fig. 2 Scheme of preference to use transport by different person categories, according to [4]

Transport sector it is also one of the major and growing contributor for air pollution. According to EU Commission report [2], in EU was emitted by different variety of vehicle 852 mln. Tonnes of CO_2. Particular was estimated that transport sector is responsible for ~30% of small particulate matter emissions, what automatically make it like a main cause of air pollution related deaths and illnesses, globally, by [12]. This all make a relevant a third challenges for a transport road sector – environmental problem.

The governments with each year pointed that settlements required to accommodate a growing elderly population of citizens. According to statistics and prognoses by UN [13], globally the number of people aged 60 years and over will be more than double until 2050. The governments started already facilitate for researchers work in direction connected with requiring transport mobility systems that can be adapted to become more inclusive and accessible to older population. From this information, obtained a forth challenges for a transport sector – demography.

In final, by review of statistics and reports provided by international organisation and researches can be pointed that in future the transport sector will be affected by different factors, which lead to a main challenges facing to road transport sector: safety; urbanization, commuting times and congestion; environment influence; demography. The pointed challenges is required a wide range of different solution (technical and services) exactly this solutions will make a trend and tendency in in the future of the road transport.

2. Technology Outlook in Road Transport

Four most fast-moving trends in the road transport sector can be observed during a detail review of research direction connected with a road transport. These trends can help to solve faced challenges and transform all road transport sector, as we know it now. The technology outlook in the road transport will help to create a methodology diagram for finding optimal trend and tendency of each challenge.

2.1. Automation and Connectivity

The International organization of Society of Automotive Engineers (SAE) in 2016 [14] was proposed to classified the vehicle automation driving by different levels for planned deployed of transports in the future. According to [14] and researches provided by [15 and 16], the automated driving of road transport can be classified in five distinct levels. These levels in general identify whether machine or human make change of the vehicle dynamic driving task (DDT). DDT include both: vehicle longitudinal control (braking, acceleration etc.) steering control. This level ranged from level 0 (where all DDT performed by driver) to level 5 (where DDT performed by machine, full automation) with additional monitoring of environment (road condition, traffic etc.). In the current moment, the automation of road vehicles in the beginning of the 3rd level of automation. From a technical point of view, automation of road transport still required a lot of research and just in beginning of developing 3rd level with a testing, were some several fatal accidents was taken a place [17]. Additional, the delays in the planed targets take a place in the vehicle automation researches [18], since the are no enough time to finally test a development technology.

Significant technical challenges for fully automated vehicle driving (DDT) related to reality remain, according to [19], and include training algorithms for ensuring safe and efficient transport behaviour in any situation during driving, according to [20]. Review of different levels of road transport automation progress (Fig. 2) can lead a conclusion that in final level, the transport sector will obtain more safety road transport adopted for urbanization and demography problems, since with full automation the human factor will be excluded from vehicles DDT.

The mean of connectivity use to describe technologies which help to communicate vehicle with other vehicles or road infrastructure (traffic signals etc.). The connectivity has a close relation with automation, since in both cases the efficient management of vehicle ride and traffic control have a place. According to [21], in close future the two direction of road transport researches – automation and connectivity, since they is closers interlinked, will be merged for more efficient management of traffic and safety in the roads.

2.2. Sharing

Sharing is one of the innovative transport strategy, which include various form of transport sharing (enables to gain short term access) from car and bike sharing to ride sharing in the mean – "Mobility as a Service" (additional, this term used to describe using digital technology's integrated in various form of transport service in one mobility access), according to [22]. According to [23] research, the transports sharing is more adopted in the centres of cities and more used by younger age people, which make a relevant a researches in the direction of improve the popularity and comfortable using a sharing technology in non-urban area and for more older people.

The mean of shared mobility, in general, include a few relevant definition, by [23]: vehicle sharing – a programme of individual fee pay in each time when person have a temporary access to vehicle and not include the cost and responsibilities' of ownership; ride sharing – vehicle service for ride, which connect drivers (cost and responsibility of ownership) and passenger (fee pay for a ride) for providing similar origin destination pairing ride; ride sourcing – on-demand vehicle service for ride, which connect drivers (cost and responsibility of ownership) and passenger (fee pay for a ride) for providing a ride only by passenger required destination. These services already find a place and popularity in most urban areas worldwide, according to [24], and help to solve a wide range of transport sector challenges from environment impact to commuting times and congestion etc.

2.3. Decarbonisation

In the EU with each year observed increasingly stricter regulation connected with CO_2 and air pollution with particulate matter. Additional, the EU have a restrict plan until 2050 to reduce air pollution in transport sector almost to zero [25], that why one of the ideas of "Transport 2050" by European Commission, its use renewable energies and improvement in energy effiency with minimal emission in all kind of road transport. For archive this goal, according to [26-27], the electrification of transport will be one of the best solution, since electrical vehicles (EVs) represent from a medium timescale and alongside of decarbonizing of road transport. Decarburization, also, addresses to use any of alternative fuels: hydrogen, biofuels etc., but the electrification of road transport has a more perspective, since more researches and governments programs pay attention in this direction.

In the EVs research field, the most perspective for technical development direction of research connected with a power system – batteries. The prospects and trends for EVs batteries development can be divided in two stage: short-term (actual right now) and long-term (will be actual after few years in next decade). The short-term strategy include that batteries should lowering in the costs with increasing energy density with limiting the cobalt content [28]. For the long-term strategy, according to research [29], the improve the range of the EVs will be reach by replace current liquid electrolyte Li-ion batteries by solid-state electrolytes, with additional improvement not only in energy density but also in safety factors. With a mention above, can be make a conclusions that zero emission in the road transport will be reach only after reaching long-term strategy for EVs batteries developments. The vehicles electrification is widely considered as viable strategy for reducing oil dependency and environment influence from the road transport.

2.4. Trend and Tendency Diagram

The future of the transport sector is affected by different factors, which create the main challenges facing to road transport sector: safety; urbanization, commuting times and congestion; environment influence; demography. Apart from growth of economy, which always correlated with transport activity increasing, new technology and trends significantly can change a way of vehicle and road infrastructure developments. The pointed challenges is required a wide range of different solution (technical and services) exactly this solutions will make a trend and tendency in in the future of the road transport. The reviewed trends in the research describe the affect the part of the overall transport system linked to road transport. By review analyses was founded four major directions for a new research tendency in transport sector future: decarbonisation; automation; connectivity, and sharing, with additional providing an explanation of solving faced challenges (Fig. 3). These future main technologies categories promise to contribute to fewer negative impacts from road transport, with new mobility paradigms for a transport.

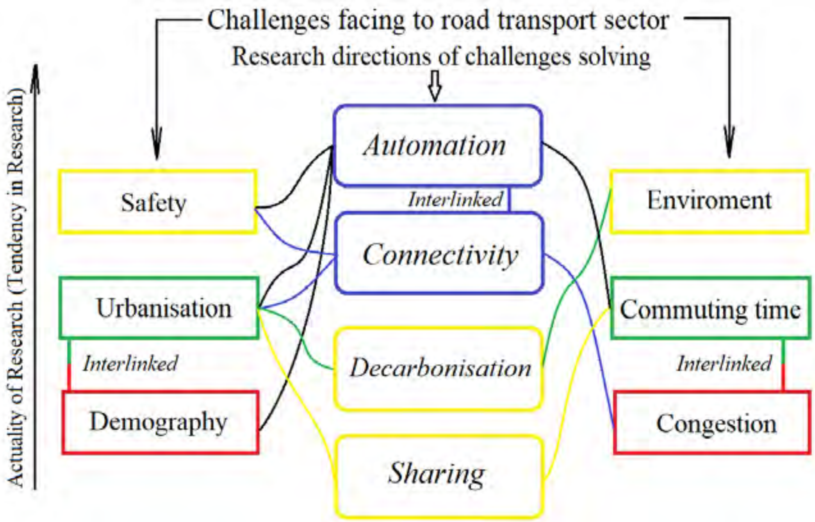

Fig. 3 Trend and tendency diagram in future research of road transport

The current diagram shows the possible evolution of the road transport sector research in the few future decades. According to the obtained diagram can be pointed four major directions for a new research tendency in the transport sector future: decarbonisation; automation; connectivity, and sharing, which help to solve the main challenges facing to road transport sector: safety; urbanization, commuting times and congestion; environment influence; demography. The research actuality line displayed that more tendency, in the current moment, go in direction of automation and less for sharing. Same time, the automation can help to solve four of six challenges facing to the road transport sector. The reviewed trends show the affect the part of the overall transport system linked to road urban area transport with establishing the essential to address the road transport externalities in order to reach an efficient, safe, sustainable and inclusive multimodal transport system in the future. These future technologies and services promise to contribute to fewer negative impacts from road transport while also generating new mobility paradigms for researchers. Researches acceptance of these trends is an important factor that will drive their research direction by pointed challenges facing to the road transport sector.

3. Conclusions

The massive increasing of using personal vehicles and increasing a number of cargo transportation vehicles lead for raising the different research needs in driving towards a better vehicle structures and road transport systems. In the current review research is analysed, according to the world scientific activities, the possible evolution of the road transport sector and personal mobility in the few future decades. Was detail reviewed in developing and planning for implementation of technologies and methods in the transport sector from energy use and emissions direction to safety and automation in a transports. The reviewing of new research in transport road sectors introduces trends from the technological and user uptake perspectives in the context of present and future mobility challenges.

By reviewing statistics and reports provided by the international organisation and research can be pointed out that the future of the road transport sector will be affected by economic and urbanisation factors, which lead to the main challenges facing to road transport sector: safety; urbanization, commuting times and congestion; environment influence; demography. To solve challenges facing to road transport sector was founded four major directions for a new research tendency in the transport sector future: decarbonisation; automation; connectivity, and sharing. The research established the essential to address the road transport externalities in order to reach an efficient, safe, sustainable and inclusive multimodal transport system in the future.

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Comparative Analysis of Methods for Regulating the Heating Power of Turnouts

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Abstract

The article discusses and provides an analysis of various thermal regulation methods with aim of finding the best method for railway turnout (point) electric heating control system. Various point heating regulation options, their properties, advantages and disadvantages are described. A comparison of various point heating regulation possibilities for optimal point electric heating regulation is performed. After performed analysis and specifying the most suitable regulation option, modelling is executed in MATLAB to evaluate achieved results. Results of the modelling are reflected in the graph surface view which indicates the correct application of chosen solution. Steps of future research and creation of expert systems for regulation of heating intensity of point electric heating are described in conclusions.
KEY WORDS: *point heating, analysis, intelligent algorithm, point electric heating*

1. Introduction

A railway network is a robust transport infrastructure that was designed and built for different and sometimes harsh climatic conditions [4, 5, 8, 20]. The biggest danger to train movement safety is winter weather in Latvia. The reason behind this is that weather is very unstable during winter season. Low temperatures and snowfalls are usually followed by thaw and positive ambient temperatures. Then after several days, a negative temperature can set in thus icing the turnout elements. Such rollercoaster in weather changes is the reason why point cleaning systems must be versatile and must be able to clean snow and ice in their different states from the turnout.

In Latvia different railway stations are equipped with different point cleaning systems. Large stations are usually equipped with point pneumatic cleaning systems, but small and medium size stations with point electric heating (PEH) systems [6, 10]. Article's main task is the comparison and analysis of different PEH regulation schemes and methods. Point pneumatic cleaning cannot always perform and clean wet snow from the turnout. This fact means that the best point cleaning method for volatile weather conditions is PEH. Due to this condition, different PEH power intensity regulation methods are under analysis in this article.

2. Comparison of Different Regulation Methods

In railway stations where PEH is installed, there are usually two regulations methods operate it. First option is simple switch on/off method [16] and the other one is regulation with feedback. In first regulation method, power is applied to the heating element, when operator has turned the heating on using dedicated remote control unit or device [13, 16]. Once turned on, PEH is working at maximum heating mode (nominal voltage and maximum power) and operator cannot regulate the heating intensity manually. There is also no automatic regulation option because the control system is obsolete and does not have such functionality.

The object described in the article is thermal element, which is attached to the turnout's frame rail. In the article it is substituted as an active resistance in the figures and calculations.

2.1. Regulation with Feedback

First correctly regulated option of feeding electric power to the thermal element is model where negative feedback loop is implemented. This option is being operated in various railway stations in Latvia which have been upgraded in recent years. In this regulation model, control scheme with feedback forms a closed data transmission loop, thus implementing control commands and monitoring of the processes taking place in the control object and the creation of necessary control commands [12, 14, 15, 19]. In other terms, regulation models with feedback are called closed network systems (Fig. 1), where flow of data from the output to the input takes place using the feedback [1, 2, 5].

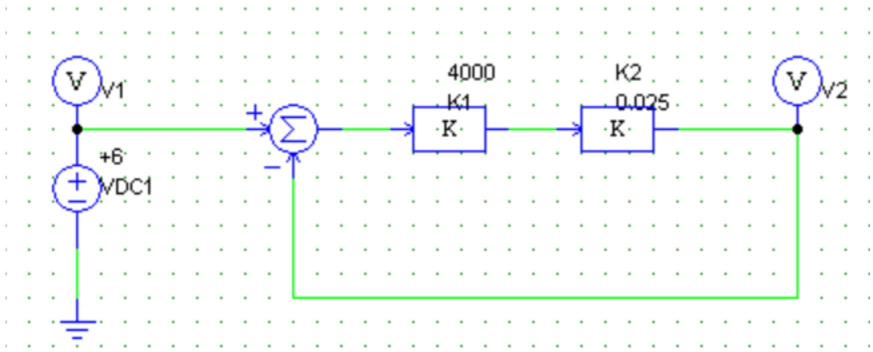

Fig. 1 Regulation scheme with feedback

The system is operated by station attendant who manually switches on the power. Alternatively, if PEH is equipped with automatic turn on/off scheme, it can be turned on automatically based on the control algorithm, e.g., when temperature of the frame rail is below the threshold limit (+5°C), then heating switches on to heat the frame rail up to the required temperature. Heating of the rail is monitored by thermal sensor which sends the signal to the adder unit (Fig. 1). Such solution allows to feed the power supply when needed and to turn it off when the heating is not necessary anymore. But this regulation method is good when rail temperature is the only factor which is considered without considering other parameters (ambient temperature, precipitation, etc.). In real life conditions low temperature can be without snow and if there is no snow then it is not necessary to heat the rail.

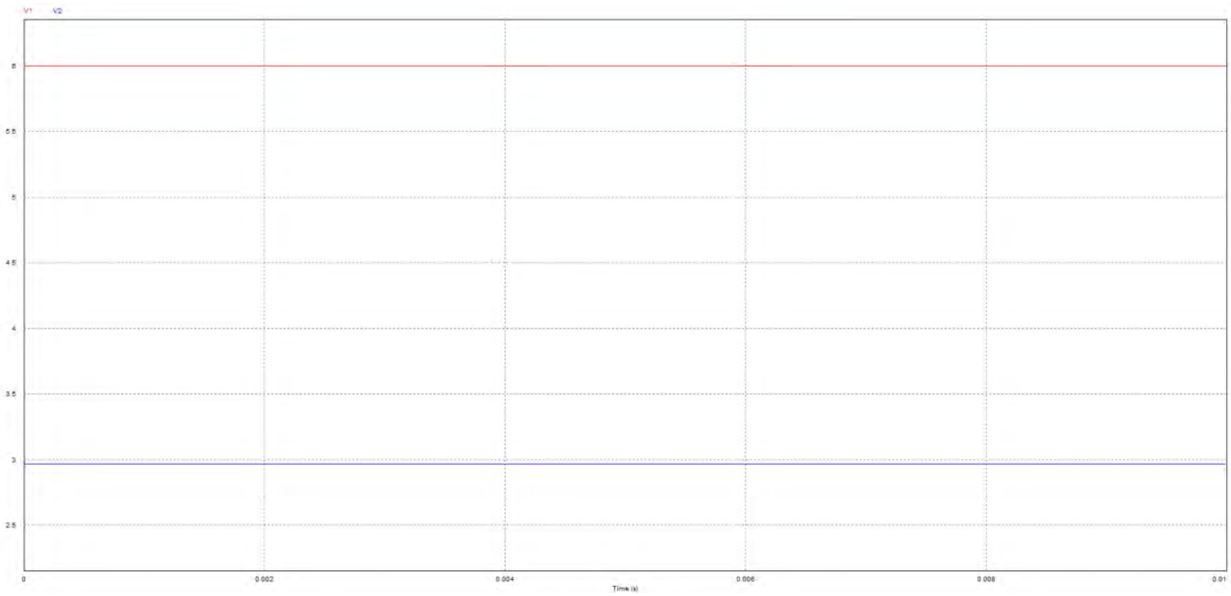

Fig. 2 Signal graph of the model with feedback

Furthermore, scheme that is shown in Fig. 1 does not take into account influence of different external factors, e.g., precipitation or ambient temperature. On site, outside air temperature is significant parameter that directly impacts thermal process, therefore described scheme has considerable disadvantage during operation. Fig. 2 shows that when outside temperature factor is introduced in the model, V2 signal's value is remarkably lower than V1 (set temperature). As can be observed from Fig. 2. if voltage is fed to thermal element and there is one impact parameter which is used for feedback control, then resulting signal is considerably different that value of the set signal. After calculation, fault level reached approximately 52% [9, 18]:

$$\Delta\Theta = \frac{\Theta_{set} - \Theta_{means}}{\Theta_{set}} \cdot 100\% = \frac{6 - 2.9}{6} \cdot 100 = 52\% . \quad (1)$$

2.2. Regulation with Feedback and Implementation of Interference Influence

By extending circuit described in paragraph 2.1. with supplementary factors and units, a scheme was developed that considers the effect of interference. Scheme is shown in Fig. 3.

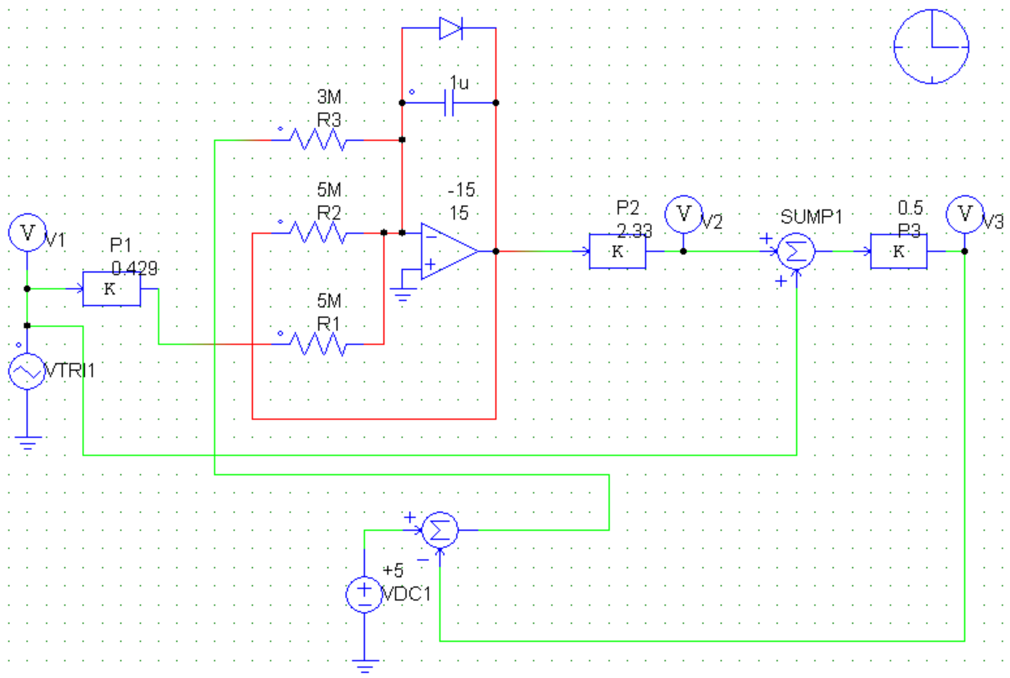

Fig. 3 Example of regulation scheme with influence of interference

In the technical example (Fig. 3), set temperature signal Θ_0 and signal from the output together with feedback $X_{out}(s)*W_{as}(s)$ are summed in the adder unit. The control unit adds the reduced error $\sigma_{xr}(s)$ in its input, thus signal from thermal sensor enters the control unit and the variance between the set temperature and the measured temperature is the reason for the control unit to act on the controlled device.

A closed loop regulation scheme has been implemented with frame rail thermal sensor S_{sl}. Output signal from rail thermal sensor correlates with the measured temperature Θ_{sl} on the rail. Next, the signal is transformed into corresponding value $-\Theta_{sl}$ using the measurement section and compared with signal of the set temperature Θ_0. Signal which corresponds to the difference between the two values Θ_0-Θ_{sl} influences the control unit that in turn controls thermal elements. Rated power is calculated as follows:

$$P = k_c \cdot (\Theta_0 - \Theta_{sl}) \geq 0\,. \tag{2}$$

Calculated power forms the output (temperature) produced by the thermal elements $\Theta_1 = W_s(s) \cdot k_c \cdot (\Theta_0 - \Theta_{sl})$, where $W_s(s)$ is transfer function of the thermal elements and s is variance operator. Function gain coefficient k_c and constant T_s are introduced to calculate mentioned transfer function $W_s(s)$:

$$W_s(S) = \frac{k_s}{1 + T_s \cdot S}\,. \tag{3}$$

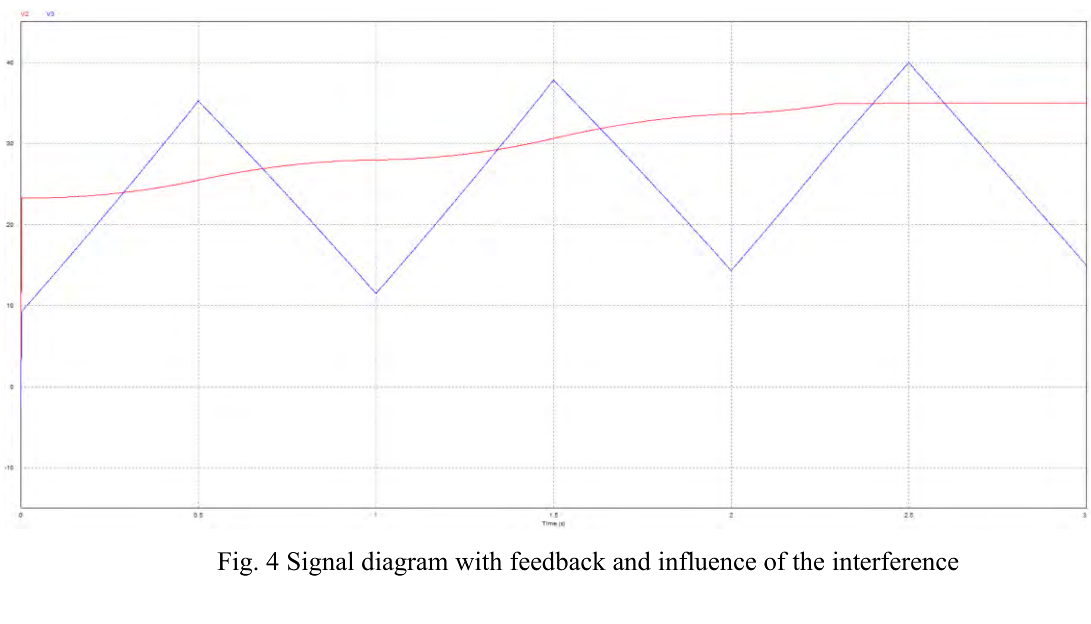

Fig. 4 Signal diagram with feedback and influence of the interference

After analysis of diagram presented in Fig. 4, the conclusion is that the temperature of the thermal element increases steadily and stabilizes at a level of +35°C in just over 2 seconds. On the other hand, temperature of the frame rail rises in a triangular pattern because signal itself is of triangular form. After 3 seconds, temperature of the frame rail reaches a positive and stabilized value of +16°C and does not decrease below +10°C during whole simulation time. According to formula (1), the calculated error level reached approximately 22-25%. Such level of error is relatively high, but this is due to the interference source which simulates outside temperature, and it is not precise. Next in order to limit level of error, regulation scheme should be upgraded with devices that cut off power when outside temperature level is +5°C or above, because, obviously, it is unnecessary to continue point heating at such temperatures.

2.3. Regulation with Regression Equation

According to researches [6, 10, 13] temperature has got the most influence on PEH power. Next comes the snowfall and the last is wind. To calculate the effect of temperature, snow and wind on PEH power, one of the options is to use regression equation. The effect of all three factors on the required heating intensity can be calculated by the following regression expression:

$$P = P_0 + a_1 \Theta^*_{amb} + a_2 N^* + a_3 V^*, \tag{4}$$

where P is resulting power; P_0 is average power; a_1 is first impact factor; a_2 is second impact factor; a_3 is third impact factor; Θ^*_{amb} is normalized ambient temperature; N^* is normalized precipitation value and V^* is normalized wind speed value.

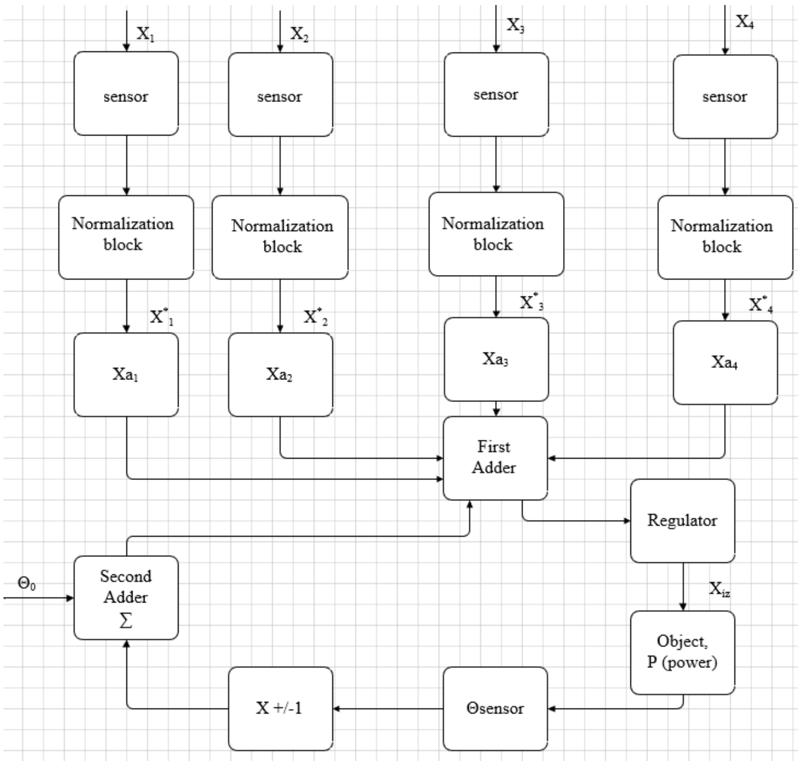

Fig. 5 Block diagram of the adjustment scheme according to the results of the regression equations

The scheme consists of stages, the main of which are the second adder ∑, the object *Object, P* and the block *X* +/–1, which implements the feedback. First adder receives 4 normalized signals based on the signals of 4 different sensors that pass through the normalization blocks. The regulator is an amplifier whose input is a reduced control signal. In the scheme (Fig. 5.), the signal from the thermal sensor flows into the adder unit and resulting variance between the set temperature and the measured temperature is the cause for the control unit's effect on the regulated object, which is a thermal or heating element (active power P). The given regulation scheme, which uses the results of regression equations, is a regulation model with frame rail thermal sensor S_{sl}, and signal correlates with the temperature of the frame rail Θ_{sensor} (Fig. 5). Next, the signal is converted to $-\Theta_{sl}$ using feedback unit and compared with set temperature Θ_0 in the adder. The variance (Θ_0-Θ_{sl}) influences basic adder, which in turn acts on a regulator at its output, which regulates the power in the control object.

In the illustrated example (Fig. 5), the second summing element ∑, is the element where signal Θ_0 and signal from the feedback $-x_{iz}(s)*W_{as}(s)$ are summed.

2.4. Regulation with Fuzzy Logic

In this paragraph, assessment of various impact factors that have influence on point heating control system is performed. Three input variables are considered – ambient temperature (°C), wind speed (m/s) and snowfall (mm/h). Use of fuzzy logic is justified because it utilises a set of linguistic rules that combine vague information with precise rules for processing non-strict variables like wind speed, temperature and snowfall intensity. To perform modelling in MATLAB, a dedicated rule base is created which is used as a basis of the control algorithm. Created rules allow formulating the principles of behaviour of the resulting graph surface plot, thus clearly showing that one or two input variables are not enough to achieve the optimal result. In addition, a certain number of rules must be applied to show acceptable results justified by experts' knowledge and experience. Knowledge of automated and intelligent systems [3, 7, 12, 18, 19] supported creation of a model in the MATLAB using Fuzzy Logic Toolbox. As a final step after simulation, the resulting graph was created in Fuzzy Logic Designer. All described and implemented laws have been processed and results are shown in 3D surface diagrams Graph Surface Views (see Fig. 6.).

As first step, 4 input variables were set: temperature, snow, rain and wind speed. Next stage is selection and specification of the characteristic function (membership function) of the input and output parameters. Among the more regularly used membership functions (Λ functions, Π functions, Gaussian functions, S functions), the most appropriate ones for each respective input parameter were chosen [7, 11, 17].

The membership functions of each input factor form a trapezoidal representation of the non-strict values: temperature - low temperature, snow - light, medium and heavy snow, rain - no rain and heavy rain and wind speed - light, medium and strong wind.

Output variable "Heating" represents several modes of heating intensity. When first mode is switched on, it corresponds to approximately of 30% of maximum heating intensity. Second mode corresponds to level of 50-60% of heating intensity and third mode equals to maximum heating intensity.

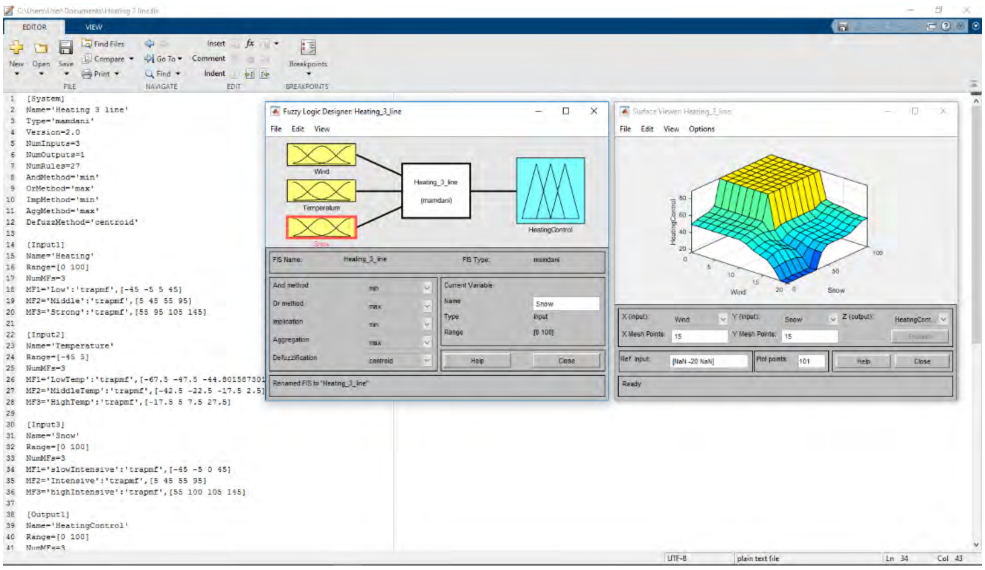

Fig. 6 Resulting graph surface view of fuzzy modelling

Resulting graph surface view (Fig. 6) is not flat or even and flat and smooth surface cannot be achieved because developed rule base is set of equations of various non-linear input variables. Resulting surface view shows crucial dependence on intensity of precipitation in the form of snow. Results also show that heating intensity in the resulting surface plot depends on following parameters (in descending order): precipitation in the form of snow, negative ambient temperature and wind speed.

Due to the fact that railway stations are located in different Latvian regions, created model can be installed in different and existing point heating systems across the state. Next step would be connecting upgraded PEH control systems in a neural network in order to test proposed solution and network in different climatic zones of Latvia. Such step would allow to build strong neural network, perform various tests for constant improvement of the solution.

3. Conclusions

The current article discusses and analyses various impact factors that influence point heating system. Different heating intensity regulation methods have been discussed and analysed. After modelling in MATLAB, the resulting graph surface view has been developed, which demonstrates point heating intensity as a function depending on the input parameters and interdependent rules that are presented as a rule base.

In the last sub-paragraph input and output variables of the fuzzy heating model have been developed and membership functions have been created. As a result of the simulation in MATLAB, it is obvious that combination of wind and snow has got a significant impact on PEH intensity. Also, when there is only snow without wind, and snow intensity is 100%, the heating intensity is also at the highest level and must be at this intensity to melt the snow in the turnout area. This can be explained as the fallen snow can block area between stock rail and the blade, thus blocking turnout from switching and causing danger for safety of train movement.

The application of fuzzy logic is very broad, but it also has limitations that are usually related to the purpose of the result. The design and development of fuzzy logic models requires a high qualification and experience of the expert composing them in the analysis of the specific situation in order to be able to fully compile the functions of the input and output sets and their degree of membership, because only by observing this, the fuzzy logic will provide the expected results.

Control of the point heating system based on regulation scheme with only one input parameter will provide a high level of error and a significant amount of electrical energy will be spent on unnecessary heating of the environment. As a result of performed modelling, a conclusion can be made that in order to obtain expected and positive result and to make PEH control system energy efficient, three and even more input variables have to be used in the model.

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Control of Frictional Interaction in a Two-Point Tribocontact “Wheel-Rail”

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Abstract

There are presented results of a study of the possibility of using ozonized air to reduce wear in the «wheel-rail» tribocontact. A technique for evaluating the effect of ozonized air, as a surface activator, on the frictional interaction in the «wheel-rail» contact is proposed, and the results of experimental studies are presented in the article.
KEY WORDS: *railway transport, coefficient of friction, wheel, rail, ozone, barrier ozonizer*

1. Introduction

The study of the process of wheel-rail adhesion, as the main process on rolling stock, is an urgent task, and its solution must be carried out in a comprehensive manner, which will make it possible to adapt the locomotive movement modes (starting, braking, freewheeling, emergency braking) to the most optimal adhesion. The complexity of research lies in the fact that it depends on many factors [1].

A number of methods of active influence on the tribological properties of «wheel-rail» contact have been developed. Among them, the main ones are mechanical [2], electric [3], plasma, hydro- and pneumatic methods for cleaning the working surfaces of rails [2]. There are studies aimed at the search and development of friction modifiers [4], surfactants, friction activators [2], studies of the effect of electric current passing through the contact on the tribological properties of this contact [3]. It has been established that the coefficient of friction depends on such factors [5]: the material of the rubbing bodies and the nature of the lubricant; friction areas of contacting parts; operating mode: temperature, speed, load, etc.

When evaluating the material of friction parts in the «wheel-rail» contact, the most important are strength, plasticity, and impact strength [6]. By alloying coatings, friction forces can be optimized, i.e. realize friction at a minimum wear rate. In this case, the normalization of the process is associated with the manifestation of the external form of the Rebinder effect [7]. A.P. Rehbinder discovered the adsorption effect of lowering the strength of solids [8]: due to the adsorption of surfactants, the surface energy of a solid decreases, which leads to an easier release of dislocations.

Rigid bodies are never perfectly smooth. Irregularities on the surfaces of the contacting bodies can be due to both the nature of the preliminary technological treatment and the process of friction and wear.

During operation, the wheel is subjected to force and temperature loads, which lead to a change in the physical and chemical state of the surface layer. There is a deformation hardening and softening of the surface layer. [9]. First, there is an increase in the density of dislocations, the formation of their clusters, and the formation of cellular and fragmentary structures [10, 11]. With an increase in the friction path, the structure of the surface layer becomes more uniform and stabilizes. This is due to the end of the run-in period.

The essence of the phenomenon of the adsorption effect of the external environment on the mechanical properties and structure of solids, which P.A. Rebinder [8, 12] consists in facilitating the deformation and destruction of solids and the spontaneous occurrence of structural changes in them as a result of a decrease in their free surface energy upon contact with a medium containing substances capable of adsorption on the interfacial surface.

The second effect caused by the action of films on the mechanical properties of solids is the Roscoe G effect [13], in which the hardness of the metal surface layer increases in the presence of oxides.

Analyzing the frictional characteristics of the surfaces on which these effects are realized, one can observe significant differences in their behavior, Fig. 1.

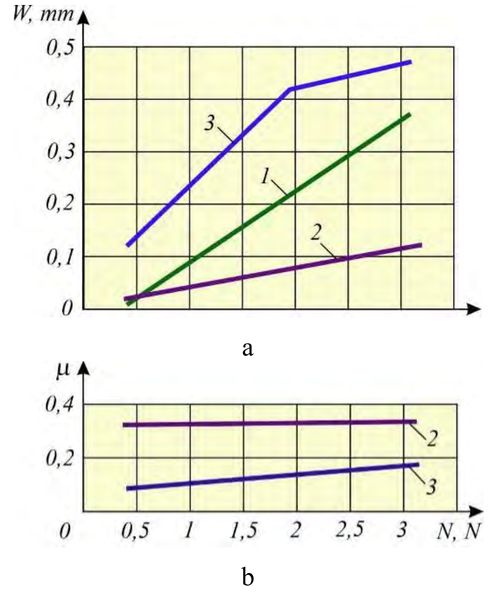

Fig. 1 Wear (a) and coefficient of friction of a ball sliding on a metal surface (b):1 – clean surface; 2 – oxidized; 3 – surface covered with water, medium – dry argon

Thus, the coefficient of friction is minimal when there is a surface-active compound on the surface, since this reduces the shear resistance compared to friction on the oxide film (Fig. 1, b).

Research V.N. Latysheva, A. M. Vulf [14], by determining the effect of oxygen on the contact pair, found that, depending on the temperature in the contact zone, oxygen can have both positive and negative effects. Iron has several oxides Fe_2O, Fe_3O_4, Fe_2O_3. At contact temperatures of 450-500°C, FeO oxides are formed on metal surfaces, which, with a further increase in temperature during structural rearrangement, transform into Fe_2O_3, which intensifies chemical-mechanical wear, and Fe_3O_4 reduces friction.

Exploration [15] found that the activity of oxygen largely depends on the state in which it is present in the contact zone (radicals, atomic, molecular oxygen, ozone, etc.). The durability of the cutting tool with the use of an ozonized flow is 4-5 times higher than when machining without lubricant cooling process agent, 3-4 times higher than when machining with coolant, and 1,5-2 times higher than when processing with compressed air.

Formulation of the problem. By this way, the study to determine the effect of ozonized air on the processes occurring in the «wheel-rail» contact is relevant, has not been fully studied and requires additional research.

2. Research Results

To determine the effect of ozonized air on the processes occurring in the contact of the wheel with the rail at the Department of Railway Transport of the Volodymyr Dahl East Ukrainian National University has improved the friction machine, which makes it possible to study the frictional properties of the «wheel-rail» contact.

The experimental studies carried out using a barrier ozonator, in which ozone was produced and fed into the «working roller-rail» contact of the automated measuring and modeling installation «friction machine», showed the following results, presented in Fig. 2.

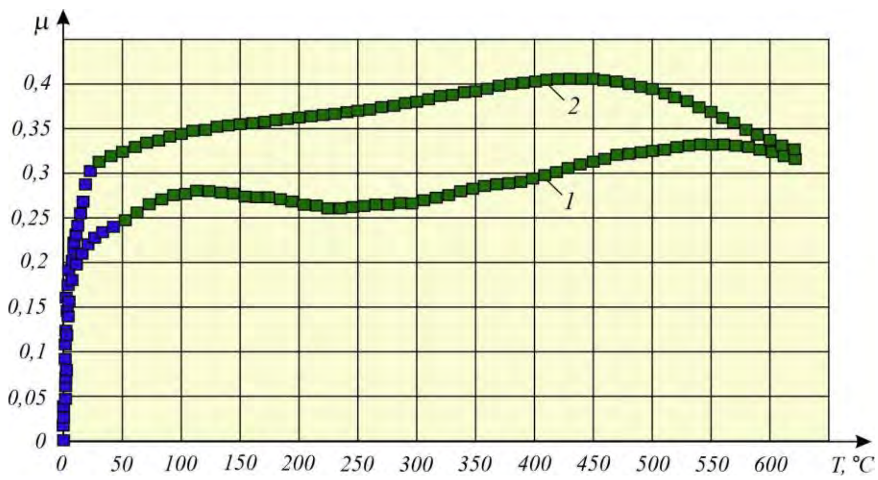

Fig. 2 The dependence of the friction coefficient on the temperature in the «wheel-rail» friction pair; *1* – dry rail, *2* – dry rail with ozonized air supply

From the graph (Fig. 2) it can be seen that when ozonized air was supplied, the friction coefficient increased, and the temperature also decreased at the maximum value of the friction coefficient from 550°C (dry rail) to 450°C.

The effect of ozone is presumably explained by the cooling of the contact spot due to the transformation of molecular diffusion into convective, which significantly increases heat transfer to the environment and leads to cooling. In addition, ozone reacts with contaminants, destroying them, and also affects the structure, phase composition and chemical activity of the material of contacting bodies, increasing the adhesion and diffusion interaction of rubbing surfaces.

The theoretical description of this process is the following method for assessing the effect of ozonized air as a surface activator on the frictional interaction in the «wheel-rail» contact.

As is known, the most common way to obtain ozone is the generation of ozone in a barrier electric discharge, where the active power of the discharge released in the discharge gap is determined by the formula [16]:

$$P = \left(\frac{2}{\pi}\right)\omega \cdot \left(C_\mathrm{d}\left(V_0 - V_\mathrm{g}\right) - V_\mathrm{g} \cdot C_\mathrm{g}\right) \cdot V_\mathrm{g}, \tag{1}$$

where V_0, V_g – are the voltage on the conductive electrodes and the gas gap, respectively, in accordance, V; C_g, C_d – are the capacitance of the gas gap and the dielectric, F; w – is the frequency of the supply current, Hz.

Passing through the discharge zone, oxygen molecules partially dissociate according to the reactions [17]:

$$\begin{aligned} &O_2 + \bar{e} \to 2O + \bar{e}; \\ &O + O_2 \to O_3 + M; \\ &O + O_3 \to 2O_2; \\ &O + O + M \to O_2 + M. \end{aligned} \tag{2}$$

In this case, atomic oxygen reacts with an oxygen molecule, forming ozone.
In a barrier ozonator, which is a cylindrical capacitor, oxygen molecules are affected by the magnetic field strength E:

$$E = F/Q, \tag{3}$$

where F – force acting on a point positive charge Q placed at a given point in the field.

The density of electrical energy in the barrier ozonator equal:

$$W = \varepsilon \cdot \varepsilon_0 \frac{E^2}{2}, \tag{4}$$

where ε – the dielectric constant of the medium inside the capacitor; ε_0 – electrical constant; E – field strength between the capacitor plates.

Volumetric energy density:

$$W_p = \frac{W}{V}, \tag{5}$$

where V – the amount of space in which energy is generated.

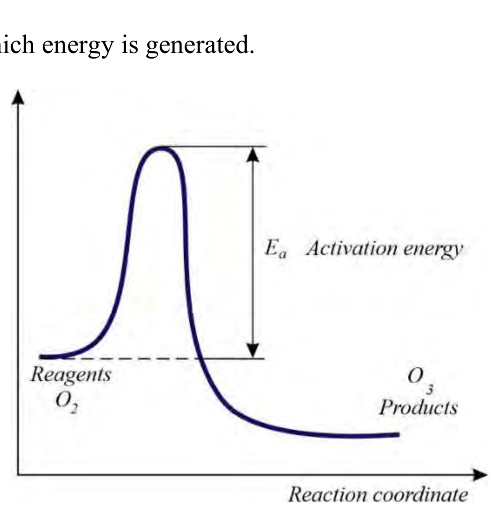

Fig. 3 Dependence of the energy of reacting molecules on the coordinate of the chemical reaction

In the course of the reaction, the molecules collide, the number of their collisions per second is enormous; if the collisions were effective, all reactions would end instantly, i.e. would have flowed in the form of an explosion, but this does not happen. A strong decrease in the temperature of the reacting system of molecules leads to a decrease in their kinetic energy, and their collisions become inefficient, and the reaction rate is close to zero. This is due to the fact that during the course of the reaction, the molecules must be grouped into an activated complex. Only active molecules with sufficient kinetic energy can form it. The energy difference of the activated complex, i.e. the energy that a charged capacitor creates and the original molecules, i.e. ozone energy is called the activation energy E_a (Fig. 3) [18, 19].

When oxygen molecules approach each other, their kinetic energy transforms into potential energy. The maximum potential energy corresponds to the energy of the activated complex. The energy barrier arises due to the mutual repulsion of chemically yet unbound oxygen atoms. Without receiving the necessary energy, it is impossible to overcome the energy barrier. By this, one of the conditions for the most efficient operation of a barrier ozonator is the creation of energy (W), which helps to overcome the energy barrier to form the largest number of ozone (O_3) energy bonds.

By this, the activation energy can be represented as:

$$E_a = W_p - W_k, \tag{6}$$

where W_k – kinetic energy of atoms O_3, equel $W_k = eEL$.

The synthesis of ozone for its further supply to the «wheel-rail» contact requires a high concentration, which is achieved by reducing the air supply rate.

The ozone concentration x in the barrier ozonizer is determined:

$$x = \frac{k_e \cdot a}{k_e + k_{1,t1} \cdot e^{\frac{E_a}{R} \cdot \frac{T_2 \cdot T_1}{T_2 + T_1}}} \left\{ 1 - exp\left[-\frac{P}{V}\left(k_0 + k_{1,t1} \cdot e^{\frac{E_a}{R} \cdot \frac{T_2 - T_1}{T_2 \cdot T_1}} \right) \right] \right\}, \tag{7}$$

where T_1 – the temperature of the liquid cooling the electrodes of the ozonator; T_2 – the temperature of the gas in the reaction zone; $k_{1,t1}$ – decomposition constant at a temperature of 20°C; E_a – activation energy of the ozone decomposition reaction.

The value of the concentration of a substance in the discharge gap makes it possible to determine the mole of the substance and the amount of energy, as well as the energy that will be released during the decay of ozone (W) and which will be directed to the contact of the wheel with the rail.

As mentioned above, to reduce the friction coefficient, it is necessary to destroy the oxide film. Researches [20, 21] have shown that for the destruction of the oxide film on the friction surface, it is necessary to break the energy bonds between the atoms of neighboring crystals, particles of pollution. The number of crystallites on the friction surface of the sample will be equal to $\frac{S_{sam}}{(n \cdot a_0)^2}$, where S_{sam} – sample friction surface area; a_0 – crystal lattice period; $(n \cdot a_0)^2$ – crystal cell face area; n – the number of atoms per crystal edge.

The number of interatomic bonds broken during friction:

$$N = \frac{S_{sam}}{(n \cdot a_0)^2} f \cdot n^2, \tag{8}$$

where f – the number of faces along which the crystal breaks off, $f = 4k + 1$ (k = 1, 2, – the number of detached crystals by depth); $f \cdot n^2$ – the number of atoms on the crystal faces.

Then the energy that is needed to detach the crystals will be equal to:

$$E = E_0 \cdot N = E_0 \cdot \frac{f \cdot S_{sam}}{a_0^2}, \tag{9}$$

where E_0 – the binding energy of an iron atom in a crystal.

The thickness of the wear layer during friction $h = k \cdot n \cdot a_0$, where $k = \frac{h}{n \cdot a_0}$, $f = 4\frac{h}{n \cdot a_0} + 1$.

If the work of friction forces, which is determined by the formula:

$$A = F \cdot V \cdot t = \mu \cdot p \cdot S_{sam} \cdot v \cdot t, \tag{10}$$

where μ – constant of friction; p – pressure on the sample; V – friction speed; f – friction time, is commensurate with the energy that is needed to detach the crystals, then $\mu \cdot p \cdot S_{sam} \cdot v \cdot t = E_0 \frac{S_{sam}}{a_0^2} \cdot \left(4 \frac{h}{n \cdot a_0} + 1\right)$, so as $4 \frac{h}{n \cdot a_0} >> 1$, we get:

$$\frac{h}{t} = \frac{p \cdot v \cdot n \cdot a_0^3 \cdot \mu}{4E_0}, \tag{11}$$

where h / t – the intensity of change in the layer thickness due to frictional wear.

3. Conclusions

Accordingly, based on the known methods of active influence on the tribological properties of the «wheel-rail» contact, which have their drawbacks, namely, the mechanical cleaning method, which is mainly used on rolling stock, pollutes the surface of the railway track with sand, which is especially dangerous in turnouts.

The application of the proposed method of controlling frictional interaction in the «wheel-rail» contact makes it possible to reduce the cost of operating the rolling stock by using the energy of electrodynamic braking as energy for the production of ozone. Based on the above, by comparing the energy that is released during the decay of ozone (*W*) with the energy that is necessary to detach the crystals of pollution from the base metal (E), one can judge the complete or partial destruction of the surface layer in the «wheel-rail» contact, and, therefore, and to increase the friction coefficient.

Acknowledgement

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Aspects of Safety in Autonomous Driving Systems

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Abstract

The article is a brief discussion on the ongoing question of safety revolving around the futuristic sustainable mobility reform- “Autonomous Vehicle (AVs)”. The aim of this study primarily focusses on understanding the aspects of safety in AVs that deals with threats that evolve from human errors and that evolve from technology. The ways to deal with these errors as safety measures and the AVs response towards safety training is validated in different methods that are advanced in comparison to the normal safety testing that a commercial vehicle is subjected to. This article shed light on the certain specific training and testing methods adopted to ensure safety of AVs in order make them reliable as a commercial mobility solution in the near future.
KEY WORDS: *autonomous vehicles, autonomous driving systems, safety threats, safety testing methods, formal testing*

1. Introduction

Autonomous vehicles (AVs) are seen as the future of sustainable mobility for a number of reasons on how it can serve human commuting. Though experts from the industries and academia tirelessly work towards solving raising issues and concerns dealing with commercialization of AVs, the safety of involving this intelligent self-driving technology in daily traffic still remains questionable. The factor of safety is envisioned in different aspects depending on the focus area. The conventionally identified addressing aspects of driving safety is categorized as active and passive safety systems [1]. These systems have been in existence long enough where specific standardizations for conditional utility is defined. Whilst in the context of AVs the aspect of safety cover wider ranges of topics involving cyber safety, software malfunction, network communication, and artificial intelligence (AI) systems [1-5]. Thus, arising the question of what safety in the context of autonomous driving is and how is it validated. Through years, different technologies that govern autonomous driving fundamentals have evolved to be capable to involve them in daily traffic for trial runs. Although there exists several cross-border trials and industrial testing, safety policy of AVs [6] is lesser known /established due to various limiting factors. Due to this reason, the perception and addressing of safety lies within the scope of a particular research [1-10]. In this article, a brief discussion of different conceptualisation and perception of safety and the methods adopted for its validation will be presented that was studied.

2. Safety Threats in Autonomous Vehicles

The complexity in the architecture as shown in a simplified manner in Fig. 1 of the driving system brings in a scope of potential error that can affect the safety of the vehicle [1, 5-8].

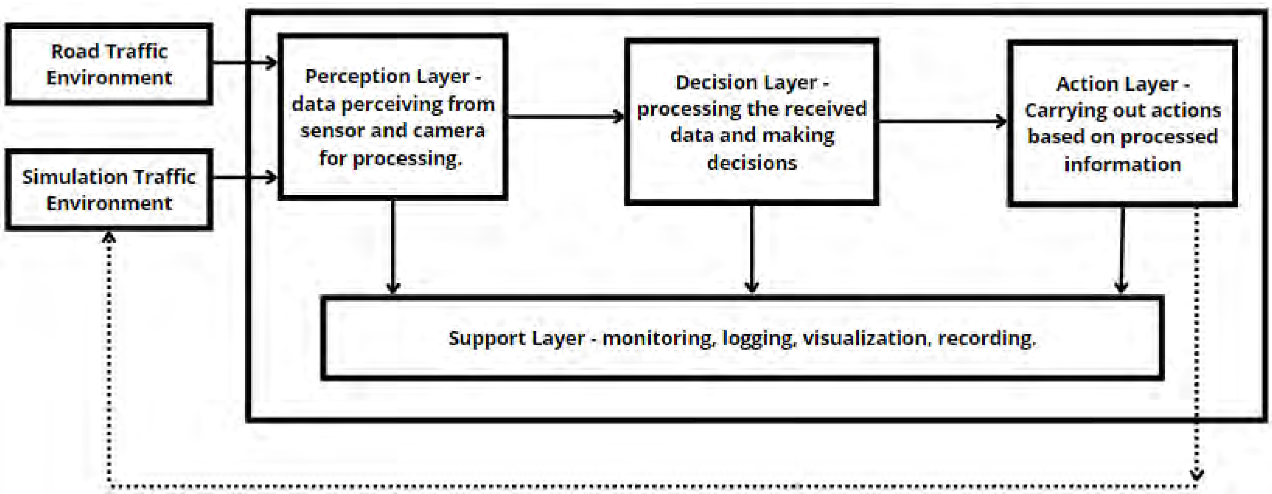

Fig. 1 Autonomous Driving Architecture [2]

This needs to be addressed and managed in a micro level to avoid errors that arise from malfunction of the driving system. The system contains fragments of hardware and software that collectively needs to efficiently perform its task in synchronization. Though AVs are reportedly smarter and efficient enough to avoid human errors there still exists the limitation it just being a programmed technology that lacks human interpretation in certain specific situation that might arises a cause of threat to safety. Hence the threats that arise can be broadly classified as technological errors and human errors.

2.1. Technological Errors

The errors that arise from different levels of automation or the functioning architecture is categorized as technological errors and are usually identified based on which layer the error occurs at. The perception-based errors are more relevant when we discuss on various factors that impact the efficiency and performance of sensors that affects the understanding of the environment causing issues. This includes that one's arising from camera, sensors, radars, LiDAR and ultrasonic sensors. The decision layer error deals with warning driver of negative outcomes to switch controls, as they were many false alarms during the initial stages of training the vehicle most were ignored, and this ignorance sometimes becomes a safety threat in case of ignoring a real one. In the case of the action layer errors, further based on the previous data the actuators are expected to function to steer back or throttle appropriately based on the inputs received from preceding layers in the architecture [1, 5-8].

2.2. Human Errors

The majority of the road accidents recorded in the US in the case AVs, turned out to be human errors associated with other vehicles, pedestrians, cyclists, and fellow drivers [1]. Before we decide to make AI or Avs liable we should understand the roles and capability of a human made technology to interpret environmental scenarios. Over exploiting or misusing these technologies in the name of testing their capability is just another way of inviting trouble and threat to society that can be well avoided. Thus, human errors associated in affecting the AVs performance in specific scenarios must be studied in depth to train AVs to act as accurately and attentively as possible as a human driver would in the case of emergencies. As there lies uncountable uncertainty parameters in trying to account such situations makes it nearly possible for AVs to be left unsupervised and leaving human error factors still existent even in the case of trying to minimize them with the help of AI.

3. Safety Testing of AVs

To verify that the AI is properly functional and has the capacity to make decisions, autonomous cars are subjected to ongoing safety testing. New data handling and security requirements are necessary to support functioning due to the growth in perception and the processing of massive amounts of data through the satellite in less than microseconds. There are two methods for teaching autonomous cars to comprehend the environment they would be operating in. The virtual reality environment, where the surroundings are modelled and provided as data inputs, is used to teach autonomous cars how to comprehend complicated case situations and functionality. The alternative way involves following the car in actual traffic to assess how well the sensors work and how they respond in relation to the total reaction. This essentially bring down to two broader aspects of testing: Scenario-based testing and Functionality-based testing (technically addressed as Formal and Sample-based) as shown in Fig 2 & 3.

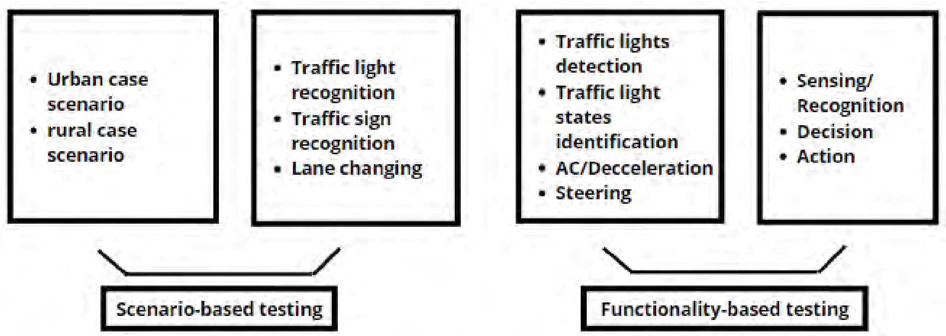

Fig. 2 Types of AVs testing [2]

3.1. Formal Methods

In order to specify and verify software and engineering designs, formal approaches apply mathematically rigorous methodologies (often in the form of logic calculi). It has an inherent benefit for safety verification jobs by definition, but its extensive use in autonomous driving has been severely constrained by the high system complexity and continuous dynamics. Technically speaking, formal methods may be defined as the process of putting system control algorithms or programs into action so that the controlled system behavior satisfies the specified requirements [3, 5, 6]. Formal approaches are less frequent, while sample-based methods are more commonly employed to create virtual situations to supplement short-term road tests. In a suitably abstracted model, formal techniques can cover the whole scenario space by providing explicit specifications. Sample-based approaches have a more irregular spread of scenario coverage owing to the randomized generation process, but start covering cases immediately at the simulation layer, making the sampling process uncomplicated. Formal methods start from safety specification at a more abstract layer, may have a bigger single coverage volume in scenario space, but the procedure to incorporate formal specification into control synthesis or monitoring can be laborious and controller math dependent. Both methods aim to translate as many proven scenarios into actual driving as possible, but there will always be a gap between simulation and driving in the real world.

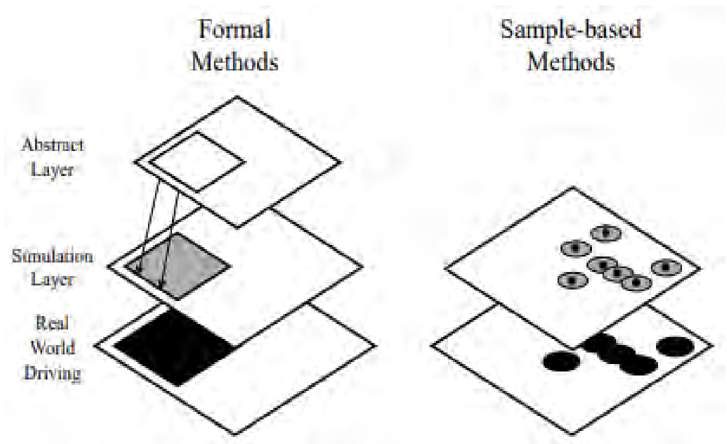

Fig. 3 Difference in Formal and Sample-based Methods [6]

3.2. Sample-based Methods

By contrast, sample-based methods need a lot of samples to establish coverage, and road tests virtually every cover corner cases. Due to hardware and labor expenses, road tests are more expensive than sample-based virtual tests whereas formal approaches, which rely on proofs and dynamics, can save the most on verification costs. Since modest updates to the evidence are frequently required, formal techniques save the most on re-verification; yet, sample-based tests, particularly road tests, are required since regression testing is required after a control update. For sample-based approaches, corner case generation is well-studied; for formal methods, corner cases are covered but not explicitly addressed; for road tests, corner cases are challenging to encounter. Road tests are realistically implementable but insufficient in terms of coverage, formal techniques have the ability to match with certification due to their rigor in theoretical evidence, whilst sample-based testing lacks certifiable validity. Accident reconstruction is simple using sample-based scenario creation, but it is not cost-effective to replicate it with real car tests. Formal techniques can use accident data to verify that formal safety standards were followed and look for design faults. As liability tracing is highly matched in road testing, less matched in sampling-based simulation tests, and least matched in models used for formal techniques due to the acknowledged problem of scalability, it may be accomplished naturally using formal methods. As long as new designs run through the same formal verification pipeline, control refactoring may be reasonably simple using formal methods-based verification. However, with sample-based testing or road tests, new additional efforts are required to re-verify the modifications.

Discussing on the subject of safety testing, it is important to know the current progress in the standards. For driver assistance features that potentially malfunction even without an equipment defect, the car industry has developed a safety standard. These problems are addressed by the ISO/PAS 21448 "Safety of the Intended Functionality" (SOTIF) standard [6, 10, 11]. It focuses on limiting risks associated with unforeseen operating situations and lack of a thorough description of what the intended function truly is. Notable highlights are:

- Limitation in understanding circumstances;
- Potential abuse and problems with human-machine contact;
- Problems related to the operating environment (weather, infrastructure, etc.);
- A focus on locating and addressing requirement holes (remove "unknowns").

In conclusion, ISO 21448 broadens ISO 26262's purview to incorporate ADAS functionality as shown figuratively in Fig. 4. Both expressly allow for potential scope expansion. However, as a pair, they are not designed to provide complete HAV safety. (An upcoming, secret revision of ISO 21448 seeks to go farther.)

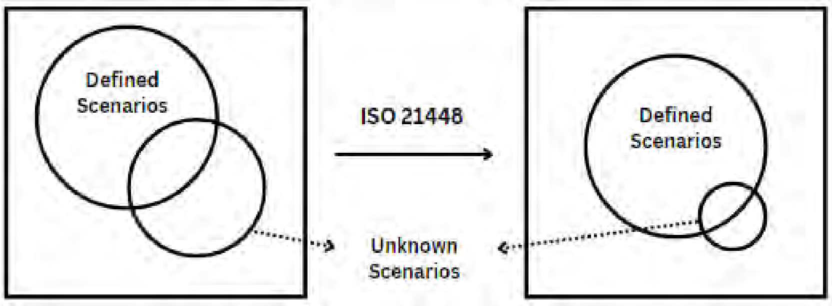

Fig. 4 Aim and process of ISO 21448 [6]

4. Challenges and Scope

The challenges lie on working towards achieving the aim of ISO 21448, as defining the unsafe paths of AVs can be a tedious process as it involves uncertainty as discussed earlier. The reduction with respect to the errors that occur in the technological level still remains a challenge that will limit the acceptance of AVs as a reliable technology [14]. The coexistence of conventional vehicles along with that of AVs is unimaginable though there are specific research concerning the modelling and planning of transport models [13,16]. The threat that involves cyber security imposes a huge concern to user as they are constantly being tracked and monitored as they seem as a privacy threat [1]. The major issue addressed in many researchers are the social response of drivers when they are deprived of the driving experience and their satisfaction of using new technology such as connected and automated vehicles. [12, 13, 15].

The improvisation of safety aspect is expected to enormously influence they social impact on how public respond towards autonomous vehicles. Industry experts and academic researchers are constantly in the process of solving technology based short comes to achieve AVs as a commercial solution to mobility issues of the current trend. With changing attitude, adoption of AVs can economical be a beneficial option not just for personal stance but for a countries economy as growingly evolving to have autonomous mobility solutions on practicality can reduce cost inquired with drivers, logistic operations and much more [2]. Not only these are futuristic solutions, but they also drive towards a sustainable way of mobility that will help reduction of carbon footprint. These are the reasons why researchers and futurists look forward to making this technology a reality.

5. Conclusions

The development of driverless cars requires extensive testing. In order to speed up the development process, it is essential to combine the already used approaches, build a set of methodologies for testing autonomous vehicles at various phases of the process, and provide repeatable, dependable, rapid, safe, affordable, and inexpensive testing techniques. In this article, we review relevant recent research, outline approaches for validating autonomous vehicle systems and functional modules of autonomous vehicles that is still under development. Understanding the evaluation methods is crucial part of validating them to achieve a fool proof system self-driving vehicle.

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Economics of Electromobility Development in the Czech Republic from the Perspective of Users

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Abstract

The article focuses on the comparison of the costs of conventional cars and electric cars. The investment and operating costs of individual transport are considered. The evaluation is made for the current prices of electricity, diesel and petrol, which underwent a dramatic development in the period between 2021 and 2022. From this point of view, it is interesting to calculate whether electromobility at high fuel prices is economically more advantageous for users of individual transport than in previous periods.
KEY WORDS: *electromobility, fuels, price, costs, cost calculation, individual car transportation*

1. Introduction

The European Union (EU) Environment Action Plan (EAP) has a long-term policy goal of achieving better and sustainable air quality that will not have a significant impact on human health or the environment. The EU aims to achieve this objective by complying with the prescribed air quality legislation issued by the EU. In the area of air pollution control, the EU issues legislation that should lead to a reduction in vehicle emissions. One of the points of the Action Plan is also to identify ineffective air pollution control legislation and to find timely solutions to achieve the air pollution reduction targets [1].

Another key decision will be to reduce emissions by building new nuclear power plants, which should be classified as emission-free energy sources once approved by the EU. Although the 'Fit for 55' plan is only a threat or a burden for many, it also brings a lot of money to the Czech Republic. To achieve the plans and targets, 600 billion euros is allocated within the EU, which converts into 15 trillion Czech crowns, of which the Czech Republic should receive almost 200 billion crowns, and 36% of which is earmarked for ecology [2].

From the point of view of general economics, this intention can be criticised from many aspects; it is, after all, a centralist intervention in the functioning of the economic system [3]. On the other hand, it is very interesting to look at the economic viability of electromobility in various segments of the transport system, especially after the price turbulence at the turn of 2021 and 2022. From a technological point of view, it must be made clear that the problem of electromobility still lies in the production of the electricity that would be required for the mass deployment of electric vehicles. The second issue is the persistent technological shortcomings of EVs, related to energy storage, recharging, range, or safety. A key condition for the use of an electric vehicle is a predetermined vehicle mode. The factors that will influence the mass adoption of alternative propulsion in transport can be summarised as follows [4]:

- the development of oil or fuel prices;
- the development of prices for alternative fuel vehicles;
- other costs associated with the operation of alternatively fuelled vehicles;
- the development of alternative fuel prices;
- technical parameters of vehicles with alternative fuel (payload, range, charging/fuelling time);
- availability of alternatively powered vehicles;
- state support for the use of alternatively powered vehicles;
- development of charging/pumping infrastructure.

2. The Principle of Economic Comparison of Vehicles with Different Types of Propulsion

The basic principle for economic comparison is to include all types of cost items that vary depending on the powertrain used. In the case of electric mobility, this includes, for example, maintenance costs, batteries (and their replacement) or the cost of purchasing the vehicle. The final relationship then specifies the price of electricity at a given price of petrol or diesel at which the total cost of operating diesel and electric vehicles is the same, and these points then form a graph (Fig. 1) in which the line p represents all combinations of electricity and petrol (diesel) prices at which the total cost (p.j./km) of using an alternative fuel is equal to the cost of using petrol or diesel [3].

$$C_{EL} = \frac{C_D \cdot S_D - \left(d_P + d_{ODP}\right)}{S_{EL}}, \tag{1}$$

where C_D – price of diesel (m.u./l); S_D – consumption of diesel (l/km); C_{EL} – price of electricity (m.u./kWh); S_{EL} – electricity consumption (kWh/km); d_P – operating cost differential (CZK/km); d_{ODP} – acquisition cost differential (CZK/km).

$$d_P = n_p^{EL} - n_p^D ; \tag{2}$$

$$d_{ODP} = \frac{N_a^{EL}}{T_L^{EL} \cdot L_{EL}} - \frac{N_a^D}{T_L^D \cdot L_D} , \tag{3}$$

where n_p^D – operating costs associated with diesel propulsion (m.u/km); N_a^D – acquisition costs of a diesel bus (m.u./ vehicle); T_L^D – the lifetime period of the diesel bus (years/ vehicle); L_{EL} – how much the electric vehicle will travel (km/year); n_p^{EL} – operating costs associated with the electric vehicle (m.u./km); N_a^{EL} – acquisition costs of an electric vehicle (m.u./ vehicle); T_L^{EL} – the lifetime period of an electric vehicle (years/ vehicle); L_D – how much the diesel bus will travel (km/year).

This relationship is graphically represented in Fig. 1.

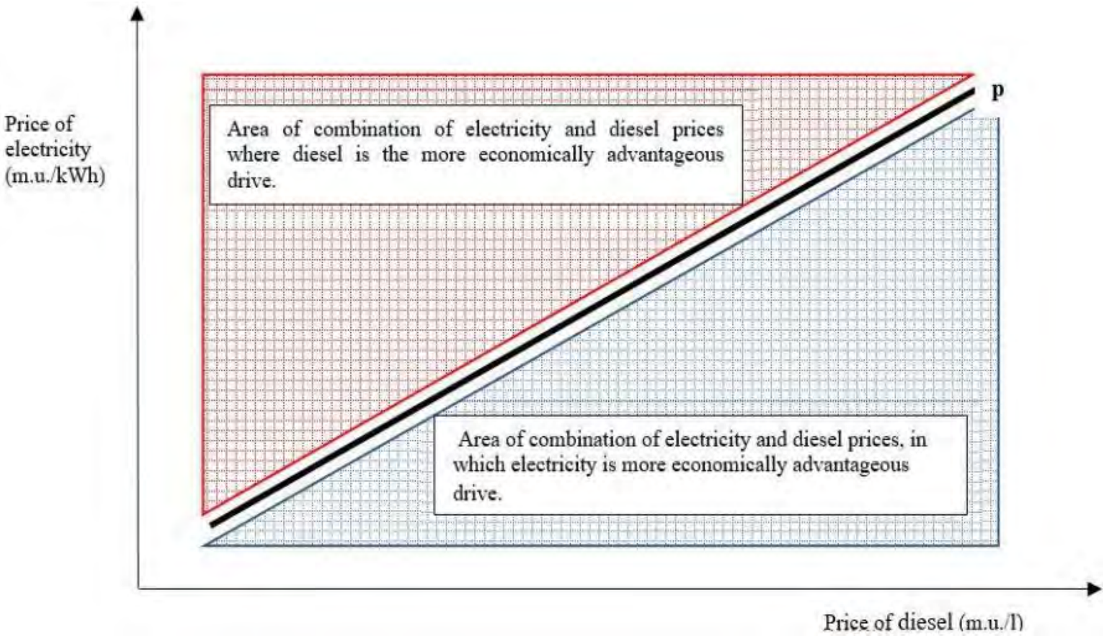

Fig. 1 Principle of graphical expression of cost equality of conventional and alternative fuel [3]

3. Cost Comparison Between an Electric Vehicle and a Conventionally Powered Vehicle

Comparing the costs of operating an electric car and a conventional car is interesting, given that the prices of electricity, diesel and petrol (as well as other energy commodities) are unusually high. The prices of electricity, diesel and petrol are shown in Figs. 2 and 3.

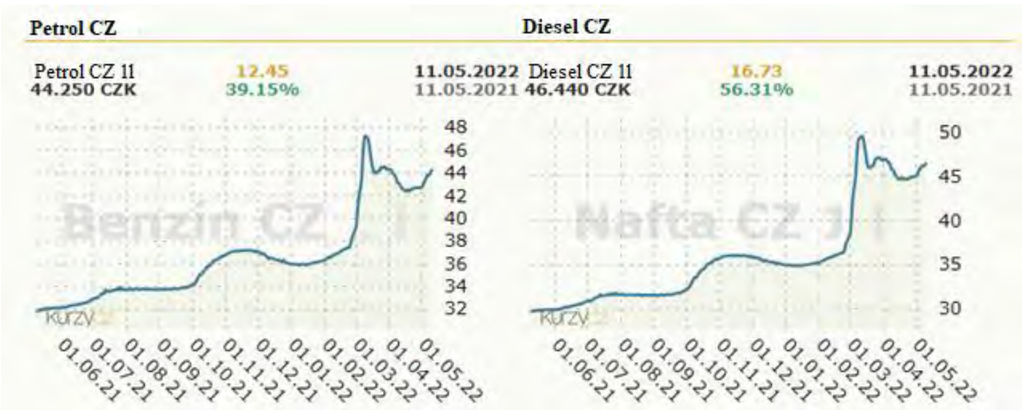

Fig. 2 Prices of fuels in the last years [5]

Fig. 3 Prices of electricity in the last years [6]

It should be mentioned that the prices of the key raw materials for electric vehicles, i.e. cobalt and lithium, have also risen significantly in the last year, mainly due to limited mining opportunities. The excess of demand over supply is then pushing up the prices of these raw materials.

The actual economic comparison is always a question of which approach to take. It is necessary to consider the following circumstances and to adopt an alternative solution according to them:

- the question is whether, with the ever-decreasing take-up of electric cars, it is possible to assume that the annual mileage of an electric car and a conventional car will be the same;
- another factor is purchasing habits, whereby users in the Czech Republic are much more likely to purchase cars on the secondary market at lower prices, while a secondary market for electric cars has not yet been created;
- we assume a lower lifetime for an electric car, especially regarding battery life.

The economic comparison was carried out on vehicles produced by ŠKODA auto a.s., a conventional diesel-powered vehicle Škoda Karoq 2.0 TDI with an output of 110 kW, and an electric vehicle Škoda Enyaq iV with an output of 109 kW. The vehicles were new, at the basic purchase price. The comparison included fuel prices in different periods, the cost per kilometre driven, their running costs and the theoretical lifetime and mileage, see Table 1. We consider the same mileage of the vehicles; of course, if the mileage of an electric vehicle is lower than that of a diesel vehicle, this reduces its economic viability.

After applying the values in Table 1 to relation (1), we obtain the values of electricity and diesel prices for cost equality, which are expressed by the straight line in Fig. 4. The figure is supplemented with the real values of electricity and diesel prices from October 2021 to April 2022. Fig. 4 shows that in the period from 05/01/2021 to 05/10/2021, when both diesel and electricity prices are low, it is profitable to purchase an electric vehicle. However, in the period from 10/10/2021 - 12/4/2022, for example, when electricity prices were high on 12/20/2021, it was significantly more worthwhile to purchase a diesel-powered vehicle. In the long term, it is very difficult to make any predictions, as we are now in a very turbulent period in terms of both electricity and diesel prices, as well as in terms of the prices of electric and internal combustion engine vehicles.

Table 1

Parameters for the calculation of economic effectiveness of a diesel car and electric car assuming they are brand-new vehicles [7]

Running costs of electric vehicle	1.78	CZK/km
Running costs of diesel vehicle	4.25	CZK/km
Purchase price of electric car Enyaq iV	1059900	CZK/car
Purchase price of diesel car Karoq	763900	CZK/car
Lifetime period of electric vehicle	8	years
Lifetime period of diesel vehicle	12	years
Mileage of electric car	20000	km/year
Mileage of diesel car	20000	km/year

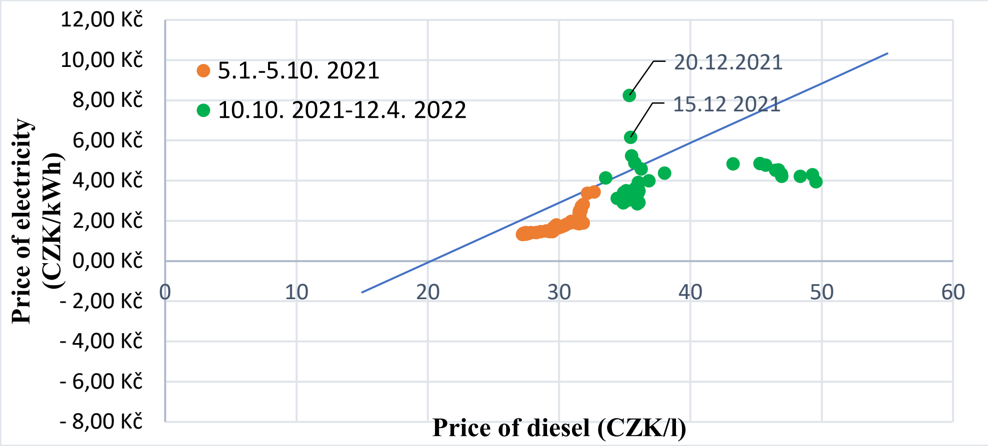

Fig. 4 Economic effectiveness – used diesel vehicle vs new electric vehicle [5], [6]

The calculation can be varied. For the purposes of this article, a comparison between a new electric car and a used diesel vehicle is also included. The economic comparison was carried out on vehicles from the manufacturer ŠKODA auto a.s., a conventional diesel-powered vehicle Škoda Karoq 2.0 TDI with an output of 110 kW, and an electric vehicle Škoda Enyaq iV with an output of 109 kW. This was a new electric and diesel-powered vehicle with a range of around 100-150 thousand kilometres, at the basic purchase price. The comparison included fuel prices in different periods, mileage costs, their running costs and theoretical lifetime and mileage, see Table 2.

Table 2

Parameters for the calculation of economic effectiveness – used diesel vehicle vs new electric vehicle [7]

Running costs of electric vehicle	1.78	CZK/km
Running costs of diesel vehicle	2.86	CZK/km
Purchase price of electric car Enyaq iV	1059900	CZK/car
Purchase price of diesel car Karoq	549000	CZK/car
Lifetime period of electric vehicle	8	years
Lifetime period of diesel vehicle	12	years
Mileage of electric car	20000	km/year
Mileage of diesel car	20000	km/year

After applying the values in Table 1 to Eq. (4), we obtain the electricity and diesel price values for cost equality, which is represented by the straight line in Fig. 5.

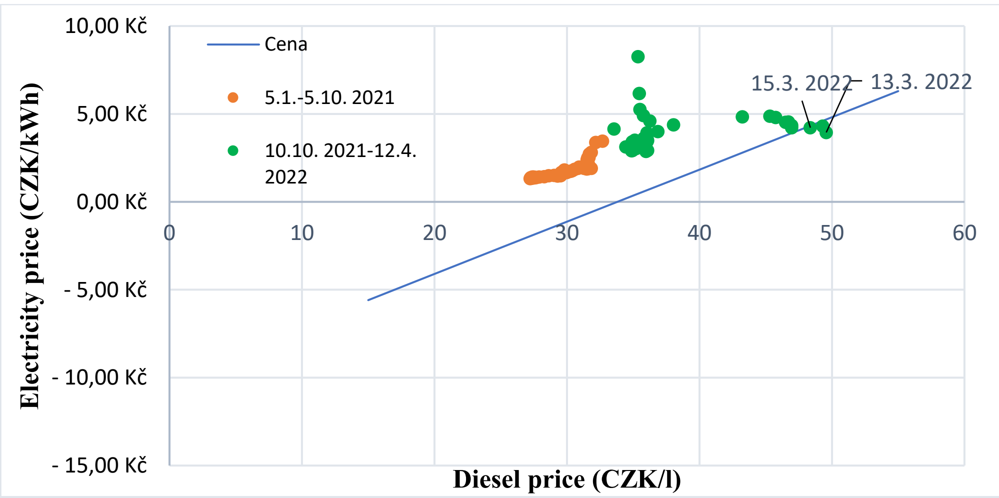

Fig. 5 Economic effectiveness – used diesel vehicle vs. new electric vehicle [5], [6]

In addition, the figure is supplemented with the real values of electricity and diesel prices from the period from October 2021 to April 2022. Fig. 5 shows that despite the higher price of used vehicles throughout the research period, a used diesel vehicle proves to be more profitable than the purchase of an alternative fuel vehicle using electricity. However, in the period of 15 March 2022, when the price of diesel was 48.37 CZK/l and the price of electricity was 4.22 CZK/kWh, both options were equally advantageous, while two days earlier on 13 March 2022, when the price of diesel was 49.31 CZK/l and the price of electricity was 3.95 CZK/kWh, the acquisition of an electric vehicle was more advantageous. In the long term, given the theoretical lifetime, fuel prices and mileage, it is more advantageous to purchase an older diesel vehicle.

4. Conclusions

The current turbulence in the energy commodity market, which is likely to continue, is slightly erasing the economic disadvantage of electric vehicles compared to conventional combustion engine vehicles, at least in the case of buying a new vehicle, where the purchase costs of an electric vehicle and a combustion engine car are not very different. For the used vehicle option, the internal combustion engine version is still preferable. An electric car would be economically more advantageous in this comparison, assuming further increases in diesel and petrol prices, which could cause serious economic problems throughout the European Union though.

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Senior Taxi as a Support for the Mobility of Seniors in the Period of Covid 19

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Abstract

Population aging, which is so relevant not only in today's developed world, but also in developing countries. Given the aging of the Slovak population and its expected continuation, it is obvious that this topic deserves attention. The effort of today's society to pay intense attention to the issues of the lives of older people and to lend a helping hand if necessary is undoubtedly current and important. An aging person is exposed to a large number of changes, which can usually be described as physical, mental and social. There is no doubt that spatial movement or mobility is an integral part of human life; there is general agreement that there is an important relationship between mobility and the quality of life of older people. With advancing age, the representation of different modes of transport also changes. It turns out that with increasing years, the number of people preferring to drive as a driver gradually decreases. With the decline in car journeys, walking and public transport are becoming increasingly important among the older generation of seniors. The Covid 19 pandemic affected all walks of life; to a significant extent also the mobility of the population. In most European countries, the pandemic has led to a significant decrease in mobility, which has been reflected in a lower number of trips per day and a shortening of distances between routes. The pandemic also had an impact on travel in the Slovak Republic; closed schools, shops and domestic work caused a significant drop in public transport passengers. The pandemic has a particularly adverse effect on the mobility of seniors. The aim of our research was to identify current problems in the mobility of seniors in Slovakia and to assess the possibility of using senior taxis for this group of people.
KEY WORDS: *mobility, taxi, safety, senior*

1. Introduction

Population aging is a process typical of the countries of the European Union. The issues of aging and the position of seniors in society are becoming constantly topical at the economic, psychological, ethical, cultural, health and social, but also philosophical levels. Active access to health, health culture and competence are now becoming not only a society-wide obligation, but above all an individual obligation. In the sense of society as a whole, it is a matter of relevant and erudite creation of conditions for optimal action of health determinants and healthy lifestyle, in individual sense about formation, stabilization and subsequent internalisation of healthy lifestyle principles so as to reflect individual potential, experience, age and possibilities. It is true that the determining position of individual responsibility and personal behaviour primarily defines the need for purposeful and intentional health promotion. This is especially true for people in the older age groups, where there is a complex of intervening variables that can significantly support or limit the quality of life. At present, the subjective health assessment of seniors is becoming increasingly important.

Quality of life is even considered a more appropriate indicator of health than morbidity and mortality [1]. The quality of life of seniors therefore depends on various factors, such as physical health, unemployment rate, mental functioning in cognition, adaptation and coping from the prevailing emotional experience, from the received and provided mental support, as well as spirituality [2]. The aging of the human body is a natural biological process, the course of which varies from individual to individual. It is influenced by many internal and external factors. It is characterized by the fact that it is programmed, long-term, and irreversible, does not repeat itself and leaves permanent changes [3]. Old age is undoubtedly an interesting phase in life. But he also has his problems. Obviously, when people reach the age of 60, a lot of things happen, or rather a lot of changes. Many of them can no longer work full time, which means they spend a lot of time in their homes. By losing their home, some lose their independence from disease, stroke and vision problems.

Many seniors who have these problems will either give up their driver's license at the request of a doctor or family member. Although we agree that this is primarily for security reasons, in principle, older people remain "trapped" in their homes. Reduced mobility can also have a significant impact on older people. It enables people to establish and maintain relationships with other people, access to professional and educational opportunities and leisure activities outside their homes, and gives them more flexibility. It enables older people to have an active lifestyle within their community, and research shows that elderly friendly transport policies (e.g. free bus tickets) are associated with increased use of public transport by older people, which reduces depressive symptoms and loneliness. During the Covid 19 pandemic, public transport has become less safe, so it is necessary to think about its alternative for specific groups of the population, especially the elderly.

2. The Impact of the Covid 19 Pandemic on Transport Demand

The demand for transport is a secondary demand, which means that it results from the demand of companies and the population for goods and services. This demand is related to the geographical arrangement, the geological arrangement, the climate arrangement and the political arrangement. The influence of groups of factors influencing the demand for transport means that the change of these factors may increase or decrease the volume of realized performances. The activities of the population, as well as human behaviour, are strongly determined by the social environment, the economic maturity of the country, the customs of the population and the transport infrastructure. The population chooses between individual and public passenger transport on the basis of these phenomena [4].

2.1. Public Transport

During the pandemic, the majority of the working population moved from the office to the so-called home office, which means that they did their job from home. Education also had to adapt to the situation and the training took place exclusively via the Internet. The impact of the pandemic has also been felt in all modes of transport around the world.

The pandemic also had an impact on travel in the Slovak Republic. Closed schools, shops and domestic work have caused a significant drop in public transport passengers. [5] The SBA states in its report 2021 that the number of passengers carried in April 2020 was a decrease of 60% compared to the previous year. It also states that the decline in gross output was recorded in the second quarter of 2020 compared to the previous year in enterprises with 0-9 employees by more than 12%, in enterprises with 10-49 employees by more than 4% and in enterprises with 50 and more employees it was a decrease of more than 20%. Some author’s viewpoint of industries, consultants and public transport companies" examined the effects of the pandemic on urban mobility. Public transport companies are very uncertain about the future, they are afraid of losing demand. They also focused on the effectiveness of the measures taken in this sector [6]. The analysis of the transport market during the pandemic was also addressed by the authors Kurowski and Huk, who in their study presented the situation of the transport market in Poland and Slovakia. Research has shown a significant decline in demand for transport services in both countries and smaller fluctuations in the supply of transport services [7].

2.2. Anti-pandemic Measures

The specific measures concerned, among other areas mentioned, the transport sector, where the activities of companies were significantly limited. Anti-pandemic measures have affected all modes of transport. The nationwide measures during the two waves of the pandemic were of a different nature. The first anti-pandemic measure in the first wave was a ban on public, mass, cultural and social events. Later, after declaring an emergency, a ban on moving without the upper airways covered came into force. The second wave of the pandemic also led to the adoption of various anti-pandemic measures, which increased the costs of all companies, regardless of their size or the sector in which they operate. Nationwide testing took place over two weekends and a negative test was required, among other things, for work. Later, a nationwide lockdown was ordered in connection with the curfew, where several exceptions applied. Another measure was the introduction of home office professions where possible. In February 2021, COVID-automat came into force, which divides Slovakia according to districts with different rules. During the second wave of the pandemic, entrepreneurs providing public passenger transport services were most affected in the transport sector.

During the COVID-19 pandemic, there was a 60% decrease in passenger transport in the passenger transport sector. The crown crisis has caused serious problems for all areas of the road transport sector. All sectors of road passenger transport were significantly affected by the COVID-19 pandemic and the measures introduced with it. These caused a massive drop in mobility, including in public passenger transport, which reached up to 60% compared to the average of the standard period. The requirements for transport arise due to the fulfilment of the goal and purpose of the relocation of persons and are based on the collective, social life of the inhabitants. They often change with changes in population, living standards and leisure, changes in employment, concentration of production and services, extended study time, interest in time savings in transport, growth in individual motoring and a lack of vacancies in the place of residence. In order for public passenger transport to fulfil its mission properly, it has been at the forefront of interest over competition in the form of individual road transport and is a major representative of passenger relocation. At the time of Covid, however, public transport posed an increased risk, especially for senior citizens.

3. Research Results and Discussion

In order to meet the research goal, it was necessary to perform an analysis of legislative requirements and restrictions on the provision of taxi services and the definition of senior taxis as an alternative to transport for seniors during a pandemic. The emergence of SARS-CoV-2, also known as COVID-19, caused a pandemic with enormous economic, health and social repercussions worldwide. The group most vulnerable to COVID-19 are older adults and those with chronic underlying health conditions [8, 9]. The importance of complying with social distancing and other public health measures during the pandemic has also impacted the usual patterns and routines of those who live in the community [10]. Complying with theantipandemic measures may mean a reduction in meaningful social contact and participation in life roles—a critical aspect of health recognised by the WHO. For older people, in particular, social isolation is often intertwined with feelings of loneliness, which can result in subjective feelings of anxiety and dissatisfaction with one's lack of meaningful connectivity with others. Although many older people live alone and engage less often in social gatherings, those in their cohort have been disproportionally affected by COVID-19 [11]. Problems with mobility are connected with the aging of population. It won't be long, and soon the entire working generation born under the previous regime, the so-called Husák children, will be old enough to receive a pension. And a large percentage of the Slovak population will move into rest regime. There will be an increasing need for cities and villages to adapt to such an onslaught of older people, because not everyone can be an active senior due to health complications, and not everyone has a family that can take care of them. It will be necessary to constantly increase the requirements for local care, and especially home care, so that the elderly can get as many things as possible on their own or with a little help. The growing affordability of cities is leading to the gentrification of metropolitan areas and their surroundings. Suburbs whose access depends exclusively on cars can marginalize car-free people - especially the elderly. Social isolation and insufficient interactions with the community are associated with poorer health. The research reveals a clear and significant link between the level of activity and the risk of social exclusion. Improving mobility reduces the risk of social exclusion. However, the preferences and improvements in public transport that allow for the mobility of seniors are not enough, and in times of pandemic, the importance of public transport for seniors is even diminishing. Around 15% of people in the EU have a disability, and this number is likely to increase with an aging demography. Reduced mobility can also have a significant impact on older people. It enables people to establish and maintain relationships with other people, access to professional and educational opportunities and leisure activities outside their homes, and gives them more flexibility. It enables older people to have an active lifestyle within their community, and research shows that elderly friendly transport policies (e.g. free bus tickets) are associated with increased use of public transport by older people, which reduces depressive symptoms and loneliness.

Taxi services are an important part of the transport system around the world. According to the authors, the European market is characterized by a high share of privately owned cars with well-developed public transport. The transport sector employs around 1 million people across the EU, representing about 8% of the total staff in the sector. Taxis have increased mobility and made it accessible to older people or people with disabilities or other disadvantages, as around 40% of EU households do not own a car and up to 50% of pensioners do not own a car or cannot drive [12]. The basic legal framework governing business in the field of taxi services in Slovakia1 is Act no. 56/2012 Coll. on Road Transport, which regulates business in the taxi sector in Slovakia [13]. The Road Transport Act regulates not only the conditions of business in road transport and taxi services, but also the rules of operation of dispatching or characterization and defining a taxi service. In § 2 par. 1) of the Road Transport Act, the operation of road transport and taxi services means a business whose subject is the provision of transport services to the public by road motor vehicles, which are type-approved for this purpose. The individual sections gradually regulate the taxi service, concession, operation of dispatching, general obligations of the taxi service operator and dispatching operator, including drivers of taxi service vehicles. According to § 26, "operation of passenger transport by vehicles with a maximum occupancy of nine persons, including the driver, as transport of individual passengers or a group of passengers to the destination according to the passenger transport contract" is considered a taxi service. The amendment to the Road Transport Act, which entered into force in April 2019, simplified the rules and conditions for the operation of taxi services, including drivers, in Slovakia in order to support modern technologies and shared economy platforms in this segment.

The basic changes brought about by the amendment to the law include the abolition of the condition of financial and professional capacity of the applicant for a concession, including the condition of owning, renting or otherwise securing a taxi rank and a place to garage or park a taxi. The condition of financial reliability has been abolished and the obligation to cover one taxi vehicle with an amount of € 1,000 has been removed. The key change was the removal of the territorial delimitation of the concession business or the enforcement of the use of a certain type or type of vehicle (including a certain location). Furthermore, the condition of professional competence and age of the driver at least 21 years has been removed (the required age has been reduced to 18 years and the requirement for at least 3 years of driving experience has been removed). The amendment made it possible to set prices for transport without the use of a taximeter using modern technologies - digital platforms, which removed the obstacle to the operation of digital platforms of the shared economy in the taxi sector in Slovakia. A senior taxi has been set up in several villages abroad and it has served as if it had been there for a long time. The service is appreciated mainly by senior citizens with health problems and also by those who can no longer drive a motor vehicle.

The main difference between a senior taxi and a regular taxi is in the price; senior taxis are often cheaper than public transport; the municipality participates in its operation. Therefore, this service becomes invaluable. There are many old people living in villages and towns who do not know how to go for medication, shopping, or culture or visit, and there is often no one to take them. According to statistics, one in five seniors over the age of 65 does not drive and has to attend medical meetings, such as visiting his doctor or physiotherapist. This problem broke out during the pandemic. Senior taxi service is becoming an integral part of the social policy of several municipalities; however, systemic solutions would be needed in this area. Similar transport services are not new in Slovakia, they are known e.g. in Bratislava, Záhoská Bystrica, Mariánka, but also in Špačince, Trnava, Nitra, Brezová pod Bradlom, Zvolen, Komárno and Brezno. In our research, we focused on the mobility of seniors during the Covid 19 pandemic and finding out attitudes to the possibility of using a senior taxi service. The survey was conducted in February to March 2022 in the Žilina region. We used the method of structured interview and questionnaire; the survey involved 148 respondents aged 65 to 84 (87 women and 61 men. The survey found that seniors reduced public transport during the pandemic by 73%, which was also related to lock down and health concerns. 62% respondents felt social isolation, 28% of seniors did not leave the house at all, 38% only for the necessary shopping, 24% due to a visit to the doctor and pharmacy, 47% of respondents were worried about using public passenger transport, 32% Only 5% of respondents used the taxi service, and in connection with the perception of the possibility of transport by senior taxi service, 58% of respondents would use this service on favourable terms. 62% of respondents reported quality of life as low. The purpose of senior taxi service is to support the mobility of seniors and facilitate access to medical care, as this category of our fellow citizens does not always have the opportunity to accompany close relatives, waiting for an ambulance is time consuming and traveling by bus in case of deteriorating health is extremely burdensome. The legislation also stipulates the requirements for a taxi vehicle. A senior taxi service vehicle can only be a vehicle that:

a) is listed in the concession and is assigned a taxi registration number in the concession; this number must be placed in the taxi vehicle in a place visible to the passenger;

b) is marked on the front left and right doors with the taxi operator's trade name and the dispatching telephone number of the ordering service, if established by the taxi operator; otherwise the carrier's telephone number;

c) has a permanently installed functional taximeter meeting the requirements for specified meters, which allows the passenger to monitor the instantaneous fare during the transport and which issues a receipt for the fare paid; the taximeter does not have to have a taxi vehicle used to transport a group of passengers who have paid the fare before the start of the transport or at the usual places on the regular transport route;

d) has a basic fare on the right front door and inside the taxi in a place visible to the passenger; this does not apply in the case of a taxi used for the carriage of a group of passengers who have paid the fare before the start of the carriage or at the usual places on the regular service;

e) is insured in the event of liability for damage caused to the passenger's health or property;

f) is equipped with a fixed or removable yellow roof lamp with the inscription TAXI;

g) it must allow the carriage of at least 50 kg of luggage at full capacity within the total weight of the vehicle or it must have a luggage or hold of at least 375 dm^3.

Hand luggage can be transported in the passenger compartment. The driver determines whether the luggage is transported as manual or luggage in the luggage compartment. If the driver designates a luggage compartment as the place of transport, the passenger is obliged to draw attention to the special nature of the luggage, in particular its contents and value, and if he requires it to be handled in a certain way or stored in a certain position. Baggage and other items are loaded and unloaded, placed or attached by the driver of the taxi vehicle; if necessary, the passenger is obliged to provide the driver with adequate assistance during storage or unloading [14]. We consider it entirely justified that, under the new Road Transport Act, every taxi driver must have a taxi driver's license and be medically or mentally fit and of good repute. Passengers must be sure that they are traveling with a certified driver who meets all legal conditions and necessary standards. It is an above-standard service of the municipality to its inhabitants in order to increase the safety and comfort of transport and thus improve the quality of life of seniors. The service should be intended for citizens over the age of 65 and for physically and disabled people without restrictions. Quality of life is the result of the interaction of social, health, economic and environmental conditions of human life and social development. This concept can include questions of the meaning of life, characteristics of the natural and social environment of a person, physical and mental state of a person, as well as subjective evaluation of life - personal well-being and satisfaction [15].

The concept of quality of life expresses a positive evaluation pole as a prerequisite for the active development of one's own human potential. By prolonging life expectancy and thus aging the population, questions about the quality of life of seniors are becoming more and more relevant. It is about examining and subsequently influencing those factors that affect the aging process in the context of quality of life in old age. Aging and old age is a source of many problems for the elderly to deal with. The risks in the life of a senior are such as reduction and loss of self-sufficiency, which is associated with problems related to the provision of daily routine activities in the care of oneself and household; the deteriorating state of health with disabilities of those functions which are important for maintaining self-sufficiency as well as ensuring adequate financial resources, which are a prerequisite for decent material security within a satisfactory standard of living; difficulties in connection with the adjustment of the life program and its implementation after retirement (planning a new daily schedule, changing the learned daily stereotypes, etc.) [16].

4. Conclusions

Everything related to the service sector for the elderly will evolve and evolve. Due to the elderly population, there are plenty of services to offer. However, a significant part of the services provided to this segment of the population are provided by institutional providers (e.g. nursing and support institutions) rather than formal non-institutional providers of services. Organizations that promote the interests and needs of older people must be partners in creation public policies and in dealing with matters that affect them. Policies affect older people and should therefore also be effectively influenced by them. It is also a prerequisite for security full and effective participation of the older generation in economic, political and social society and at the same time a means of ensuring continued active integration older people in the process of developing and strengthening their rights. The goal is to create a company friendly to all age groups, in which older people will also be created conditions for a dignified active life. There is a need to remove barriers that lead to the exclusion and isolation of seniors from the public, political, social and working life on the basis of difficult access to transport infrastructure. During the Covid 19 pandemic, the use of senior taxi services is a good alternative. To do business in a senior taxi service it is necessary to meet the specific conditions to obtain the license / concession to perform a taxi service.

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Transportation Optimization of Homogeneous Freight in the Transport Systems

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Abstract

There are situations where, due to various circumstances, a large number of direct routes in the freight traffic running (which were traditionally used) can not satisfy transport users. Then there is a need to find new routes for the transportation of freight from departure points to destinations. The authors present an example to solve the transport task by setting of transportation routes in an extensive network, taking into account the specifics of transportation of homogeneous freights on concrete sections of railways. This allows optimizing the plan of transportation for homogeneous freights in the transport systems. This is relevant for the development of new transport routes, especially in modern conditions.
KEY WORDS: *transportation, homogeneous freight, transport task, route*

1. Introduction

An important factor in the political and economic development of countries/territories is the effective operation of transport, transport infrastructures, and transport segments. Their main tasks are transportation – freight, passenger, luggage, tourist [1-3]. A significant part of these transportations is an important component of production processes – both industrial and agricultural. Since their volumes are the basic economic indicators of any state.

When choosing a type of transport, the importance of environmental factors is increasing, in particular, reducing fuel consumption, reducing adverse environmental effects. Therefore, there is a reorientation of a significant part of transportation to the usage of more environmentally friendly modes of transport [4-6].

Currently, transportation is actively carried out by railway and motor transport [7, 8]. However, on long distances of transport routes (above 200 km according to European requirements) there is a decrease in the usage of motor transport [9]. And this is because compared to the motor, railway transport:

- provides a high level: of reliability and safety of traffic, movement of goods, mobility of the population [1, 2];
- requires less allotment of land per ton- and passenger-kilometer [2];
- enhances environmental friendliness and energy efficiency of transport processes [10-12];
- has a reduced adverse effect on climatic changes, workability, and physiological state of a person [2, 9].

Also with the upgrading/modernization of rolling stock units [13-15] and their elements [16, 17], re-equipment of infrastructure facilities [18], railway transport provides accessibility and quality of services.

2. Actuality

In modern conditions, to ensure life, support/development of the economy, and increase competitiveness, also all enterprises require a professional approach to the management of transportation processes. Depending on the placement of production, the transport system is approaching either the places of raw materials extraction (minerals) or the consumers' location.

The organization toward the direction of trade flows by defined routes is a factor in the stability of railways, and the transport component in economic costs is essential. The movement of traffic flows should be carried out on sections and directions that are economically beneficial. Therefore, it is important that the minimum transportation costs have to be provided in the transport service market; to meet the timing of goods delivery, execution of consignor/consignee requests, etc. This should foresee a reduction in the costs of railways for processing and inactivity of cars at stations, the performance of technical and freight operations, running of trains on the sections of railways, maintenance of technical infrastructure and staff costs. This should ensure the concentration of marshaling at stations, reduce the time spent the duration of cars at stations, and increase the degree of usage for the technical means of transport.

But the situations arise when, owing to various circumstances, a large number of direct routes in freight traffic running (which were used traditionally) can not meet the demand and needs of transport users [19]. Then there is a need to find new routes for freight transportation from departure points to destinations. Such routes should also provide the smallest economic costs of transportation – this is a way to reduce the prime cost of transport services and increase the efficiency of transport operational activity of railways.

The system in the organization of new car flows should also provide: a plan of transportations; acceleration of circulation for the rolling stock units; increasing the transit facilities; reducing operating costs and prime costs of transportation, etc.

3. Problem Statement

The development, production, processing/refining, delivery, and consumption, concerning minerals has the visible significance in the present growth. The fuel industry provides the production with energy, and power engineering – raw materials. A prerequisite for its development in Ukraine is a raw material base, in particular, coal (Fig. 1), with unique deposits of coal [20, 21].

Fig. 1 The map of the coal base in Ukraine

And in 2014, the situation emerged with a coercive change of coal routes running (by the railway), which was extracted in the Donetsk coal basin (Fig. 2) [22].

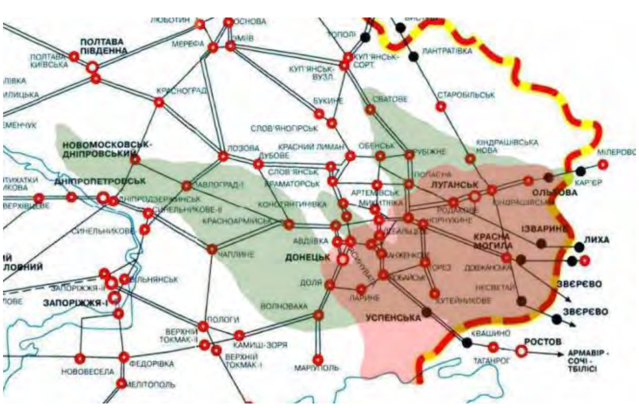

Fig. 2 Organization of car flows of coal from the Donetsk coal basin until 2014

Fig. 3 Organization of car flows of coal from the Lviv-Volyn coal basin

In this regard, attention was focused on the Lviv-Volyn coal basin (Fig. 3) [22]. Therefore, in new conditions, in order to optimize the costs of transportation, let us consider the problem of transportation of homogeneous freights by railways. To do this, we will search for optimal routes with the help of a transport task. This is a specific task of linear programming used to determine the most transportation economical plan for homogeneous products from the supplier to the consumer (Fig. 4) [19].

Fig. 4 The way to deliver homogeneous products from the supplier to the consumer

Let us consider the transport network in the form of a graph (Fig. 5). It consists of connected departure points by the track $A\left(\vec{i}=1;\, n\right)$, the destination of freights $B\left(\vec{j}=1;\, m\right)$ and other transit points $C\left(\vec{k}=1;\, r\right)$.

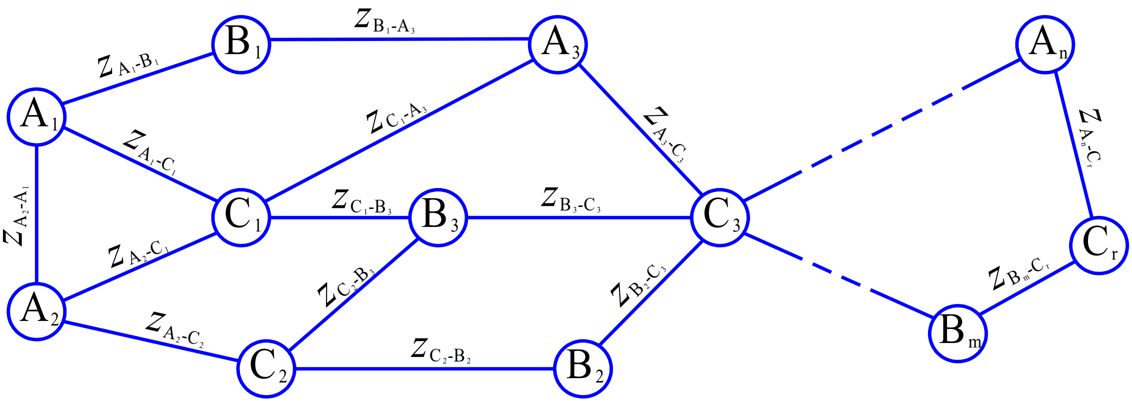

Fig. 5 The transport network in the form of a graph

At each of the departure points there is a homogeneous freight in quantitiesX_i, and its needs the destinations are Y_j. It is assumed that departure points and destinations can perform the function as transit ones.

We will make the calculation of optimization for the homogeneous freights transportation in transport systems with regard to the operational characteristics. These are statistics of stations that are a part of a specific section of the railway: the length of the receiving-starting tracks of stations (departure/destination), the maximum permissible weight of the train on the section, its profile, weight norms, number of cars. It is also necessary to take into account the volumes (in conventional units): production of products, consumption of products, dispatch of products in cars, receiving products in cars. Based on this, there is an opportunity to analyze reasonably the efficiency of sections operation where freight transportation is carried out. The results of the section operation and expenses on its workability depend on such indicators as: the number and parameters of the rolling stock units, a series of train locomotives and their traction characteristics, the type of traction, the number of cars in the train.

4. Meeting the Challenge

To determine the optimization of transportations on the entire route running, it is necessary to determine the size of the car flows on each of the service sections.

The maximum number of cars on the train we will determine in two ways:

1)

$$k_{maxw} = \frac{Q - P_{loc}}{q_{car}}, \tag{1}$$

where Q – maximum permissible weight of the train on the section, tons; P_{loc} – locomotive weight, tons; q_{car} – gross weight for one car, tons; defined as:

$$q_{car} = q_g + q_t \,, \tag{2}$$

where q_n – net weight (average load of one car); q_t – tare of one car;

2)

$$k_{max\,\kappa} = \frac{\ell_{rs} - \ell_{loc}}{\ell_{car}} \,, \tag{3}$$

where ℓ_{rs} – the smallest length of the receiving-starting track on the section; ℓ_{loc} – length of a locomotive; ℓ_{car} – length of one car.

From two obtained values we get less and round it to a smaller integer k_{max}.

For each section, the tonnage rating is set Q_{max} – restrictions on the maximum weight of the train, depending on the profile of the track, train locomotive, and other restrictions. And it is adopted from normative documents of the Railway Transportation Directorate.

The characteristic of the track development of the station also has an impact on the forming of the transportation plan. In particular, the length of the receiving-starting tracks (ℓ_{rs}) determines the maximum length of the train, which can be located on the tracks of the arrival or departure stations.

It is approved with the State Statistics Service of Ukraine, Ukrzaliznytsia JSC, all data are recorded in an e-book in the form of tables in MS Excel environment. As an example, we present the final table (Table) of cars traffic with variable cells.

Table

Car flows

Get to	B_1	B_2	…	B_m	B_1^{tr}	B_2^{tr}	…	B_m^{tr}	A_1^{tr}	A_2^{tr}	…	A_m^{tr}	C_1	C_2	…	C_m
Get from	Y_1	Y_2	…	Y_m												
A_1	X_1		…				…				…				…	
A_2	X_2		…				…				…				…	
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
A_n	X_n		…				…				…				…	
A_1^{tr}			…				…				…				…	
A_2^{tr}			…				…				…				…	
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
A_m^{tr}			…				…				…				…	
B_1^{tr}			…				…				…				…	
B_2^{tr}			…				…				…				…	
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
B_m^{tr}			…				…				…				…	
C_1			…				…				…				…	
C_2			…				…				…				…	
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
C_m			…				…				…				…	

Target cells are the sum of all transportation costs. They include formulas (4-6), which display the sum of all values of the table of total costs for the car transportations on sections:

$$X_i = \sum x^{depar\ loc}_{A_i, B_j, C_k} \,; \tag{4}$$

$$Y_i = \sum x^{arriv\ loc}_{A_i, B_j, C_k} \,; \tag{5}$$

$$\sum x^{arriv\ tran}_{A_i, B_j, C_k} = \sum x^{depar\ tran}_{A_i, B_j, C_k} \,, \tag{6}$$

where $\sum x^{depar\,loc}_{A_i,B_j,C_k}$ – the sum of all local cars departing from the station; $\sum x^{arriv\,loc}_{A_i,B_j,C_k}$ – the sum of all local cars arriving to the station; $\sum x^{arriv\,tran}_{A_i,B_j,C_k}$ – the sum of all transit cars arriving to the station; $\sum x^{depar\,tran}_{A_i,B_j,C_k}$ – the sum of all transit cars departing from the station; $x_{A_i,B_j,C_k-A_i,B_j,C_k}$ – integers; $x_{A_i,B_j,C_k-A_i,B_j,C_k} \geq 0$.

After the process of searching for solutions is completed, the Table of car flows on the service sections will automatically be filled with numbers. And this is the number of cars running on each section of the route. These figures are the solution to the set task and will provide the lowest financial costs for transportation. It will optimize the freight transportation plan in the transport systems. Due to this, it will be possible to analyze more reasonably the efficiency of routes operation for freights transportation in new conditions.

5. Conclusions

Choosing an optimal route for transportation of homogeneous freights by railways in new conditions was realized with the help of a transport task. When solving the problem, real factors affecting the number of actions in transport systems are taken into account. The presented example to solve the transport task for the setting transportation routes in an extensive network takes into consideration the specifics of transportation on concrete sections of the railway.

The result of solving the transport problem is the best option for transportation of freights from departure stations to destinations that reduces transport costs. This can be used to solve a transport task with any homogeneous freights on the railway in the transport systems. This is relevant to mastering new transport routes, especially in modern conditions.

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Signal Analysis of the Armature Rotation Irregularities in the Traction Electric Motor by Unsupervised Anomaly Detection Methods

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Abstract

Reducing the cost of maintenance and repair of vehicles is possible due to the early detection of malfunctions development and more complete use of the equipment resource. The introduction of contemporary information technologies allows real-time monitoring of the technical parameters for the equipment. Anomaly detection methods are used to process monitoring results. The paper presents the results of using the Unsupervised Anomaly Detection methods to analyze the signal of the rotation velocity irregularity of the armature shaft in the traction electric motor of a locomotive. When analyzing signals corresponding to faulty electric motors, anomalous components were identified. As the example of analyzing the signal of an electric motor with an increased radial clearance, the possibility of detecting the development of a malfunction at an early stage has been confirmed. The conducted research confirms the possibility of using anomaly search methods to control the technical condition of the traction electric motor in a locomotive during bench tests.
KEY WORDS: *technical monitoring*, *electric motor, unsupervised anomaly detection, DBSCAN, OneClassSVM, Elliptic Envelop, Isolation Forest*

1. Introduction

Monitoring the technical condition of a vehicle is a process of continuous supervision of its technical condition and processes occurring in operation. At the same time, monitoring can be implemented both continuously during operation using built-in (on-board) control systems, and periodically during bench tests, equipment performance testing, etc. Specifics of using intelligent technologies when choosing locomotive maintenance strategies are given in [1].

The main advantage of monitoring is the ability to detect an incipient malfunction early without exclusion of the locomotive from service. The use of information obtained from monitoring tools in the planning of repairs and the development of a maintenance system makes it possible to avoid the contradictions set forth in the works [2, 3]. The main contradictions are the insufficient amount of collected statistics, the constant change in operating conditions, the inadmissibility of failure occurrence of critical objects, and the reduction of the service life for the controlled object in the event of a failure. Thus, during the operation of the locomotive, monitoring its technical condition makes it possible to increase the efficiency of the maintenance system without the introduction of more complex diagnostic systems. Processing the results of monitoring the technical condition of locomotive nodes is a simpler task than diagnosing. At the same time, the results of monitoring are the initial data for analysis by diagnostic systems. In this regard, the introduction and improvement of methods for analyzing data from monitoring systems is an actual task.

2. Literature Review

The application of monitoring to control the technical condition of locomotives is more relevant for locomotives equipped with on-board diagnostic systems [4], as it can identify hidden faults and monitor the state of locomotive nodes in all operating modes. It is also possible to use monitoring during tests and break-in tests of nodes and assemblies of locomotives.

The main task of monitoring is to identify anomalies in the operation of equipment. An anomaly in the operation of the equipment is the appearance of unexpected values (patterns, ratios of values, etc.) in the data set [5]. The concept of an anomaly in data is closely related to such concepts as Novelty and outlier. The difference between these concepts is considered in detail in [6]. The difference between novelty and anomaly is that an anomaly is the appearance of non-typical features in the behavior of equipment during typical operating conditions. Novelty is the appearance of new signs in the behavior of equipment when operating conditions, external factors, or any other reasons change. Novelty, as a rule, manifests itself as a result of a fundamentally new behavior of the object. At the initial stage, the values corresponding to the novelty will be considered as an anomaly, later, with the help of experts in the maintenance of this type of equipment, the classification of the values is either an anomaly or a normal state.

Researchers in [5-7] distinguish three types of anomalies: point, contextual, and group. A point anomaly when one or more measurement results differ significantly from the rest of the measurements. As a rule, such anomalies arise as a result of failures in the work of measuring instruments. For example, a one-time signal loss is the result of the impact of external electrical interference. Detecting this type of anomaly is easily done with the simplest methods. To eliminate the impact of point anomalies on the operation of recognition algorithms, the measurement results are pre-processed by filtering algorithms (cleared). The complexity of data cleaning is that it is necessary to prevent the data deletion characterizing the development of a malfunction.

Contextual anomalies are those that manifested in the discrepancy between the values of interrelated parameters. The fact of an anomaly is determined not by the value of the sensor signal, but by the correspondence of the sensor signal to the operating conditions of the equipment at the given moment. For example, the temperature of the armature winding of a traction electric motor may be 120°C at a certain moment, while after one second the temperature of the winding cannot be 60°C. The discrepancy lies in the rate of temperature change. At the same time, values of winding temperatures of 60 and 120°C are permissible from the viewpoint of boundary exceedances.

The collective anomaly manifests itself in interconnected data. These are measurement results that are considered to be anomalies when analyzed simultaneously with other data points. The deviation of the temperature value of one axle box unit from the temperature of the other axle box units of the locomotive in operation is an example of a collective anomaly. Similarly, the deviation of the cooling air temperature at the outlet of one of the electric traction motors from the air temperature at the outlet of the other motors can be considered an anomaly.

Currently, many methods and algorithms for anomaly search for various types of data have been developed [8-11]. Anomaly search methods are widely used in various branches of science and technology.

Let us consider the experience of using anomaly search methods for monitoring the technical condition of vehicles and equipment in the industry. According to [8], the search for anomalies in the data set that have been received from the sensors installed on the equipment is a classic task, which is solved using model methods (Digital twin) [9], machine learning methods [10], statistical analysis methods [11], neural networks [6] and a number of others. Both parameter values without additional transformations and values after additional processing can be used as initial data for anomaly search. An example of additional processing is the use of methods of data dimensionality reduction to simplify the process of interpreting the results [12, 13]. In addition to using sensor signals as control values, the concept of the index for the equipment technical condition (equipment health index) is pointed out in a number of studies [14, 15]. Using the index for the equipment technical condition allows you to control it in a generalized form, without being bound to specific parameters.

3. Methodology

In this article, we will consider the application possibility of using anomaly search methods to control the technical condition of the locomotive electric traction motor at bench tests. The signal of the rotation velocity sensor of the armature shaft is used as a controlled parameter. A technique for diagnosing an electric traction motor by the rotation velocity irregularity is given in [16]. Diagnosis of rotation velocity irregularity is performed using a high-precision incremental optical sensor of angular displacement (encoder). The sensor is installed on the technological cover of the bearing shield from the side of the collector. Using an adapter, the encoder shaft is rigidly connected to the armature shaft. The number of pulses (resolution) during measurements is 625 pulses per one complete revolution of the shaft. By processing the signal from the incremental sensor, we obtain information about the current value of the angle of a shaft rotation relative to the reference index mark (by the method of chained additions), as well as about its angular velocity. Diagnosis by the armature rotation irregularities is carried out when the electric motor is idling. Such a diagnostic system is available and does not require significant capital investments for its implementation.

The encoder signal is a time series with a frequency of 625 points since 625 values of the instantaneous rotation velocity of the armature correspond to each revolution of the motor armature. The methodology of time series analysis is used to analyze data on the technical condition of equipment and detect anomalies [17, 18]. The use of methods for working with time series is quite effective if there are measurement results gathered over a significant period of time, which makes it possible to trace the development of anomalies from a good state to a possible failure. The purpose of this publication is to demonstrate the possibilities of using unsupervised anomaly search methods (unsupervised learning) for signal analysis of the armature rotation irregularities in the traction electric motor. For processing, the results of tests for four traction electric motors in various technical conditions were used.

The most common anomaly detection methods using machine learning approaches, according to [8], are: Support Vector Machines for one class (OneClassSVM), Isolation Forest, and Ellipsoidal Data Fitting (Elliptic Envelope). The clustering algorithms DBSCAN, k-NN, and a number of others are also successfully used to detect anomalies. All methods described are unsupervised learning methods. The task of all anomaly detection methods is to answer the question of which class the analyzed data belongs to: normal or anomalous.

The task of the OneClassSVM method [19] in the classical version is to determine the hyperplane that divides the measurement results of the normal and anomalous classes. If, as a result of measurements, m points in n-dimensional space are obtained.

$$x_1, x_2, \ldots x_m \in R^n \,. \tag{1}$$

Each of the points describes the state of objects belonging to one of the classes, and the coordinates of the points in space act as signs. The result of applying the OneClassSVM method is a function that allows you to divide classes from each other. With a linear separation of space R^n, the task of the method is to calculate the parameters of the hyperplane that divides the anomalous and normal classes:

$$\langle w,x\rangle - b = 0, w \in R^n, b \in R, \tag{2}$$

where w is the vector, normal to the hyperplane, x is the point of the hyperplane, b is the real number constant.

If for some point $p \in R^n$ inequality is satisfied (3), then it is considered that point p belongs to the first class, if the condition (3) is not satisfied, then the point belongs to the second class:

$$\langle w,p\rangle - b \geq 0. \tag{3}$$

Thus, the task of the OneClassSVM method is to construct a linear classifier, which is specified by a vector $w \in R^n$ and a number $b \in R$.

Modern implementations of the OneClassSVM method allow using not only a linear space division but also a polynomial one, the Gaussian RBF function. Examples of using the OneClassSVM method to determine anomalies are described in [19, 22].

Isolation Forest is the unsupervised learning belonging to the family of decision trees. The concept of using the method is that anomalous values are closer to the root of the decision tree because anomalous values are easier to distinguish from other ones. In line with [20], when processing the data flow from sensors, the data set Z is divided into a sequence of n-dimensional vectors:

$$Z = \{z(1), z(2), \ldots z(t), z(t+1), \ldots\}, \tag{4}$$

where $z(t) \in R^n, t \geq 1$.

First of all, the data set Z is divided into blocks of equal length. In our case, each of these blocks consists of 625 points corresponding to one revolution. The main task of using the anomaly search method is to perform block analysis $z(t)$ and to single out anomalous values from this block. The complexity of singling out anomalous values requires the use of some criterion S by the value of which one or another value belongs to the class of anomalies. According to [21, 22], in the Isolation Forest, the condition is used (5):

$$S(x,n) = 2^{-\frac{E(h(x))}{c(n)}}, \tag{5}$$

where $h(x)$ is the path length of the observation, $E(h(x))$ is the average of values $h(x)$ from all sets of isolation trees. $c(n)$ is the average path length of an unsuccessful search in the binary search tree, n is the number of external nodes.

For each value from the block $z(t)$, the value of the criterion S is calculated. A value close to one indicates an anomaly, and a value significantly less than 0.5 indicates the absence of an anomaly. If all values of the S criterion for values from the block $z(t)$ are close to 0.5, then the entire block does not have clearly defined anomalies.

The elliptic Envelope is based on an evaluation of the conformity of the data distribution to the normal (Gaussian) distribution law. The basic idea is that the distribution of the measured data is represented as a Gaussian distribution while singling out a group of unlikely data for the model. If something is unlikely within the model, then it is probably an anomaly. An ellipse is generated around the central data cluster and outliers are detected using the minimum covariance determinant. Mahalanobis distance is used as a metric (6):

$$d(x,\mu,C) = \sqrt{(x-\mu)^T C^{-1}(x-\mu)}, \tag{6}$$

where x is input data, μ is the average value, C is the covariance matrix.

DBSCAN refers to unsupervised learning methods. The method performs clustering based on the packing density of data points. The result of the method is the selection of groups and clusters in the data set. The algorithm groups points together that are closely spaced (points with many close neighbors), marking those points as outliers that are lonely in areas of low density (the nearest neighbors are located far). The DBSCAN parameters are: minPts is the minimum number of points (threshold) grouped in place for the area to be considered dense; eps (ε) is the distance measure that will be used to define the location of points in the vicinity of any point.

The construction of an anomaly detection system consists of four stages: the collection of initial data, the systematization of the collected data, the formation of additional numerical features, and the construction of an object behavior model [23, 24]. In the simplest version, the stage of generating additional numerical features can be skipped.

Anomaly detection is performed using the behavior model of the monitored object.

4. Results

The results of measuring the rotation velocity of the armature shaft of four traction electric motors that were in various technical conditions were processed using the above-considered methods for detecting anomalies without a teacher. At the same time, the engine m1 was in good condition after the overhaul. The results of measuring the rotation velocity of the armature in this traction electric motor are used as a reference signal when training the anomaly detection models.

The m2 and m3 motors required the overhaul and had malfunctions. When disassembling faulty motors, the following defects and malfunctions were found: loosening in mount and, as a result, rolling the front pressure washer on the shaft, microcracks in the welded connection of the front pressure washer with the armature shaft (motor m2), surface corrosion of the pump bodies, exceeding the allowable radial clearance of the anchor roller bearings (motor m3). The motor m4 had a radial bearing clearance of 0.13 mm and 0.17 mm with a limiting value of 0.20 mm.

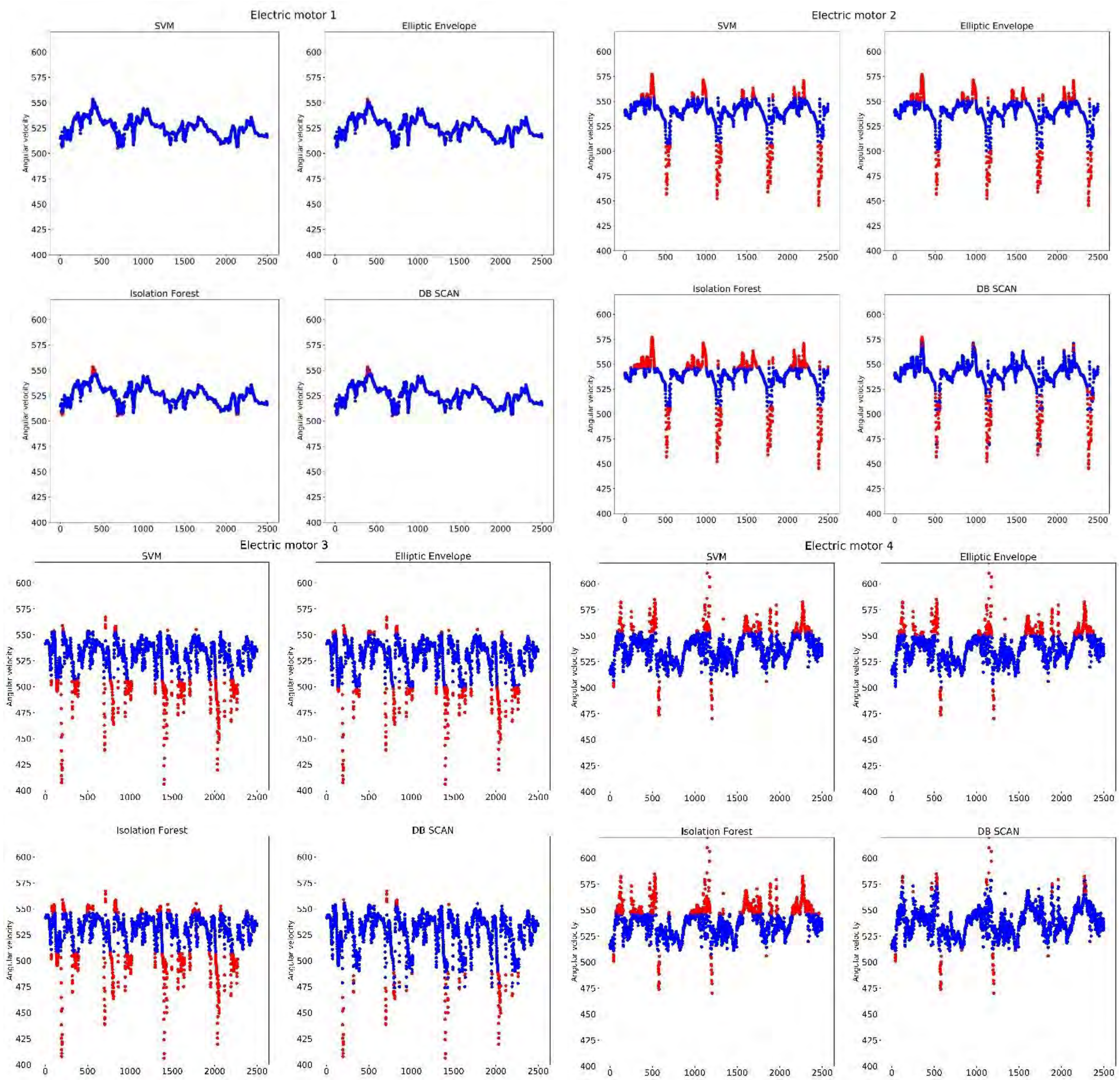

Fig. 1 Determination of anomalies in the signal of armature rotation irregularities (electric motors m1 - m4)

The results of processing the signal of the rotation velocity of the armature shaft in the traction electric motor by anomaly detection methods are shown in Fig. 1.

The values of the instantaneous rotation velocity of the armature (in red) by machine learning algorithms, are determined to be anomalous. As it can be seen from Fig. 1, all four considered methods single out anomalous velocity values and can be used to control the technical condition of the electric motor at monitoring. However, each of the methods has its own characteristics.

To evaluate the accuracy of models used in anomaly recognition, anomalies were searched for the signal corresponding to the m1 motor. As a result of processing the signal in m1 motor, the OneClassSVM algorithm provided an anomaly recognition accuracy of 99.9%, the Elliptic Envelope algorithm – 99.5%, the DBSCAN algorithm – 99.1%, the Isolation Forest algorithm – 98%. By recognition error, we mean the assignment of normal values to an anomalous class. The m2 and m3 electric motors had pronounced malfunctions. In the signals corresponding to these motors, all algorithms have identified a clear allowable range in changing the rotation velocity of the armature. The technical condition of the bearings in the m4 electric motor was approaching the red lines. The rotational velocity signal does not have such pronounced peaks as in the m2 and m3 motors, while the algorithms have identified anomalous areas in the signal waveform. After comparing the results in the work of algorithms, we also see that the OneClassSVM and Elliptic Envelope algorithms have a narrower range of normal values. The DBSCAN algorithm has the widest range of acceptable (normal values), concurrently, the DBSAN algorithm defines some of the values from the anomalous zone as normal values. Examples of such misclassification are displayed on the graphs corresponding to the m2 and m3 motors. A feature of the Isolation Forest algorithm, in comparison with others considered, is that this algorithm tends to determine the anomalous values of the upper part of the graph. An example of such a classification is visible in the images corresponding to the m2 and m4 electric motors.

5. Conclusions

The conducted research confirms the possibility of using anomaly search methods to control the technical condition of the locomotive traction motor during bench tests. The signal of the armature shaft velocity sensor was used as a controlled parameter. All the considered methods for detecting anomalies make it possible to determine the presence of a malfunction in the bearings and the mechanical part of the engine. The detection of anomalous components in the signal of the m4 engine, the radial bearing clearance of which was approaching the maximum allowable limit, allows us to speak about the possibility of early detection of a malfunction. The considered methods differ in different levels of sensitivity, the width of the range of permissible deviations of the signal. The use of the considered methods for detecting anomalies makes it possible to determine the presence of deviations from the norm in the technical condition of the controlled unit or unit, while the considered methods do not allow determining the cause of the deviation. To determine the cause of the deviation, it is necessary to perform additional processing of the speed signal in order to highlight additional information features in the signal, as well as apply supervised machine learning methods.

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Possibilities of Shortening Travel Times on the Railway Line Zvolen - Košice

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Abstract

The railway connection between Zvolen and Košice is crucial, given the service of district towns in the south of central Slovakia and in the south-east of Slovakia. After setting a two-hour all-day express cycle, the popularity of this connection between passengers has increased, but the problem is travel time. Today, it is at the level of three hours and twenty-five minutes. The main goal of the conference paper is to analyse the current situation and outline the possibilities of reducing travel time. A limiting condition for reducing travel time is compliance with the current standard of service in the context of train stops in all towns. It is assumed that with such a reduction in travel time, there will be an increase in the use of this rail connection by passengers, despite the poor technical condition of the railway line on some sections. At the same time, the rail connection between the two cities is expected to be more competitive with bus transport and at the same time attract more passengers who switch from individual car transport to rail transport, thus consolidating their passenger position in the state's transport system.
KEY WORDS: *Zvolen – Košice railway line, travel time, passenger trains, fast trains*

1. Introduction

Rail transport should play a key role in the state's transport and communications system. In particular, passenger transport should, as far as possible, take place by rail. At the same time, it is necessary to look for ways to speed up travel time so that train transport becomes more attractive.

Ways to speed up rail transport are also being sought on the Zvolen - Košice railway line. The 233 km long train journey currently takes 3 hours and 25 minutes in both directions [1]. On this route, it is possible to speed up travel time by omitting the Fiľakovo railway station. It is possible to stop the train at the Fiľakovo zastávka railway stop, which is in the immediate vicinity of the bus station. Subsequently, the train would continue through the so-called Fiľakovo triangle outside the Fiľakovo railway station.

The main goal of the article is to assess the above-mentioned solution of acceleration based on isochrones of accessibility, which will draw quite accurately and compare the pedestrian accessibility of passengers from these two points. The article will also create a qualitative analysis based on the services provided by the Fiľakovo railway station and the Fiľakovo zastávka railway stop to passengers. Based on this analysis, proposals will be presented at the end that could help passengers in a possible change of train route.

2. Literature Review

The literature review will focus on speeding up passenger rail transport. This acceleration can be implemented in various ways that we imagine and will try to find parallels with our article.

Acceleration of rail transport is a fundamental factor in the development of transport. In the article [2], the authors try to implement the acceleration factor in urban public transport. Given the need to link modes, this article can make a significant contribution to transport integration.

The process of accelerating rail transport can be achieved, for example, by purchasing new rolling stock. In the article [3], the authors deal with new light rail vehicles for urban transport in Istanbul. Acceleration vibrations are a major problem, so a computer simulation was used to address this shortcoming, which revealed the cause of the problem and contributed to possible solutions.

Acceleration of rolling stock also brings with it discomfort in the form of oscillations, which increase due to higher speeds. Article [4] deals with oscillation comfort levels. A simulation in the ADAMS rolling stock simulator was used to reduce the negative effects. The analysis was also carried out on buses in the context of road inequalities. The comparison brought results in favour of rail transport and at the same time outlines the possibilities of eliminating oscillations, which will increase the level of comfort and use of rail transport.

If we are talking about increasing the speed of rolling stock, one of the most important elements is safety. Article [5] deals with the safety of the new MONIT suspension hook system. Tests of this system were carried out on a railway line near the town of Zmigrod in Poland. This paper presents analysis of the results obtained from the tests of the rail vehicles' suspension monitoring system prototype.

Another possibility of accelerating rail passenger transport is the construction of new tracks, which would be reserved only for passenger transport. Article [6] deals with the possibilities of building new tracks within an urban agglomeration in China. The article also focuses on interventions in urban planning and compares the advantages and disadvantages. In Slovakia, the construction of any new line is still pointless, due to the lack of funds that go to the railway sector. The situation is different in the Czech Republic, and concrete steps are already being considered and steps are being taken to build high-speed lines.

High-speed lines and their rolling stock are a special option for speeding up passenger rail transport. This type of line is very costly in construction and the decision to build a high-speed line requires an extensive financial and economic analysis that demonstrates the need and return. Article [7] [8] deals with the possibility of testing a new high-speed electric unit. Testing is primarily focused on the passenger comfort indicator. At high speeds, it is necessary to pay attention not only to safety but also to this indicator. The experimental results show the good possibilities of excellent riding comfort if this train launches commercial line in service.

Acceleration of rail transport is also possible on the basis of the used rail vehicle. Article [9] deals with the possibilities of increasing the speed and comfort of rail transport on the Indian Railways network through the deployment of electric locomotives. The paper compares the dynamic properties of individual tractions using mathematical equations at different speeds. Such acceleration through traction exchange is small, but very necessary, also from an ecological point of view. In Slovakia, electrification of lines has been stagnant for a long time, but it is hoped that this will change, given the better use of Euro funds.

In the literature review, we have seen various possibilities for increasing the speed of rail transport. From the purchase of new vehicles, through the change of traction to the construction of new railways. Although these measures are effective, they are very economically and financially costly. In our article, we bring the possibilities of speeding up rail transport by much less costly measures of changing the train route.

3. Current State of Operation of the Zvolen - Košice Train Line

Since the change of the train timetable, trains have been added to the two-hour incomplete cycle in both directions on the basis of an order from the Ministry of Transport. Table 1 shows the current timetable of the train line in question.

Table 1

Timetable railway line Zvolen - Košice [1]

Railway station	RR 911	RR 915	RR 917	RR 919	RR 921	RR 923
Zvolen os. st.	**5:13**	**9:13**	**11:13**	**13:13**	**17:13**	**19:13**
Detva	5:31	9:31	11:31	13:31	17:31	19:31
Kriváň	5:35	9:35	11:35	13:35	17:35	19:35
Lučenec	**5:58**	**9:58**	**11:58**	**13:58**	**17:58**	**19:58**
	6:00	**10:00**	**12:00**	**14:00**	**18:00**	**20:00**
Fiľakovo	**6:12**	**10:12**	**12:12**	**14:12**	**18:12**	**20:12**
	6:14	**10:14**	**12:14**	**14:14**	**18:14**	**20:14**
Jesenské	**6:39**	**10:39**	**12:39**	**14:39**	**18:39**	**20:39**
	6:41	**10:41**	**12:41**	**14:41**	**18:41**	**20:41**
Číž kúpele	6:54	10:54	12:54	14:54	18:54	20:54
Tornaľa	7:10	11:10	13:10	15:10	19:10	21:10
Plešivec	**7:23**	**11:23**	**13:23**	**15:23**	**19:23**	**21:23**
	7:25	**11:25**	**13:25**	**15:25**	**19:25**	**21:25**
Rožňava	**7:38**	**11:38**	**13:38**	**15:38**	**19:38**	**21:38**
	7:40	**11:40**	**13:40**	**15:40**	**19:40**	**21:40**
Moldava nad Bodvou	**8:09**	**12:09**	**14:09**	**16:09**	**20:09**	**22:09**
	8:11	**12:11**	**14:11**	**16:11**	**20:11**	**22:11**
Košice	**8:38**	**12:38**	**14:38**	**16:38**	**20:38**	**22:38**

It follows from the timetable that the incompleteness of the two-hour cycle is caused by the interruption of this cycle at 7:13 and 15:13. Train departures from the departure station and train arrivals to the destination station are marked in red. Train stays at train stations longer than one minute are marked in green. All trains on this route are included in the commercial regional fast trains (RR) category.

Table 2 shows the current timetable of the train line in question in the opposite direction. For the sake of completeness, it should also be noted that a night train connecting Bratislava and Prešov still runs on this line in both directions.

Table 2

Timetable railway line Košice - Zvolen [1]

Railway station	RR 910	RR 912	RR 914	RR 918	RR 920	RR 922
Košice	**5:23**	**7:23**	**9:23**	**13:23**	**15:23**	**17:23**
Haniska pri Košiciach	5:34	-				
Moldava nad Bodvou	5:50	7:48	9:48	13:48	15:48	17:48
Rožňava	6:20	8:19	10:19	14:19	16:19	18:19
Plešivec	6:30	8:30	10:30	14:30	16:30	18:30
Tornaľa	6:44	8:44	10:44	14:44	16:44	18:44
Číž kúpele	7:04	9:04	11:04	15:04	17:04	19:04
Jesenské	**7:17**	**9:17**	**11:17**	**15:17**	**17:17**	**19:17**
	7:19	**9:19**	**11:19**	**15:19**	**17:19**	**19:19**
Fiľakovo	7:46	9:46	11:46	15:46	17:46	19:46
Lučenec	**7:58**	**9:58**	**11:58**	**15:58**	**17:58**	**19:58**
	8:01	**10:01**	**12:01**	**16:01**	**18:01**	**20:01**
Kriváň	8:26	10:26	12:26	16:26	18:26	20:26
Detva	8:30	10:30	12:30	16:30	18:30	20:30
Zvolen os. st.	**8:48**	**10:48**	**12:48**	**16:48**	**18:48**	**20:48**

The structure of the return schedule is quite different. For the first morning train, a train stop is added at the Haniska station near Košice due to the commuting of employees of the U. S. Steel Košice steel plant. At the same time, stays of more than a minute at most railway stations are shortened, but nevertheless the travel time is the same as in the direction Zvolen - Košice.

Fiľakovo railway station is located at the railway kilometer 146,309. There are a total of four passenger train platforms at this train station. They are level, which reduces the safety of passengers when boarding and alighting [10].

The following services are available to passengers at the Fiľakovo railway station [11]:

- bus stop;
- international and domestic sales of travel documents;
- station restaurant;
- sanitary facilities.

In determining time availability, isochrons are used, ie map lines connecting places with the same time value of attendance from a selected point [12]. According to the selected methodology, a distance of up to 7 minutes on foot is considered to be an attractive time-space availability of the stop in terms of regular attendance. Accessibility is limited in time, as the length of the pedestrian transfer is influenced by various factors, such as the elevation of the access road or its technical condition [13]. The overall accessibility of the railway station is expressed by the attraction circuit, while its upper limit is defined by a walking distance of up to 1,500 m. However, in order to reflect the increasing demands of the public on the quality of public passenger transport, we will consider the walking distance, speed, and walking time according to Table 3.

Table 3

Background for plotting isochrones of accessibility

walking distance	**500 m**
	1 000 m
walking duration	**6 min.**
	12 min.
walking speed	**5 km/h**

The data in Table 3 are the same for the Fiľakovo railway station and for the Fiľakovo zastávka railway stop. Fig. 1 shows the accessibility isochrones for the Fiľakovo railway station.

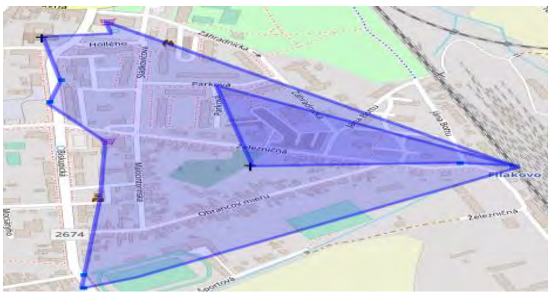


Fig. 1 Isochrons of accessibility within 500 m and 1000 m for Fiľakovo railway station

Based on Fig. 1, it is possible to identify in Table 4 the basic points that fall within the pedestrian accessibility we have determined.

Table 4

Availability from railway station Fiľakovo

Distance	Civic amenities
500 m	bus stop “Fiľakovo železničné stanica”
	cemetery
1 000 m	police station
	fire station
	bus stop “Fiľakovo pošta”
	post office
	two supermarkets
	car parks

An important element of functioning public passenger transport is the continuity of trains and buses. Table 5 provides an analysis of the continuity of rail and bus transport from the Fiľakovo railway station and the Fiľakovo bus stop, “Fiľakovo, železničné stanica” on a working day.

Table 5

Analysis of rail and bus transport links [14] [15]

Departure	To destination	It passes through the villages	Possible transfer from the train
5:27	Bus station Fiľakovo	bus with internal service of the town Fiľakovo	-
7:30	Lučenec	Fiľakovské Kováče, Holiša	
8:50	Rimavská Sobota	Šavoľ, Buzitka, Veľké Dravce, Husiná, Dolné Zahorany	
12:20	Dolné Zahorany	Šavoľ, Buzitka, Veľké Dravce, Husiná	RR 914, RR 917
14:15	Ožďany	Šavoľ, Buzitka, Veľké Dravce, Nové Hony	RR 919
14:50	Tachty	Šíd, Čamovce, Šurice, Hajnáčka, Gemerský Jablonec, Stará Bašta, Nová Bašta, Studená	
16:15	Dolné Zahorany	Šavoľ, Buzitka, Veľké Dravce, Nové Hony, Husiná	RR 918
16:19	Šiatorská Bukovinka	Biskupice, Belina, Radzovce, Čakanovce	
18:14			RR 920
21:25	Bus station Fiľakovo	bus with internal service of the town Fiľakovo	-
22:10	Rimavská Sobota	Šavoľ, Buzitka, Veľké Dravce, Husiná, Dolné Zahorany	
Arrival	**From destination**	**It passes through the villages**	**Possible transfer to the train**
5:27	Šiatorská Bukovinka	Biskupice, Belina, Radzovce, Čakanovce	RR 911
7:30			RR 910
8:35	Rimavská Sobota	Šavoľ, Buzitka, Veľké Dravce, Husiná, Dolné Zahorany	-
13:14	Šíd	-	RR 919
13:40	Sušany	Hrnčiarske Zalužany, Ožďany, Nové Hony, Šavoľ, Buzitka, Veľké Dravce	-
14:27	Fiľakovo, Novona	bus with internal service of the town Fiľakovo	
15:30	Rimavská Sobota	Šavoľ, Buzitka, Veľké Dravce, Husiná, Dolné Zahorany	RR 918
16:19	Bus station Fiľakovo	bus with internal service of the town Fiľakovo	-
18:14	Lučenec	Fiľakovské Kováče, Holiša	
21:25	Šiatorská Bukovinka	Biskupice, Belina, Radzovce, Čakanovce	

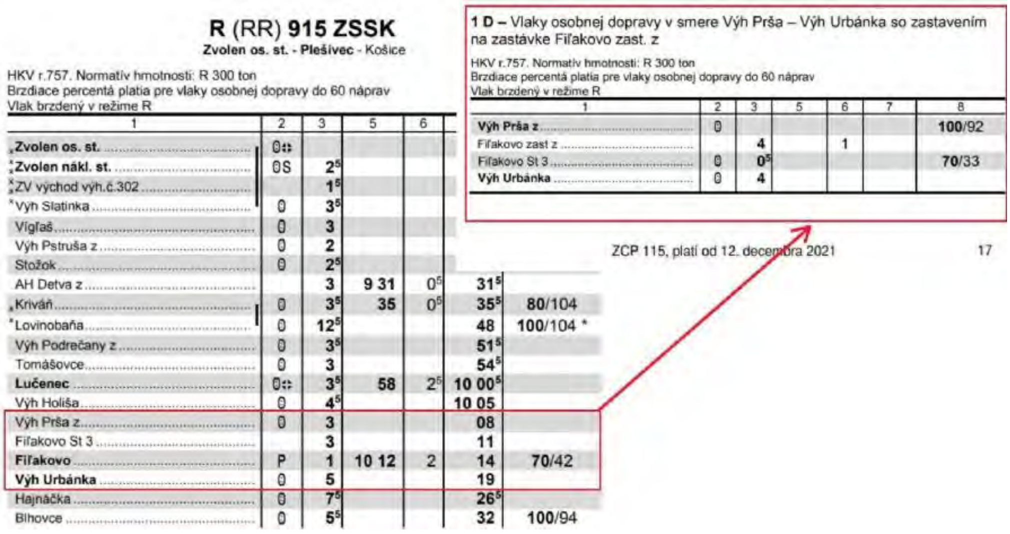
The table shows that the possibility of changing from train to bus or vice versa is not optimal. This option is not guaranteed for all connections. In addition, the bus service is very uneven in the morning, especially in the morning. Not one bus leaves / arrives at the bus stop between 9:00 and 12:00. It can be stated that the current situation is quite unsatisfactory.

4. Shortening of Travel Times by Redirecting Trains of the Zvolen - Košice Line Outside the Fiľakovo Railway Station

Around March 2022, the first reports of a change in the transport service of the town of Fiľakovo by rail began to appear. It is considered that from the second Sunday in December 2022, when the annual pan-European change of timetables is planned, the Zvolen - Košice line will change its route and will no longer serve the Fiľakovo railway station. An example of the proposed state is shown in Fig. 2.

Fig. 2 Drawing of the proposed measure for acceleration of trains on the railway line Zvolen - Košice [16]

According to the proposed model, the trains would stop at the Fiľakovo zastávka railway stop and then continue via switch 39 to the Urbánka turnout outside the Fiľakovo railway station. A comparison of the time saved can be seen in Fig. 3, which is a cut-out of the current and proposed timetables.



R (RR) 915 ZSSK
Zvolen os. st. - Plešivec - Košice

HKV r.757. Normatív hmotnosti: R 300 ton
Brzdiace percentá platia pre vlaky osobnej dopravy do 60 náprav
Vlak brzdený v režime R

1	2	3	5	6		
Zvolen os. st.	0					
Zvolen nákl. st.	0S	2^{5}				
ZV východ výh.č.302		1^{5}				
Výh Slatinka	0	3^{5}				
Vígľaš	0	3				
Výh Pstruša z	0	2				
Stožok	0	2^{5}				
AH Detva z		3	9 31	0^{5}	31^{5}	
Kriváň	0	3^{5}	35	0^{5}	35^{5}	80/104
Lovinobaňa	0	12^{5}			48	100/104 *
Výh Podrečany z	0	3^{5}			51^{5}	
Tomášovce	0	3			54^{5}	
Lučenec	0	3^{5}	58	2^{5}	$10\ 00^{5}$	
Výh Holiša	0	4^{5}			10 05	
Výh Prša z	0	3			08	
Fiľakovo St 3		3			11	
Fiľakovo	P	1	10 12	2	14	70/42
Výh Urbánka	0	5			19	
Hajnáčka	0	7^{5}			26^{5}	
Bilhovce	0	5^{5}			32	100/94

1 D – Vlaky osobnej dopravy v smere Výh Prša – Výh Urbánka so zastavením na zastávke Fiľakovo zast. z

HKV r.757. Normatív hmotnosti: R 300 ton
Brzdiace percentá platia pre vlaky osobnej dopravy do 60 náprav
Vlak brzdený v režime R

1	2	3	5	6	7	8
Výh Prša z	0					100/92
Fiľakovo zast z		4		1		
Fiľakovo St 3	0	0^{5}				70/33
Výh Urbánka	0	4				

ZCP 115, platí od 12. decembra 2021 17

Fig. 3 Comparison of current and proposed state in the context of time saving [17]

It follows from the above that the time saved is not as significant as expected. When the train runs through the Fiľakovo railway station, its travel time between the Prša turnout and the Urbánka turnout is 11 minutes, including a two-minute stop at the railway station. When the train runs outside the Fiľakovo railway station, the journey time on the same section of the line is a total of 9.5 minutes, including a one-minute stop at the Fiľakovo zastávka railway stop. This results in a saving of 1.5 minutes.

Another important factor is the availability for other modes of transport, ie bus transport. In Fig. 4, the availability isochrones are generated based on Table 3.

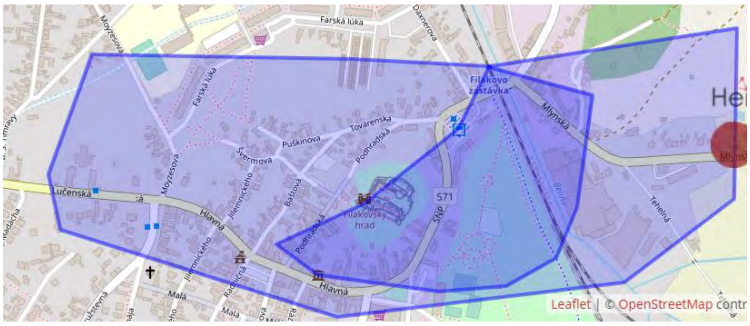


Fig. 4 Isochrons of accessibility within 500 m and 1000 m for Fiľakovo zastávka railway stop

Based on Fig. 4, it is possible to identify in Table 6 the basic points that fall within the pedestrian accessibility we have determined.

Table 6

Availability from railway stop Fiľakovo zastávka

Distance	Civic amenities
500 m	bus station
	restaurant
	castle
	park with small zoo
	car parks
	tourist information centre
1 000 m	bank
	accommodation
	library
	gymnasium
	supermarket
	church

In the immediate vicinity of the railway stop there is a central bus station, which is served by all bus lines that pass through Fiľakovo. At the same time, we can see from Table 6 that civic amenities are at a higher level and passengers have at their disposal several services within walking distance of a maximum of 1,000 m.

One of the main disadvantages is the non-existent sale of travel documents. As passengers have at their disposal the sale of international and domestic travel documents at the Fiľakovo railway station, it is necessary to ensure at least the national sale of travel documents at the Fiľakovo zastávka railway stop. It can also be outsourced if it is more economical. However, this is the subject of further research.

Another disadvantage, due to which the inhabitants of Fiľakovo wrote a petition, is the gradual reduction of railway transport at the Fiľakovo railway station. The truth is that transit freight is already being diverted outside the Fiľakovo railway station and passenger transport has been cancelled on the Fiľakovo - Somoskoújfalu (Hungary) railway line since 2011. On the other hand, the railway station also includes a locomotive depot, which maintains the station's position despite the declining performance of passenger rail transport. At the same time, the route through the railway station can be used at the time of the triangle.

5. Conclusions

The aim of the article was to point out the possibilities of accelerating the Zvolen - Košice train line. On this train line, it is possible to change the route outside the Fiľakovo railway station. However, due to the service of the town of Fiľakovo by rail, it is necessary for the train to stop at the Fiľakovo zastávka railway stop. This has several key advantages (save time 1.5 minutes; the immediate vicinity of the bus station; better civic amenities; better use of the town's tourist potential; the possibility of using the passage through the railway station in case of exclusion on the triangle) and disadvantages (absence of sale of travel documents; short train stays; reducing the importance of the railway station Fiľakovo; the possibility of creating a traffic jam at the closure of a level crossing by a train; increasing the risk of a train-car collision at a level crossing).

The isochrones of availability also proved the advantage of this step. At the same time, however, it is necessary to eliminate or at least minimize these shortcomings before starting the entire project.

Acknowledgment

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Fatigue Analysis of a Tanker Semi-Trailer Structure

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Abstract

Vehicle structures are subject to a wide range of loads. From the resistance forces in bearings, friction between parts, loads due to road irregularities, etc. The structure of the semi-trailer tanker is subject to stresses caused by the fluid being transported, which are not predictable. Therefore, it is important that the design of the support structure takes into account the variable loads and fatigue loads imposed on the vehicle.

In this work, a fatigue study is conducted on the structure of a semi-trailer for a food tanker, one of the tractor semi-trailer types. This paper analyzes the methods of random fatigue analysis and its application. The main methods used to perform the analysis are identified. The importance, conditions, and essential structural aspects of the use of tanker semi-trailers are analysed. The artificial path that randomly varies, the dynamic equations of motion, and the dynamic model were described using Matlab software. After calculating the loads due to the path (power spectrum), this is applied in Ansys. The natural frequencies and stresses calculated from the power spectrum are then applied to the fatigue study of the tanker semi-trailer structure.

KEY WORDS: *fatigue, random load, power spectral density, semi-trailer, tanker, truck.*

1. Introduction

Components subjected to random load fatigue (using PSD or sinusoidal) are often designed and tested using numerical platforms to estimate life expectancy, cycle counts, and ensure the performance of the mechanical system. Finite element modelling requires the use of a number of parameters (material properties such as Young's modulus, density, stiffness of connections between components, choice of model element, etc.) to solve the problem. Some of these parameters are determined by testing with inherent uncertainty, while others have inherent variability. It is important to be aware of the impact of this variability/uncertainty on the model responses. In order to investigate the robustness of the design, innovative methods have been developed to determine the sensitivity of the model responses to uncertain parameters.

It is common practice to investigate the commonly calculated stresses, loads and the resulting damage to the structure. There is a wide range of structural damage and distortion. One type of structural damage is fatigue fractures, stress concentrators. These can be addressed in a variety of ways, both theoretical and practical, for example, by studying a structure subjected to deterministic periodic sinusoidal or complex periodic loading. In simple terms, a single numerical value of amplitude. Unfortunately, this aspect does not take into account real-life conditions, and it should be noted that this aspect is much more complex and requires more than one method to describe fatigue due to randomly varying loads. Teixeira et al. in their work [1], described the main concepts that need to be evaluated to investigate fatigue due to random small loads (vibration), which will be discussed in more detail in the paper. Article [2] provides a definition of fatigue: fatigue is localized structural damage that occurs when a structure is subjected to cyclic loads, and fatigue fracture is one of the most common causes of failure of machinery in everyday life. [2] states that in the automotive industry, it is mandatory to estimate the lifetime of the required components to be able to design long-life parts in the first stage of development. Automotive design engineers often assess the fatigue life of vehicle components or the whole vehicle by means of individual component fatigue tests or whole vehicle driving simulations, but these assessment methods can make it difficult to detect damage in a timely manner due to the time and money constraints involved. Consistent with the authors of reference [2], it can be argued that virtual fatigue analysis using finite element analysis can reduce the time and money spent in the development phases of new vehicles or vehicle components. The paper [3] states that fatigue damage is usually assessed by time and load signals, usually in the form of structural stresses. This aspect is appropriate for periodic loading, but random loading testing requires a very long time record to accurately characterise the loading process. For the latter reason, it may not be possible to perform a numerical finite element analysis, especially when modelling dynamic resonance [3]. Suggests an alternative, which is to use frequency domain fatigue calculation, where random load and result (response, output) are categorised as power spectrum density (PSD) functions and dynamics are modelled as linear transfer functions. Arguments in support of this idea can be found in other references [4-10].

System dynamics can be expressed in either frequency or time domain, but calculating body dynamics in the time domain requires a large amount of time, time-interval data and produces large amounts of output data. On the other hand, body dynamics in the frequency domain can be calculated more easily and quickly using the structure transfer function.

The purpose of the work is to investigate the response of the semi-trailer support structure to varying loads and to calculate the fatigue analysis of the structure. Objectives:

1. Determine the capacity of the support structure of the tanker semi-trailer.
2. Calculate the load power spectrum.
3. Perform an analysis of the natural frequencies of the support structure of the tanker semitrailer.
4. Perform a fatigue analysis of the tanker semi-trailer support structure.

2. The Fourier Transformation

The Fourier transformation (FT) is an important tool in mathematics, physics, computer science, chemistry, and the medical and pharmaceutical sciences [11, 12]. FT provides an alternative representation of a function or signal, i.e., it shows how any waveform/function can be rewritten as the sum of simple sine and cosine functions. The paper [13] states that the application of the Fourier transformation allows the calculation of the spectrum of any signal by decomposing the signal into a sum of elementary oscillations. When the signal is nonperiodic, the result is a continuous spectrum, and the continuous spectrum is described by a spectral density function [14]. The FT and its inverse Fourier transformation (IFT) allow a signal to be transformed from the time domain to the frequency domain and vice versa. For a wavelength T of which N uniform samples are imaged over a uniform time interval $\Delta = T/N$, the discrete Fourier transformation (DFT) can be written as follows [15, 16]:

$$X_k = \frac{1}{N}\sum_{j=0}^{N-1} x_j e^{-i\left(\frac{2\pi jk}{N}\right)}; \tag{1}$$

$$f_k = \frac{k}{T}\left(k = 0 : N-1\right), \tag{2}$$

where x_j is the coefficient of the discrete time series; X_k is the complex discrete Fourier coefficients; f_k is the frequency associated with each complex coefficient.

The results computed by the discrete Fourier transform will be discrete, i.e. an array of numbers. If the signal is non-periodic, the result is a function of the spectral density [16]. Depending on whether only the amplitude signal is analysed, or whether the phase signal is analysed as well, the representation in the frequency domain will differ. In the present work, the amplitude is relevant and the latter is symmetrical with respect to the origin, so the spectral density function is mapped only in the positive frequency band [16]. This function is usually evaluated using a fast Fourier transform algorithm, which greatly increases the software computational speed [17]. If it is clear from the signal that the function is a power function, plotting the amplitude of X_k shows the frequency of the function. Engineers use this information to design structures and components so that their natural frequencies (also known as resonant frequencies) are far from the frequencies of the peak load. If the system operates as a linear function of a time variable, its response is a frequency response function (FRF), denoted by $H(f)$, which converts the input function $x(f)$ into an output $y(f)$. The finite element method (FEM) is commonly used to calculate the FRF. If the forcing function is not deterministic, its magnitude and phase vary randomly. The best way to represent this is then to use the PSD periodogram, which is the power distribution of the signal over the frequency range. The PSD discrete frequency f_k is related to the Fourier coefficient [16]:

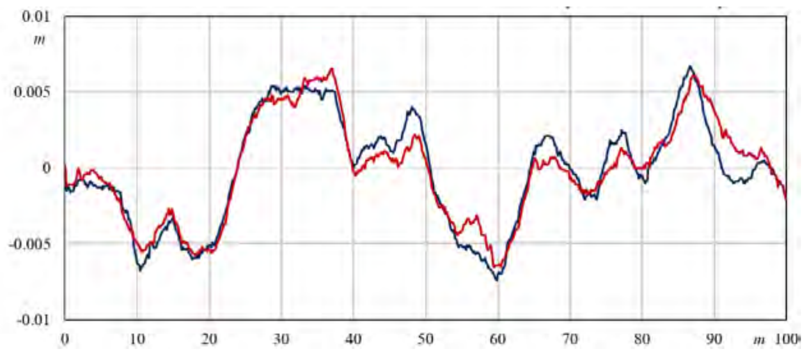
$$G_x\left(f_k\right) = 2TX_k^* X_k, \tag{3}$$

where, X_k^* is the complex conjugate of X and G; G_x is the PSD function.

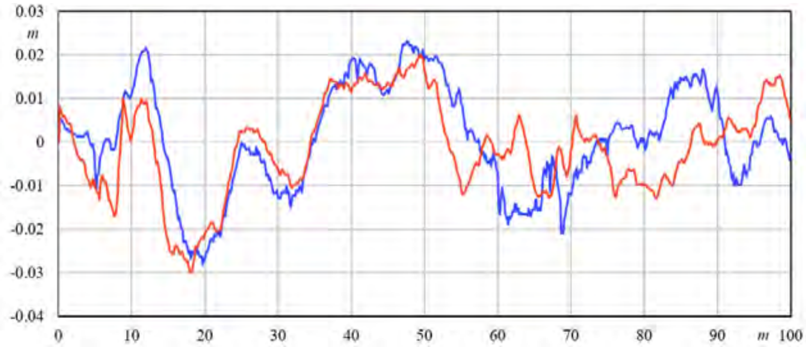
3. Road Description

Determining the durability of vehicle components often requires a description of the specific load. It is desirable to have a model of the loading environment that is independent of the vehicle and that can be composed of many components, such as driving behaviour, road roughness, hills, radius of curvature, load imposed by the load, etc. Typically, stochastic models are used to describe the variability of the measured track profile; in particular, Gaussian distribution processes are often used. Thus, assuming that the car is in a stationary state, the constant speed and the linear relationship between the road surface and the vehicle reactions are also stationary and consistent with a Gaussian process. [18]. Typically, stochastic models are used to describe the variability of the measured track profile, and in particular, Gaussian distribution processes are often used. Thus, assuming that the car is in a stationary state, the constant speed and the linear relationship between the road surface and the vehicle reactions are also stationary and consistent with a Gaussian process. However, the measured profiles are not accurately represented by a stationary Gaussian model. One way to solve the problem, which is followed by many authors, is to model the road surface with a stationary Gaussian process only in situ. By this we mean that the surface can be divided into short and variable length Gaussian sections. Furthermore, it can be assumed that the segments have the same normalised spectral density but with different variances. Assuming that the standard deviations of the narrow sections are random, the resulting road roughness model is non-Gaussian and heterogeneous. If the segments are relatively long, then the transients caused by the transition deviations can be neglected, and standard tools developed for Gaussian processes can be used for practical computation [18].

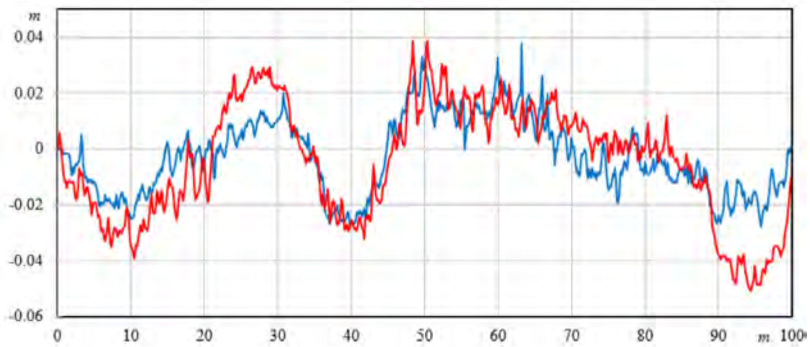
For the tanker semi-trailer vibro-frequency simulation, microprofile recordings of real Lithuanian roads were used: smooth asphalt, rough asphalt and gravel road (Fig. 1) Records were obtained from road surface measurements with a DYNATEST 5051 RSP laser profilograph. As road profile records are also characterised by distinctive, section-specific features, the possibilities of formalising the road microprofile profile by extracting typical features of road surfaces of different qualities have been explored. The formalisation of the road inventory takes into account the fact that road microprofile records are discrete, with a relatively large step size-information on the height of the micro-roughness at a single defined line, according to the International Roughness Index (IRI) calculation methodology, is recorded every 0.147 m [19-21].



a



b



c

Fig. 1 Longitudinal microprofile of the road: a − smooth asphalt; b – uneven; c − gravel road; red-right wheel, blue-left wheel

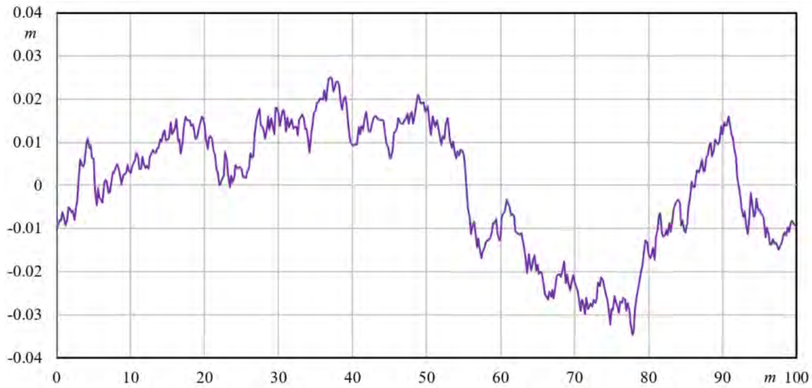
According to ISO 8608:2016, roads are divided into 8 categories based on angular spatial frequency, named A to H inclusive, according to the English alphabet. A corresponds to the highest class of road and H to the lowest [22]. According to ISO 8601, the PSD of a random profile path can be written as follows:

$$G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-W}, \tag{4}$$

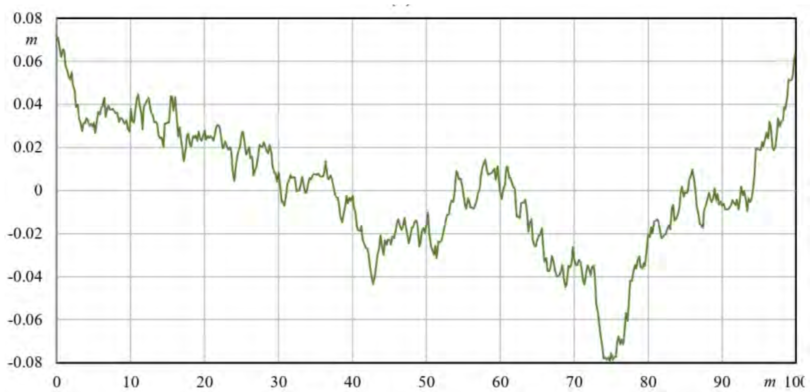
where n is the spatial frequency, n_0 is the reference frequency with a value of 0.1 m^{-1}, $G_q(n)$ is the PSD value at n spatial frequency, and W is the waviness, which represents the frequency structure.

For practical use, according to the ISO classification of road roughness pavements, an artificial road profile can be created from a stochastic image by considering the power spectral density (PSD) function of the vertical displacements obtained using the Fourier transform of the stochastic process describing the road profile, correlation function [22].

For the generation of the road roughness, Matlab software is used to write the programming code, following the methodology discussed above, for the road design. Examples of the road generated using Matlab are shown in Fig. 2. To evaluate the different time moments, it is necessary to calculate how long it takes the vehicle to travel the distance between the axles. The time is deducted from the velocity expression because the vehicle speed and the distances between the axles are known. The first axis will experience the vertical excitation given above without time difference.



a



b

Fig. 2 Fragments of an artificially generated road micro-profile: a − category C road; b − category D road

4. Development of an FE Model of a Liquid-Filled Tanker Semi-Trailer

The subject of this study is the support structure of a tanker semi-trailer. The model shall be designed using the computer program SolidWorks. The tank-semitrailer has a capacity of 33000 litres. The tanker is divided into three compartments. The capacities are: 11000 l / 7500 l / 14500 l. The tanker fill level is 80% in the first and third compartments and 20% in the second. The tanker shall be of LDX 2101 stainless steel. This metal has a yield strength of 580 MPa and an ultimate strength of 769 MPa. The tanker must be cylindrical in shape with a cylinder diameter of 2000 mm. The outer shell is 2.5 mm thick, the bulkheads are conical, and the ends are cylindrical (Fig. 3).

Fig. 3 CAD model of a tanker semi-trailer

The dynamic computational model consists of a geometric model of finite elements, plus external loads that act on the tanker-trailer, the boundary conditions due to the vertical excitation of the road (Fig. 1 and 2), and the dynamic elastic and damping elements of the chassis (Table 1). In the numerical model of the tanker-semitrailer, the mechanical characteristics of the base metal LDX 2101 are assigned to the finite elements, while in the elastic deformation zone and in the case of cyclic loading, the materials are characterised by the mechanical characteristics determined by the mechanical tests on the materials. The damping and stiffness of the semi-trailer suspension was selected based on the manufacturer's data and for the rest of the elements based on references from the literature references [23-26].

Table 1

Dynamic characteristics of tanker semi-trailer

Stiffness of the truck's rear suspension	k_2, N/mm	1122
Truck rear suspension damping	c_2, N·s/mm	54
Truck rear tyre stiffness	k_{12}, N/mm	4250
Truck rear tyre damping	k_{12}, N·s/mm	6
Unsprung mass of the rear axle of the lorry	m_2, kg	1100
Semi-trailer suspension stiffness	c_2, N/mm	97
Semi-trailer suspension damping	k_2, N·s/mm	45
Semi-trailer tyre stiffness	c_{13}, N/mm	850
Semi-trailer tyre damping	k_{13}, N·s/mm	3
Unsprung mass of semi-trailer axle	m_3, kg	550

Ansys Workbench/Mechanical computer software is used to build the FE model. Since the vertical random excitation analysis and the power spectrum have been performed, the chassis is not evaluated and the load can be applied immediately to the tanker semi-trailer superstructure. From the CAD tanker semi-trailer model, a finite element mesh model is created, consisting of 177187 nodes and 158653 elements.

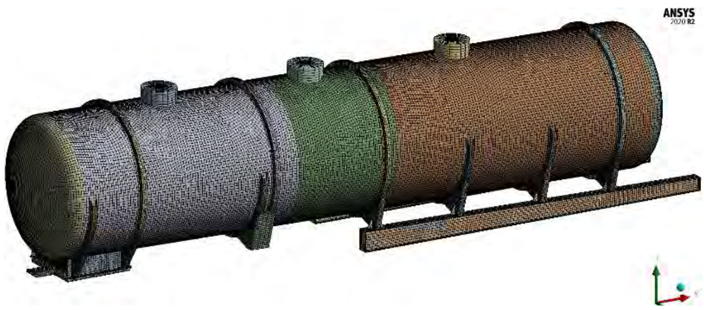


Fig. 4 FEM model of a tanker semi-trailer

In the finite-element model, degree of freedom constraints are imposed on the investigations. It allows free motion only in the Y-axis direction (vertical). An additional frictionless support shall be added at the tanker-trailer coupling point. The stiffnesses of the springs, coupling, and chassis modelled in the Y-axis direction have been calculated and are shown in Table 1.

5. Calculations of the Eigenmodes and Frequencies of a Liquid-Filled Tanker Semi-Trailer

The finite element mesh of a liquid-filled tanker semi-trailer is used to calculate the eigenmodes and frequencies of the vibrations. This calculation does not take into account the displacements presented. From the calculations performed, only the most significant results have been extracted according to the mass participation factor/coefficients. Of the 30 mode calculations, 3 states are significant, with a total mass participation factor of 87% of all mass participation factors. Therefore, it can be assumed that these three modes are the most significant and that the rest of the calculations are insignificant and do not need to be evaluated (Fig. 5).

***** MODAL MASSES, KINETIC ENERGIES, AND TRANSLATIONAL EFFECTIVE MASSES SUMMARY *****

				EFFECTIVE MASS					
MODE	FREQUENCY	MODAL MASS	KENE	X-DIR	RATIO%	Y-DIR	RATIO%	Z-DIR	RATIO%
1	4.376	8.230	3112.	0.3586E-04	0.00	0.1642E-04	0.00	20.80	75.04
2	5.388	11.87	4804.	0.6254	2.26	19.74	71.22	0.2758E-04	0.00
3	10.95	5.522	0.1308E+05	0.1381E-03	0.00	0.3504E-05	0.00	1.793	6.47
4	19.53	6.145	0.4627E+05	21.78	78.57	0.2581	0.93	0.5965E-03	0.00
5	20.81	6.010	0.5135E+05	0.7682E-02	0.03	0.1067E-03	0.00	1.521	5.49
6	25.13	3.913	0.4877E+05	1.090	3.93	0.7846	2.83	0.3807E-05	0.00
7	25.76	5.238	0.6859E+05	0.1408	0.51	1.829	6.60	0.6827E-05	0.00
8	26.94	0.7943	0.1138E+05	0.7979E-05	0.00	0.1199E-04	0.00	0.8694	3.14
9	28.20	2.382	0.3738E+05	0.1717E-01	0.06	0.4866E-03	0.00	0.1332E-06	0.00
10	29.50	1.709	0.2935E+05	0.2590	0.93	0.7726E-01	0.28	0.2379E-07	0.00
11	30.47	0.6120	0.1122E+05	0.5396E-06	0.00	0.1570E-05	0.00	0.2095	0.76
12	31.24	1.308	0.2521E+05	0.2277	0.82	0.5332	1.92	0.1659E-07	0.00
13	32.25	2.047	0.4202E+05	0.2462E-01	0.09	0.7429	2.68	0.4071E-05	0.00
14	33.76	0.7469	0.1681E+05	0.1567E-01	0.06	0.3045E-01	0.11	0.2562E-05	0.00
15	33.90	1.831	0.4154E+05	0.5584E-06	0.00	0.2623E-05	0.00	0.4117E-02	0.01
16	34.55	2.527	0.5956E+05	0.1496E-01	0.05	0.1661	0.60	0.2593E-05	0.00
17	34.80	2.507	0.5993E+05	0.1008E-05	0.00	0.2487E-05	0.00	0.1349	0.49
18	35.96	1.636	0.4174E+05	0.8029	2.90	0.3027E-02	0.01	0.1096E-04	0.00
19	36.09	1.745	0.4485E+05	0.7862E-02	0.03	0.4473E-02	0.02	0.1991E-05	0.00
20	36.47	0.8124	0.2133E+05	0.1766E-06	0.00	0.4320E-06	0.00	0.3799E-02	0.01
21	36.86	2.252	0.6038E+05	0.5126E-04	0.00	0.3703E-06	0.00	0.2890	1.04
22	37.69	1.845	0.5175E+05	0.4722E-01	0.17	0.3212E-02	0.01	0.3209E-05	0.00
23	38.12	0.4013	0.1151E+05	0.5290E-05	0.00	0.9335E-07	0.00	0.3223E-02	0.01
24	38.66	0.3057E-01	901.7	0.3166E-04	0.00	0.2074E-06	0.00	0.7254E-03	0.00
25	38.71	0.9290	0.2748E+05	0.1142	0.41	0.4855E-03	0.00	0.2218E-05	0.00
26	39.05	2.286	0.6881E+05	0.1350E-05	0.00	0.1580E-09	0.00	0.1008E-01	0.04
27	39.67	2.040	0.6337E+05	0.1116E-05	0.00	0.9478E-06	0.00	0.2495E-01	0.09
28	40.12	1.520	0.4828E+05	0.1868E-05	0.00	0.4461E-05	0.00	0.2269	0.82
29	40.23	0.3964	0.1267E+05	0.5518E-01	0.20	0.3498E-01	0.13	0.1004E-07	0.00
30	40.32	1.341	0.4304E+05	0.8888E-05	0.00	0.2855E-05	0.00	0.1144	0.41
sum				25.23	91.02	24.21	87.35	26.01	93.82

Fig. 5 Ansys/Workbench table of natural frequencies

From Fig. 5, it can be observed that of the 30 shapes and frequencies calculated, the mass participation rate in the X and Z directions is 91.02% and 93.82% respectively, and in the Y direction 87.35%. In percentage terms, in the X, Y and Z directions, the 4, 2 and 1 modes are 86.32%, 81.53% and 79.98% respectively. According to these results, these 3 modes are the most significant in the eigenfrequency analysis. The calculation of the eigenfrequency modes and frequencies of the tanker-trailer has resulted in 3 main states that are most at risk from potential resonance.

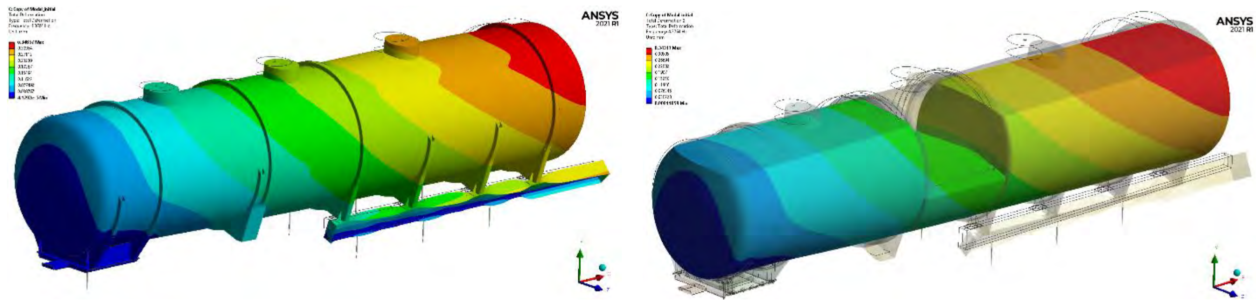


Fig. 6 The first eigenmodes and frequency (4.38 Hz)

6. Calculations of Random Dynamic Loads and Fatigue for Tanker Semi-Trailer Filled with Liquid

In this step, the response of the support structure to the applied excitation spectra in the Y direction is calculated. The excitation power spectra are further adapted from previously performed frequency and shape mode calculations. Different power spectra are applied at the mounting locations of the coupling and the chassis. The following figure shows how much PSD is applied to the calculations and what results are obtained.

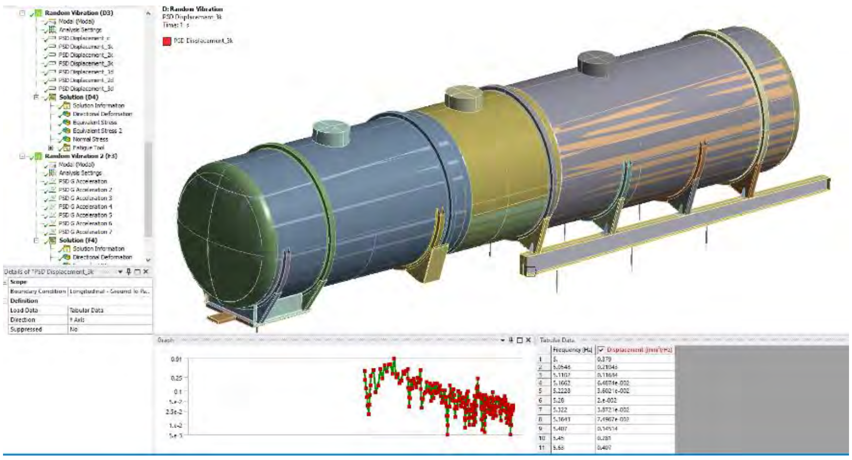


Fig. 7 Random excitation load

The analysis provides results that follow a normal distribution. According to this theory, it is assumed that the stresses, displacements in the 1σ range will not exceed the calculated stresses and displacements 68.26% of the time. Fig. 8 shows the results of the equivalent stresses after applying knee PSD and natural frequency excitation. For the 1σ case, the resulting stresses are 37.8 MPa, for the 2σ case 75.7 MPa, and for the 3σ case 113.5 MPa. This means that 99.72% of the time, the stresses will not exceed 113.5 MPa.

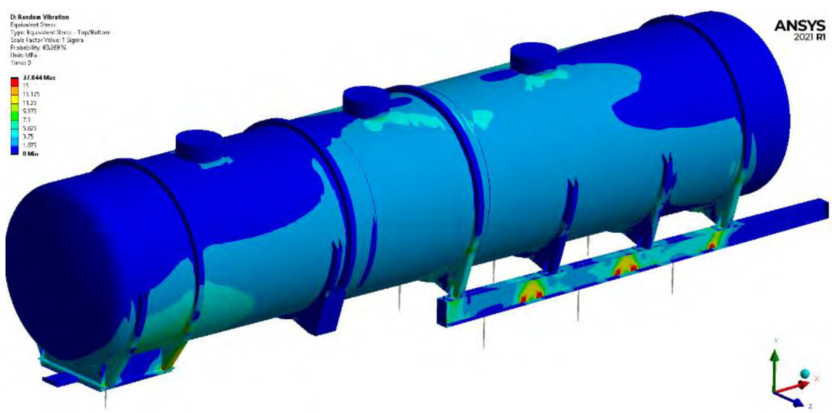


Fig. 8 Normal stresses for 1σ distribution

In the final stage of the calculation, the calculated PSD can be applied to the fatigue calculations of the supporting structure. The fatigue calculation is carried out using the Ansys Workbench - Random vibration - Fatigue tool. At this stage, the total life in seconds and the damage are obtained. The lifetime indicates how long a given point will be undamaged. According to the theory, the tanker's supporting structure is only as strong as the weakest point of the tanker. Fig. 9 shows the calculation of the fatigue life of a tanker. The red distributions at the anchorages indicate the weakest points in the structure.

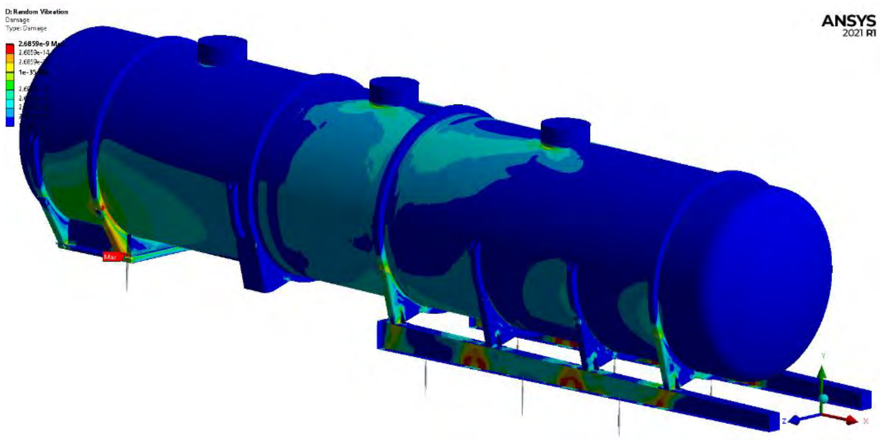


Fig. 9f Damage of structure caused by fatigue

Fatigue damage is mapped at the point with the lowest lifetime. At an initial speed of 90 km/h, the vehicle would have traveled 9 307 980 km before suffering fatigue damage. According to the results, the most problematic areas are in the frame. In particular, special attention must be given special attention. Weld fatigue could also be addressed and improvements could be made to the frame.

7. Conclusions

After analyzing the main methods for random fatigue calculations and the literature on the calculations performed, the main calculation methods were selected. A faster and less resource-intensive solution is frequency domain analysis using PSD. The design of the tanker and their types and requirements have been analysed. Tanker semi-trailers are basically classified according to the type of cargo, number of chambers, and breakwaters.

The Matlab code used to describe the road generates a random class 6 (D-E) road for a truck with a tanker-trailer travelling at 90 km/h. The road is generated randomly. Once the path has been generated, a delay is applied according to the calculated results. The result is that the first axle overtakes the second axle in 0.104 seconds, and the third axle in 0.424 seconds.

In order to calculate the power spectrum of the random excitation, a dynamic model of the car has been built, and a Matlab/Simscape model has been developed. The Simscape model was fitted with the previously generated path and the random excitation power spectrum was obtained and applied to the semi-trailer fatigue calculation.

The eigenfrequency analysis showed that, according to the mass distribution table, out of the 30 calculated states, 3 are the most important: 1, 2, 4. These shapes have the greatest influence on the oscillation in the Z-, Y-, X-axis directions. The most important form is 2, because the track profile and the load act on the Y axis.

A fatigue test on a tanker-trailer has shown that the load-bearing structure will perform its function for up to 103422 h or 9307980 km on a Class D road at a speed of 90 km/h. The damage to the tanker is 2.7e-9, indicating that the load-bearing structure of the tanker semi-trailer is still serviceable after this distance. The most problematic areas of the structure are the frame, the anchorages and the welds.

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Photocatalytic Disinfection: Direction for the Treatment of Ship "Greywater" from Pathogens and Difficult-to-Degrade Organic Compounds

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Abstract

Ship's sewage consists of "black water" and "greywater" that contain bacteria, viruses, detergents, and microplastic particles. Untreated ship's sewage, which is more concentrated than the land-based wastewater, makes release into the marine environment more alarming. Therefore, sewage disinfection is a crucial challenge for humanity to combat pollution of pathogens and persistent organic pollutants. There is an urgent need for sewage treatment methods that are more efficient and environmentally friendly. Strong oxidizing radicals whose formation is based on photocatalytic technologies are very promising. The paper aims to provide an overview of photocatalytic technologies treating pathogens, including transfer of severe acute receptive syndrome coronavirus 2 (Covid-19) and persistent organic pollutants in ship's greywater.
KEY WORDS: *sewage, pollutant, semiconductor-assisted photocatalysis, antimicrobial agents, titanium dioxide*

1. Introduction

Shipboard sewages are much more concentrated than onshore effluents. Onshore effluents were formed from groundwater infiltration, rainwater, and greywater from households. In addition, ship vacuum collection systems increase concentration even higher, making ship sewage the most concentrated in all sectors [1].

The prevention of pollution of ship-generated effluents has been governed since 2003 by the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex IV. In Annex IV to MARPOL 73/78 ship sewage includes both "black water" and "greywater". "Black water" relates to the sewage from toilets and urinals and drainage from medical premises, and drainage from spaces containing living animals or other wastewaters when mixed. "Greywater" represents drains from washbasins, galley sinks, showers, laundries, baths, and washbasin drains but does not include "black water" [2]. The amount of greywater produced depends on the type of vessel. It can range from 105 L (e.g., from a tanker) to 254L (e.g., from a cruise ship) per person per day [3-5]. Regulations do not apply to the discharge of greywater [5]. The information published by MEPC 74/14 (Norway) and MEPC 71 / INF.22 (Netherlands) on poor wastewater quality is a cause for concern, revealing a huge gap between the rules developed by the IMO and the reality that exists. Coliform bacteria in the STP samples were found to be 10 million to one billion times larger than specified in the effluent standard [2]. Although, a review by the IMO draws attention to the various waste streams from a ship that can cause microplastic pollution. A particular concern is cruise ships, as they carry a large number of passengers and generate a large amount of waste compared to other ships [6, 7]. It should be emphasized that ship greywater may also contain pharmaceuticals, per-, and polyfluoroalkyl groups, and toxic and environmentally hazardous chemicals used in disinfection and cleaning operations during ship operation that are harmful to aquatic organisms [8, 9].

Physical or chemical disinfectants may be used for disinfection. In practice, chlorine or chlorine compounds are most used onboard to kill most microorganisms. During the disinfection process, chlorine reacts with organic substances to form trihalomethane (THM), which is a carcinogenic compound. Chlorination can also nitroso dimethylamines (NDMA), a development associated which human cancer. Furthermore, certain bacteria have been discovered to be immune to such chemical materials. If these substances reach the sea, they are dangerous to marine organisms and the ecosystem [10, 11]. A dechlorination step is required to keep the chlorine concentration below the 0.5 mg / l limit. However, some chlorine-based sewage treatment plants do not have a dechlorination stage [10, 11].

Security measures in the field of sanitation have always been followed by passenger ships. However, with the covid-19 pandemic raging, cruise passengers and crew and the cruise industry were at the forefront. Cruise vessels with many passengers and crews became Covid-19 incubators, and infections on vessels such as Diamond Princess were described as floating nightmares [7].

Water disinfection is currently a major challenge for humanity. There is an urgent need for methods that are effective, inexpensive, environmentally friendly, and do not promote gene exchange between bacteria. To achieve this, strong oxidizing radicals are promising in this regard [13].

1.1. Photocatalysis and Photocatalysts

Photocatalysis is a catalytic process that takes place under the influence of catalysts and light. The main principle of this process can be explained by the widely accepted theory. The process is based on the ability of a photocatalytic material to absorb photon energy more than its bandgap energy and to generate electron and hole pairs. These materials form a family of photocatalysts. The formation of electron and hole pairs promotes the formation of particles such as hydroxyl radicals (OH*) and superoxide anions (O2-), which promote oxidation-reduction processes. It should be mentioned that the photocatalyst does not undergo any chemical changes during and after the reaction.

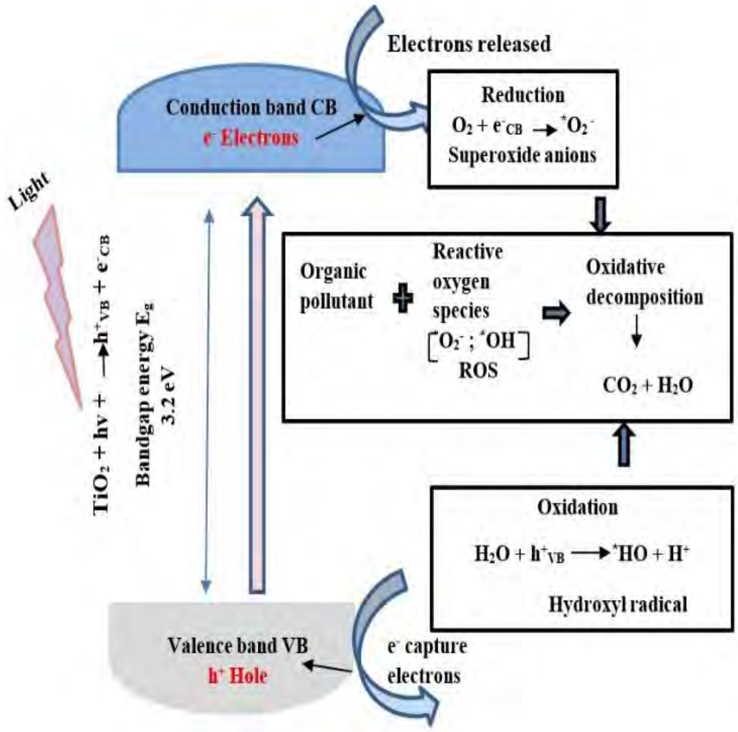

Fig. 1 Principle of operation of TiO_2 photocatalysts

As early as the 1970s, the Japanese scientist Akira Fujischima discovered that titanium dioxide (TiO_2) had photocatalytic properties, but a few years later it was discovered to attract water molecules, namely hydrophilic properties [14].

TiO_2 has almost all the properties required for an ideal photocatalytic material [15], making it the most studied material for photocatalysis. The use of titanium dioxide in electrochemical cells is based on the transfer of electrons from the valence band (e_{VB}^-) to the conductivity band (e_{CB}^-) under the influence of UV or VIS activated. The wavelength of light is related to the energy of light - the shorter the wavelength, the higher its energy. Thus, the photocatalyst will receive less energy in visible light than if it were used in UV at the same radiation intensity. Therefore, most photocatalysts are more active in UV than in VIS. The absorption of a photon with an energy of $h\nu \geq Eg = 3.2$ eV on the surface of titanium dioxide causes several reactions with a complex mechanism, including many different steps. However, basically (Fig. 1) in the process of reduction of organic pollutants oxygen receives electrons and an oxygen radical is formed, which reduces the molecules of organic compounds.

However, basically (Fig. 1) in the process of reduction of organic pollutants oxygen receives electrons and an oxygen radical is formed, which reduces the molecules of organic compounds.

1.2. Photocatalytic Action on Microorganisms and Viruses

Since December 2019, the new coronavirus 2 (SARS-CoV-2) or COVID-19, a severe acute respiratory syndrome, has taken over the world globally. It is a positive-chain ribonucleic acid (RNA) virus with a crown-like appearance under an electron microscope due to the presence of sharp glycoproteins on the shell. The major route of transmission of the Covid-19 virus is by human-to-human inhalation. Based on its symptoms, the transmission may also occur with airway droplets and aerosol transmission. Diseases caused by Covid-19 are predominantly respiratory, but symptoms may include cough, fever, nausea, and diarrheal. For this reason, researchers have focused on different modes of transmission, including wastewater. The first Covid-19 viruses were discovered in hospital wastewater by Dutch scientists, and then in other countries [16, 17]. It should be noted that contaminated effluents with this dangerous virus must be specifically disinfected, as they can pose chemical, biological, and physical risks to public and environmental health. Unfortunately, due to the small size and unique properties of viruses, it is difficult to remove and deactivate them. The chlorination technique is one of the most common viral disinfection methods using chlorine gas, chloramines, or hypochlorite solution. A previous study reported that chlorination can remove SARS-CoV-1 effectively [18]. Unfortunately, chlorination was opposed due to mutagenic and carcinogenic disinfection of products. Security must be seriously considered in the fight against a pandemic, performance, and the environment.

Photocatalysis is capable of killing a wide range of organisms including Gram-negative and Gram-positive bacteria, including endospores, fungi, algae, protozoa, and viruses, and has also been shown to be capable of inactivating prions [19]. Killing is most efficient when there is close contact between the organisms and the TiO2 catalyst. The killing activity is enhanced by the presence of other antimicrobial agents such as Ag [20]. The acquisition of dual-function materials, which would improve the formation of ROS and thus limit the entry of unwanted pollutants, is necessary for the development of marine wastewater treatment systems.

This paper aims to review studies about photocatalysis that can be used for ships greywater disinfection and method effectivity can be tested with spectrophotometric methylene blue testing method as it is set in ISO 10678:2010 standard method for photocatalyst activity tests.

2. Methods for Photocatalyst Preparation

The synthesis of TiO2 nanowires is performed in the Anton Paar BRT MASTERWAVE microwave synthesis reactor using a Teflon reaction chamber with a capacity of 1 liter. A 670 ml suspension of 10 M KOH solution should be prepared to which 10 g of TiO2 P25 nanopowder is added. The synthesis of nanofibers is carried out at a temperature of 245°C, which ensures a pressure of 29,1 bar, and a microwave power of 1700 W. The suspension is stirred at a speed of 700 rpm. Reaction time 30 minutes. After synthesis, the suspension is cooled to 55°C and transferred to a porcelain beaker. Particles are allowed to sediment. The alkali solution is decanted, and the residue is diluted with deionized water. The sedimentation - decantation process is repeated several times to get rid of the presence of alkali in the sample. The precipitate is filtered through a nitrocellulose membrane filter, with a pore diameter of 1 µm, washed several times with 1 M HCl solution until the pH is between 6 and 7. Then rinsed with 96% ethanol. The precipitate obtained is dried at 120oC for 12 h. Various impurities of potassium titanate are formed in the synthesis as small by-products to remove them, a small amount of the resulting nanofiber sample is stirred for at least 12 h at 6 M HCl at room temperature, then rinsed with water to a pH of 6-7. The resulting nanofibers are heated at 5000°C for 2 hours.

The dual-function material was obtained by modifying TiO2 with a silver (Ag) by two different methods.

In the first method, a certain amount of AgNO3 is transferred to a 100 ml graduated flask, dissolved in deionized water, diluted to 100 mL, and transferred to a quartz beaker. To the resulting solution added 1.00 g of a sample of TiO2 nanofibers. The resulting suspension is stirred for 30 minutes, then the quartz beaker is placed 11 cm from the UV light source (FEK-56, 120W mercury lamp) and irradiated with UV radiation for 40 minutes. Under the influence of UV radiation, Ag + cations are reduced and TiO2 overlaps with silver nanoparticles. The resulting suspension is filtered through a 1 µm nitrocellulose membrane filter and rinsed with deionized water and ethanol. The precipitate obtained is dried in air at 1200C for 12 hours and then heated in air at 5000 C for 2 hours. The obtained samples had grey color.

In the second method, 1.00 g of TiO2 is added to 25 mL of ethyl alcohol and dispersed in an ultrasonic bath for 1 h. Added 30 mL of deionized water to the suspension and heated at 50-55°C for 1 hour. The fixed quantity of the AgNO3 solution was diluted with 10 mL of deionized water and added 0.5 mL of 0.18 M K2CO3. The pH of the solution is adjusted to 6.5 using ammonium hydroxide solution. The resulting solution is added to the TiO2 suspension, and the pH is adjusted to 6.5 - 7.0 using dilute ammonium hydroxide. The resulting suspension is stirred and heated at 50-550°C for 1 hour. Then added sodium borohydride or formaldehyde solution in small portions, form a dark precipitate, stirred, and heated for a further 1 hour. The resulting suspension is filtered through a 1µm nitrocellulose membrane filter and rinsed with deionized water and ethanol. The precipitate obtained is dried in air at 1200°C for 12 hours and then heated at 5000°C for 2 hours.

The MB methodology described in ISO 10678: 2010 "Fine ceramics (advanced ceramics, advanced technical ceramics)" was used to evaluate the photocatalytic properties. Determination of the photocatalytic activity of surfaces in an aqueous medium by degradation of methylene blue". In turn, to determine the specific surface of the samples, we used the BET method, which uses a gas chromatograph HROM-3 and an integrator И2.

3. Results and Discussion

Both, chemical precipitation, and UV precipitation were used to modify TiO2 nanofibers with Ag nanoparticles. Both methods obtained silver nanoparticles on the surface of TiO2 nanofibers, however, X-ray diffraction analysis (Bruker AXS, D8 Advance) did not show the characteristic peaks in silver in any of the obtained samples, so it was not possible to determine the size of silver crystallites by the Scherer method. The results of the X-ray fluorescence analysis (Bruker AXS, Pioneer S4) are summarized in Tables 1 and 2. The practically determined silver concentrations in the samples are very close to the predicted silver concentrations in the samples. TEM was used to determine the average size of silver crystallites. The average size of the silver crystallites will be determined to be in the range of 20 to 25 nm if the sample is obtained by chemical precipitation, but if the UV content is reduced, the crystallite size will be in the range of 10 to 15 nm. As the silver content of the sample increases, the specific surface area of the sample decreases slightly. It ranges from 72.1 to 77.2 g / m2.

Table 1

Properties of samples with silver-modified TiO2 nanofibers under UV radiation. With Ag-modified photocatalysis was obtained using NaBH4 as a reducing agent

Name of the sample	Modifier content, %	Specific surface, m2 / g	Average crystallite size, nm
TiO_2-NF-0,1%Ag-CR	0.10	77.1	10
TiO_2- NF-0,5%Ag-CR	0.55	76.4	15
TiO_2- NF-1%Ag-CR	1.12	74.7	15

Table 2

Properties of samples with silver-modified TiO2 nanofibers. With Ag-modified photocatalysts were obtained using UV radiation

Name of the sample	Modifier content, %	Specific surface, m2 / g	Average crystallite size, nm
TiO_2-NF-0,1%Ag-CR	0.11	77.2	20
TiO_2- NF-0,5%Ag-CR	0.48	74.1	20
TiO_2- NF-1%Ag-CR	0.98	72.7	25

The results of photocatalytic activity measurements of TiO2 nanofibers modified with silver nanoparticles under the influence of UV radiation are summarized in Tables 1 and 2

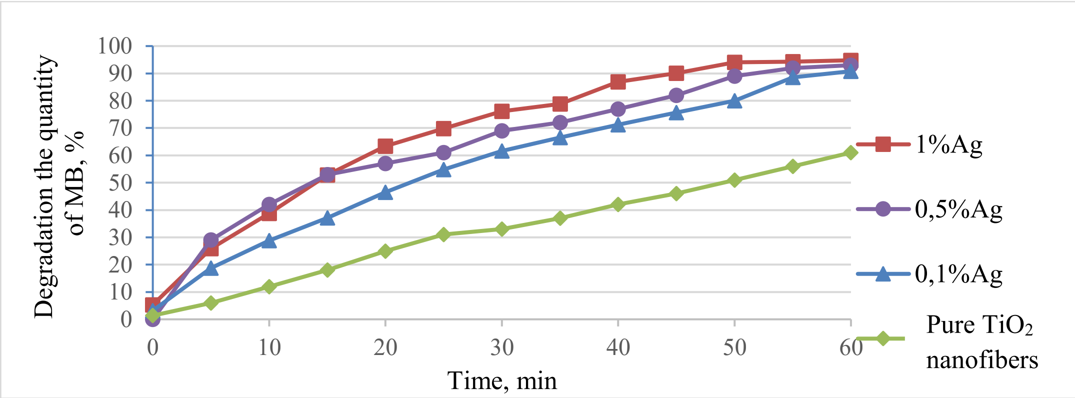

Fig. 2 Photocatalytic activity with silver-modified TiO2 nanofiber samples under UV radiation. Photocatalysts modified chemically

The sample modified with 1% Ag obtained using NaBH4 as a reducing agent, compared to the sample of unmodified TiO2 nanofibers, has degraded 44% more MB after 40 minutes. After 1 h, depending on the silver content in the photocatalyst, the amount of MB degraded reaches 90.79-94.80%. It has been determined that as the silver content of the sample increases, its photocatalytic activity also increases. Although the results are similar, the difference between the photocatalytic activity results of the samples reaches more than 15% during the experiments. The sample of TiO2 nanofibers with 0.5% Ag content, in the first 15 minutes of the experiment shows slightly higher photocatalytic activity than the photocatalyst with 1% Ag content, however, in the 25th minute, the difference in results is already 8.83%.

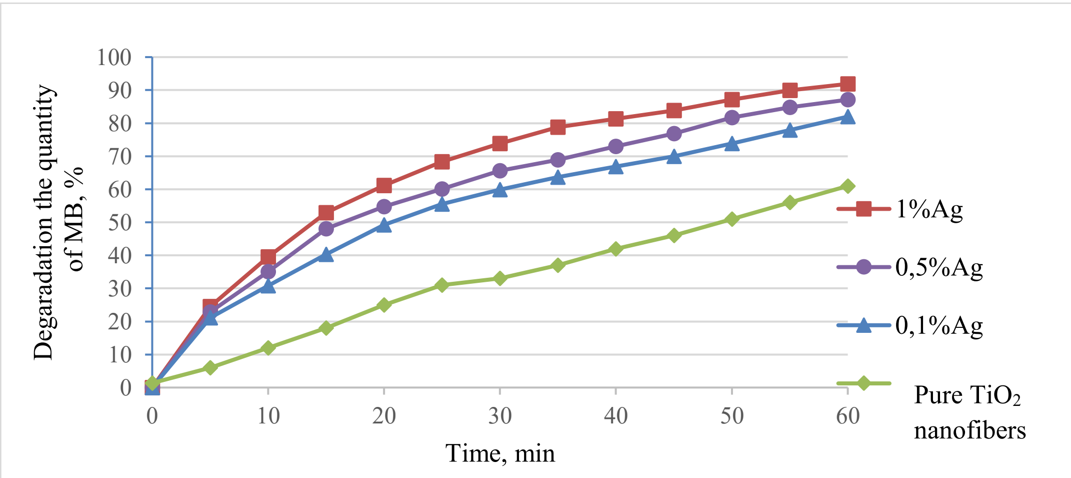

Fig. 3 Photocatalytic activity with silver-modified TiO2 nanofiber samples under UV radiation. Photocatalysts modified using UV radiation

The photocatalytic activity of the samples modified with UV coating was found to be lower compared to the samples modified with sodium borohydride. The highest result is obtained with a sample containing 1% Ag, which degraded 91.89% MB per hour, while samples with a silver content of 0.5% and 0.1% degraded only 87.11% and 81.88% MB, respectively. The lower photocatalytic activity can be explained by the larger size of silver crystallites in the samples. Using both modification methods, the relationship between silver-modified TiO2 nanofibers is valid - as the content of silver in the sample increases, its photocatalytic activity in UV radiation also increases.

Ag enhances photocatalysis by enhancing charge separation at the surface of the TiO2 [21]–[25]. Ag+ is antimicrobial and can also enhance the generation of ROS.

4. Conclusions

Given the potential threat of viruses to human health, their eradication is a relevant area of research. Chlorination, which is widely used in ship disinfection, produces carcinogenic compounds. Fortunately, semiconductor photocatalysis has pointed to the potential of alternative technology with the benefits of a valuable facility, high efficiency, and an energy-saving procedure to deactivate various viruses. Dual functional materials can generate ROS, which is a powerful weapon in the fight against viruses and microorganisms. TiO2 nanofibers modified with low (≤1%) silver content have very good photocatalytic activity. The added high toxicity of Ag will give the photocatalyst the ability to kill microorganisms and pathogens. Based on the above results, the next study in this area should focus on the experimental test of the dual photocatalyst TiO2 / Ag for the disinfection of the ship's "grey water".

Acknowledgments

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Simulation of Braking Processes in Freight Trains

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Abstract

The article presents the results of theoretical research of the processes occurring in the brake cylinders on freight wagons in trains of different lengths. A detailed analysis of the real time dependences of the forces of pressing the brake pads on the wheel for various braking methods (adjustment, full service and emergency braking), which were obtained during experiments with freight trains of different lengths, was carried out. Based on the analysis performed, approximating expressions for brake pad pressure diagrams on the wheel are proposed, which can be used to estimate the longitudinal dynamics of trains using mathematical modeling in real or accelerated time. The above dependencies are especially relevant when a train is controlled using a special onboard computer system. In this case, it is necessary to quickly estimate to what results, from the point of view of traffic safety and achievement of the control goal, the implemented control modes will lead to.
KEY WORDS: *longitudinal dynamics, braking forces, brake cylinder, braking modes*

1. Introduction

Sometimes, it becomes necessary to obtain the results of train motion simulation in real time or even in accelerated time [1-6]. For instance, one may need to evaluate the influence of the chosen running modes on running safety [7-9]. In such cases, the speed of simulation is the main demand to the modelling system. The most time-consuming subtask in the train longitudinal dynamics simulation is modelling of the train's braking system [10-15].

2. Model Description

Braking force depends mainly upon the braking mode, the place of the wagon in a train and running velocity [2, 10]. Two first mentioned factors influence the pressure in a braking cylinder and the speed of its filling. To study the processes of brake cylinders filling, the experimental dependencies for the trains of various lengths were obtained with the help of pressure sensors, installed in several braking cylinders distributed along the train length, for the trains with 60, 100, 120, 150 and 180 wagons [11].

Cylinder filling time depends on the train length and varies from one experiment to another. The piecewise-linear approximations of the obtained pressing processes in the 27th wagon, for the full service braking are shown in the Fig. 1.

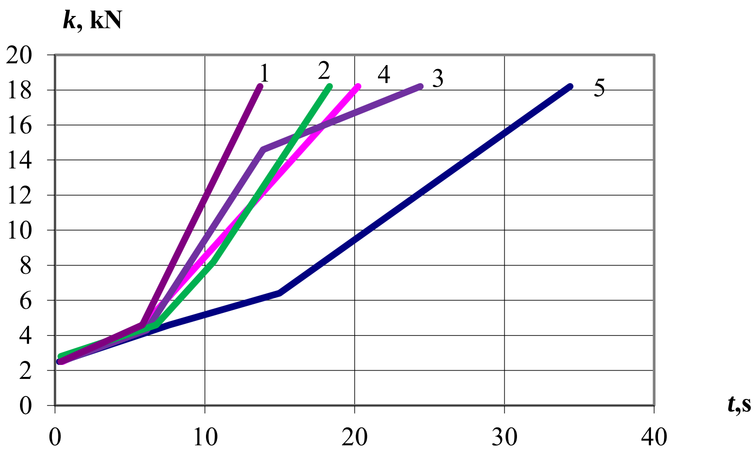

Fig. 1 Brake shoe pressing in the 27th wagon for the trains of different lengths

Here the lines *1*, *2*, *3*, *4*, *5* correspond to the train sets of 60, 100, 120, 150 and 180 wagons. As one can see from Fig. 1, brake cylinder's filling time increases with increasing of the train length, but some deviations are also possible. They are caused by unstable work of distributors.

The database of brake cylinders filling diagrams for the various train lengths has been created. For the particular length, the corresponding diagram is chosen from the database. If the database does not have information about the particular length, the necessary diagram is interpolated. It is also necessary to have diagrams for the same length both for emergency braking and for full service braking, as their time-dependencies differ from each other.

Diagrams for the full service braking and adjustment braking differ only by the maximal level of pressure in a brake cylinder which, in its turn, depends on the discharge of the braking pipe.

Processes taking place in the 60 wagons train are analysed as an example. Similar results can be obtained for trains up to 180 wagons. In Fig. 2, the lines *1*, *2*, *3*, *4*, *5* show the pressing diagrams for the 1st, 12th, 27th, 43rd and 60th wagon.

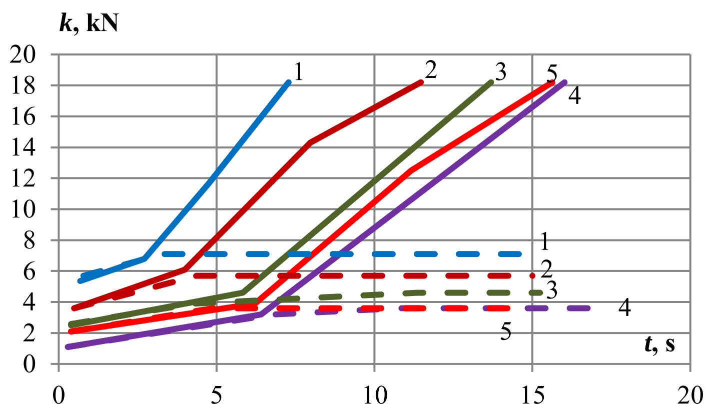

Fig. 2 Piecewise-linear approximation of the real pressing diagrams for the different wagons during full service (solid lines) and adjustment (dashed lines) braking

3. Results

To decrease the simulation time, it is worth to replace the real diagrams of the brake shoes pressing with the interpolating ones. Some examples of such an interpolation are given below.

While analysing the real diagrams, one can distinct two phases. The first phase reflects the more intensive pressure growth from zero to the first node point within a short time interval, the second phase represents the following pressure growth up to the maximal value k_{max}.

Fig. 3 presents the diagrams of the brake shoes pressing in a freight train during full service braking.

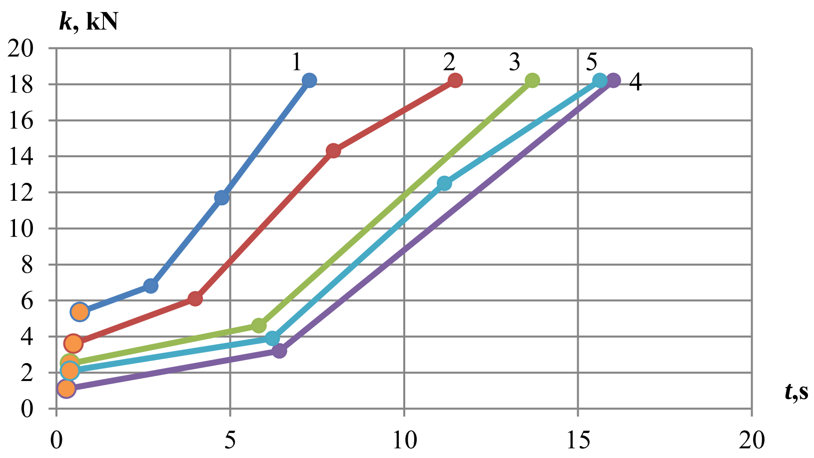

Fig. 3 Pressing of the brake shoes for different wagons in a train

Here the lines *1*, *2*, *3*, *4*, *5* correspond to the change of pressing force in the 1st, 12th, 27th, 43rd and 60th wagon during full service braking. The values in the first node point are marked with a larger marker. From the figure, one can see that pressure growth to the first node takes place in a more intensive way. Thus, it seems reasonable to find out the coordinates of the first nodes $k_1(j), t_1(j)$ separately. To do this, the experimental values were approximated with the functions:

$$k_1(j) = 0.004 \cdot \frac{(j+7.96)\cdot(j-89.02)}{j+4.7}; \tag{1}$$

$$t_1(j) = \frac{16.14 + 0.078j}{22.06 + j} \tag{2}$$

where j – is a wagon number.

The time of brake cylinders filling up to the maximum value k_{max}, increases in relation to the first source of discharge. The time of pressing force change from zero to the maximum value of k_{max} has been approximated with the function:

$$t_{max}(j) = 23 \cdot \frac{j + 9.9}{33.07 + j}\ . \tag{3}$$

The pressing force change from the first node point on the plot till the maximum value has been approximated with another formula:

$$k(j) = k_1(j) + \frac{k_{max} - k_1(j)}{\left(\frac{t}{t_{max}(j)}\right)^4 + 0.05} \cdot \left(\frac{t}{t_{max}(j)}\right)^5 . \tag{4}$$

Fig. 4 shows the change of pressing in the 27th wagon of a freight train during full service braking.

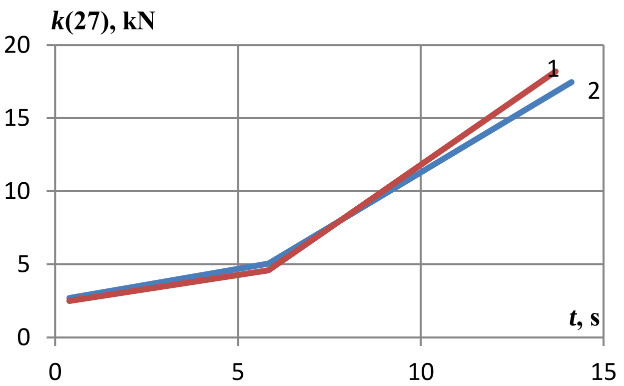

Fig. 4 Pressing in the 27th wagon of a freight train during full service braking

Here the line 1 is for real data, and the line 2 is for approximation with rational functions in the node points.

During the full service braking cylinders are being filled faster, so the results for this braking mode were obtained by the same methodology, just the function parameters were different.

The maximum longitudinal forces and the breaking distances starting from the 30 km/h velocity also were investigated for difference braking mode (full service, adjustment, and emergency). It was assumed that the wagons are equipped with air distributors of No. 483 type switched to medium operation mode, composite braking pads and spring friction shock absorbing devices between the wagons.

Fig. 5 shows the distribution of the maximum longitudinal forces along the train length. The solid lines correspond to the results obtained during experiments with a real train, and the dashed lines correspond to the computed results.

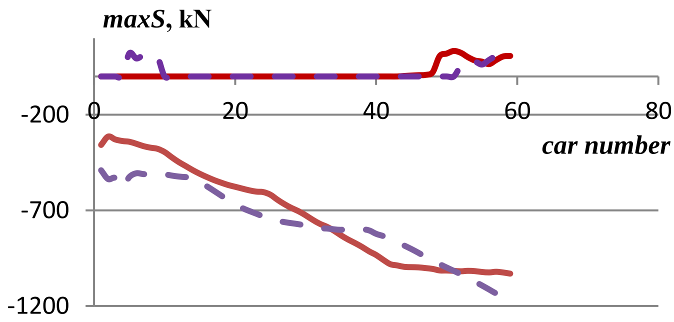

Fig. 5 Distribution of the maximum longitudinal forces along the train length during full service braking

The brake distances and the duration of braking for mentioned above braking modes were also calculated. The modeling results are shown in Fig.5 and Table 1.

Table 1
The braking distances and times during the braking

Braking mode	Experimental results		Modelling results	
	L, m	T, s	L, m	T, s
Adjustment	37	525	38	538
Full service	24	135	24	137
Emergency	22	121	22	123

The results of the freight train braking give a good match to the experimental data.

4. Conclusions

The real processes of filling the brake cylinders of freight wagons in trains of different lengths under different braking modes were analyzed.

Rational functions have been used to approximate the actual diagrams of brake pad pressure for various train wagons. These functions can be used for modeling braking processes in freight trains.

The level of the greatest longitudinal forces and the magnitude of braking distances were researched using various methods of modeling processes in the brake cylinders of freight cars.

The obtained dependences of the pressing force on time can be used in modeling pneumatic braking of trains of various lengths, including connected ones.

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The Real Added Value of Corporate Social Responsibility of Automotive Brands and Its Implications for Marketing Management

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Abstract

Traditionally, corporate social responsibility has been perceived in two major ideological flows – on the one hand as a prospective source of competitive advantage and on the other hand as a real expression of corporate philanthropy and awareness of corporate citizenship commitments. Nowadays, the situation seems to be slightly changed. The concept of corporate social responsibility has been included into majority of business models as a stable pillar of sustainable business development. Especially in the conditions of the markets with significant carbon footprint. The automotive industry is one of such a markets. Thus, it starts to be disputable whether the accent on corporate social responsibility should be widely communicated or it should just be silent immanent part of marketing management activities. The aim of this paper is to determinate the attitudes of consumers to the corporate social responsibility of automotive brands in conditions of Slovak Republic. The research has been conducted in April 2022 on the sample of 2000 respondents. The selection of the respondents in the sample set took place at random and was based on the number of Slovak citizens older than 18 years. The quantitative assessment method was applied to the processing of the information obtained from the questionnaire survey. This study would serve as a pilot study for further nationally based analyses focused on the issue of corporate social responsibility and its implications for marketing management of automotive brands.
KEY WORDS: *corporate social responsibility; CSR; brands; brand loyalty; automotive brands; marketing management*

1. Introduction

Brand loyalty as a phenomenon relevant for successful brand value building and management has despite its wide scientific development still many hidden aspects [1]. The black box of consumer loyalty has been created on the pillars of various brand loyalty sources where each of them has different importance for individual consumer. However, it can be stated that there are still the same sources, just their importance varies based on the personality and individual characteristics of consumer. One of such a pillars is corporate social responsibility [2]. At least it has seemed to be. Currently, the status of this concept is widely discussed. Is it still a competitive advantage and a brand loyalty source or is the added value of corporate social responsibility decreasing as it has become to be expected aspect of business performance and product itself? The research in this aspect has been unfortunately interrupted by the COVID-19 pandemic aspects of the issue [3-5]. Other trend in the corporate social responsibility research is the fragmentation of this topic among sectors and markets in favour of services [6, 7]. Thus, the detected situation which lies in the conversion of the status of corporate social responsibility in scope of brand loyalty has not been analysed appropriately so far. Especially in case of sectors where it is assumed that this topic is due to their carbon footprint and environmentally harming performance widely developed and there is no more scientific gap to fulfil [8]. Based on the above mentioned, the aim of this paper is to determinate the attitudes of consumers to the corporate social responsibility of automotive brands in conditions of Slovak Republic.

2. Literature Review

Corporate social responsibility (a.k.a. CSR used in later text of the paper) is defined as a form of self-regulation that reflects a business's accountability and commitment to contributing to the well-being of communities and society through various environmental and social measures [9]. However, the consumer perception of CSR is frequently restricted on one of the pillars of this concept – environmental pillar [10]. Thus, the concepts of green marketing and CSR seem to be replaced one by one in case of many consumers and environmental pillar increases in its importance in scope of marketing management activities. Such a situation is not favourable for the practical implementation of CSR in case of companies where the motivation of CSR implementation is utilitarian. Unfortunately, the share of such a companies on the total of CSR implementing companies is still relatively high [11].

Despite the character of motivation sources for the CSR implementation, the relationship between this concept and consumer loyalty has been identified [12]. Thus, the phenomenon of consumer loyalty is not only closely connected with consumer satisfaction but more than that with the brand value building and management processes. Especially in case of investment demanding purchases.

According to Manyanga et al. customer satisfaction is a measurement that determines how well a company's products or services meet customer expectations. It's one of the most important indicators of purchase intentions and customer loyalty [13]. As such, it helps predict business growth and revenue. In case of automotive industry, this issue has been analysed by Hur er al. who examined the relationship between green consumption value, satisfaction, and loyalty of driving hybrid cars [14].

Customer loyalty describes an ongoing emotional relationship between the company resp. brand and the customer, manifesting itself by how willing a customer is to engage with and repeatedly purchase from you versus your competitors [15]. In case of automotive industry, this issue has been analysed by Bennett and Graham and Jorgensen et al. [16, 17]. Surprisingly, much more than in case of car brands, brand loyalty is scientifically discussed in scope of car rental and insurance resp. repair services brands [18-20].

Thus, it is obvious that the issues of consumer satisfaction and brand loyalty of automotive brands are not the matter of interest of contemporary scientific society. However, the trend of the CSR concept and its position in the processes of brand loyalty building and management starts to be discussed across individual sectors [21-25].

When consumer loyalty and satisfaction are discussed, this issue is almost irrelevant in scope of marketing management of automotive industry. Expressed by other words – there is no place for absence of satisfaction of consumers on the way to consumer loyalty creation as the consumer satisfaction started to be part of the core product aspects [26]. Thus, satisfied consumer is the alpha and omega of marketing management without any space for corrective activities while in case of consumer loyalty, the space for CSR incorporation is more wider. Moreover, the strength of the CSR relevance for consumer satisfaction resp. loyalty varies in accordance with individual specifics of consumers [27, 28]. While for consumers who are strictly environmentally oriented (so called green consumers), the CSR concept is crucial element of their satisfaction and they cannot realize their consumption in favour of products where this concept would be absent, in case of consumers who are considered as benefit seekers, the CSR concept can be differencing aspect personalizing competitive advantage of producer [29]. Back to the brand loyalty, in case of no green consumers, CSR could be managed as brand value source and one of the crucial loyalty pillars [30]. In this way of meaning, the CSR concept can have strong image making aspect. This assumption is opposite to the original construct of brand loyalty based on the CSR as leading motive of green consumers [31]. However, it is not said that CSR is irrelevant for this category of consumers, just the perception is different – for them, the CSR is not brand loyalty source, it is a core product part. From this point of view, also the marketing management activities should be realized. While green consumers focus on the product (and partially some aspects of distribution), activities of the company oriented to the non-green consumers should be based on the communication activities. This issue is also very important from the perspective of international market performance of car brands – not only in scope of trading but also producing. Sutoova and Koca state that internationally recognised CSR standards, codes of conduct (cross-industry and industry-specific used in electronics, automotive and steel industry) and selected codes and supplier evaluation approaches applied by individual customer organisations could cause a malformation in the CSR perception especially by green consumers whose attitudes could secondary influence the social status of brands and also their brand value based on image attributes in case of non-green consumers [32].

Based on the theoretical background regarding to the main goal of the paper, research hypotheses should be formulated to identify the following:

- Whether when making purchasing decisions, consumers prefer an automotive brand that behaves socially responsibly.
- Whether consumers perceive the socially responsible strategy of automotive brand as a brand value increase factor.
- Whether consumers perceive the socially responsible strategy of automotive brand as a factor to ensure brand loyalty.
- Whether consumers perceive the socially responsible strategy of automotive brand as a competitive advantage.

3. Methodology

The article is focused on the determination the attitudes of Slovak consumers to the corporate social responsibility of automotive brands. This includes providing the theoretical background and analysis of the corporate social responsibility from the viewpoint of Slovak and foreign authors. The important sources for secondary data were scientific researches, annual companies report, statistical databases, published professional publications. In order to found out the attitudes of Slovak consumers to the corporate social responsibility of automotive brands, a questionnaire survey was conducted. Based on the analysis and results of the questionnaire survey, benefits of the application of corporate social responsibility in the marketing strategy of automotive brands are highlighted such as increasing the brand value, ensuring brand loyalty and gaining competitive advantage.

General scientific methods were applied for the processing of the data as well as mathematical-statistical methods to evaluate the data collated from the results of the questionnaire survey and to statistical hypothesis testing.

The aim of the questionnaire survey was to analyse the attitudes of Slovak consumers to the corporate social responsibility of automotive brands.

The questionnaire survey was conducted in April 2022 on the sample of 2000 respondents. The selection of the respondents in the sample set took place at random and was based on the number of Slovak citizens older than 18 years. The quantitative assessment method was applied to the processing of the information obtained from the questionnaire survey.

In order to achieve the main aim of the article, based on the theoretical background and survey results, four research hypotheses are formulated:

Based on the theoretical background and the survey results, with regard to the main goal of the article, research hypotheses are formulated:

- Hypothesis 1: When making purchasing decisions, 50% of respondents prefer an automotive brand that behaves socially responsibly.
- Hypothesis 2: More than 50% respondents perceive the socially responsible strategy of automotive brand as a brand value increase factor.
- Hypothesis 3: More than 50% respondents perceive the socially responsible strategy of automotive brand as a factor to ensure brand loyalty.
- Hypothesis 4: More than 50% respondents perceive the socially responsible strategy of automotive brand as a competitive advantage.

The marginal rate 50% was set as the expression of the simple majority [33].

Statistical hypotheses testing is aimed on the statement of the assumption of unknown parameters in the basic set, which is formulated as a statistical hypothesis and its validity is verified by statistical procedures based on selection characteristics. The statistical hypotheses testing is based on the decision whether to accept or reject the hypothesis regarding the basic set, in accordance to the information from the available choice. In verification of the hypotheses, the methodology of statistical hypothesis testing consisting of the following steps were met:

1. Formulation of the null hypothesis (H_0).
2. Formulation of the alternative hypothesis (H_1).
3. Determining the level of significance (α).
4. Calculation of test statistics and probability.
5. Decision. [34]

The test statistic for hypotheses 1 – 4 we calculated by using the method testing a single proportion by one-tailed testing because it is commonly used [35, 36].

Significance level α was determined at 0.05.

4. Results

Of the 2000 respondents in the sample set, 1254 (62.7%) were female and 746 (37.3%) were male. From the results of the questionnaire survey, it is obvious, that 51.05% of respondents prefer an automotive brand that behaves socially responsibly when making purchasing decisions. As the most important benefit of using a socially responsible strategy for the automotive brand, most respondents (54.66%) identify increasing brand value. 52.30% of respondents indicated brand loyalty and 49.17% gained a competitive advantage.

To verify the statistical hypotheses 1 – 4, we used the method testing a single proportion. Results of verification these statistical hypotheses are shown in Table.

Significance level α was determined at 0.05. The test criteria were calculated according to:

$$T = \frac{p - \pi_0}{\sqrt{\frac{\pi_0 \cdot (1 - \pi_0)}{n}}} \,. \tag{1}$$

By using the tables of the normalized normal distribution, we find the critical value for the left-tailed test (2) in the case of hypothesis 1 and the right-tailed test (3) for hypothesis 2 – 4.

$$T < -z_{2\alpha} \,; \tag{2}$$

$$T > z_{2\alpha} \,. \tag{3}$$

Table shows, that in hypotheses 1 and 4 the inequality does not apply, so we accept the hypothesis H_0. In hypotheses 2 and 3 the inequality applies, so we reject the hypothesis H_0, i.e., accept the alternative hypothesis H_1. Our results indicate strong position of the concept of CSR in scope of automotive brand loyalty creation. There was not discovered appropriate evidence about the formalism od the CSR incorporation into business models in automotive industry without impact on buying behaviour of consumers. However, two other issues have been detected – the need of careful scanning of CSR good practice in all the countries where the automotive brand operates and the need of separate research of localization of the CSR on the product levels in scope of its satisfaction forming prospective depending on the type of consumers.

Table

Verification of statistical hypotheses

Calculation of the sample proportion: $p = \frac{m}{n}$	**Satisfaction of the condition** $n \cdot \pi_0 \cdot (1-\pi_0) > 9$	**Test criteria**	**Critical field**	**Inequality**	**Acceptance or rejection of the hypothesis**
Hypothesis 1: H_0: When making purchasing decisions, 50% of respondents prefer automotive brand that behaves socially responsibly. H_1: When making purchasing decisions, less than 50% of respondents prefer automotive brand that behaves socially responsibly.					
$p = 0.5105$	500 > 9	0.939	-1.645	0.939 < -1.645	H_0 accepted
Hypothesis 2: H_0: 50% respondents perceive socially responsible strategy of automotive brand as a brand value increase factor. H_1: More than 50% respondents perceive socially responsible strategy of automotive brand as a brand value increase factor.					
$p = 0.5466$	500 > 9	4.168	1.645	4.168 > 1.645	H_0 rejected
Hypothesis 3: H_0: 50% respondents perceive socially responsible strategy of automotive brand as a factor to ensure brand loyalty. H_1: More than 50% respondents perceive socially responsible strategy of automotive brand as a factor to ensure brand loyalty.					
$p = 0.523$	500 > 9	2.057	1.645	2.057>1.645	H_0 rejected
Hypothesis 4: H_0: 50% respondents perceive socially responsible strategy of automotive brand as a competitive advantage. H_1: More than 50% respondents perceive socially responsible strategy of automotive brand as a competitive advantage.					
$p = 0.4917$	500 > 9	-0.742	1.645	-0,742 >1.645	H_0 accepted

Source: Own processing

5. Conclusions

The aim of this paper was to determine the attitudes of consumers to the corporate social responsibility of automotive brands in conditions of the Slovak Republic. The research was conducted in April 2022 on a sample of 2000 respondents. The selection of the respondents in the sample set took place at random and was based on the number of Slovak citizens older than 18 years. The quantitative assessment method was applied to the processing of the information obtained from the questionnaire survey. It has been found out that when making purchasing decisions, 50% of respondents prefer automotive brand that behaves socially responsibly; more than 50% of respondents perceive socially responsible strategy of automotive brand as a brand value increase factor; 50% of respondents perceive socially responsible strategy of automotive brand as a factor to ensure brand loyalty and 50% of respondents perceive socially responsible strategy of automotive brand as a competitive advantage. These results are valuable source of knowledge for marketing managers of automotive brands who consider the corporate social responsibility as a brand loyalty source. This managerial concept has been confirmed as relevant brand loyalty pillar and the original presumption about the loss of this status has been denied. However, it should be analysed in details, whether the fact that 50% of respondents prefer automotive brand that behaves socially responsibly indicates that corporate social responsibility forms the core of the project or it is located at upper product levels. Thus, it could be separately discussed the processes of brand loyalty building and brand loyalty management, where could be difference between corporate social responsibility perceptions between loyal and non-loyal consumers.

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Methods of Improving the Information Logistics of a Trucking Company on the Example of the US Refrigerated Cargo Market

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Abstract

The article presents a method of improving the information logistics of the carrier on the example of AVA Carrier LLC (USA, Nebraska). The article summarizes the 6-year experience of the authors, which was aimed at solving the problems of information support and information logistics of the trucking business in particular. The methodology involves the use of the following cloud information services as public: FleetOne (fuels and lubricants); ComData (travel loans); Ipass and Ktag (toll roads); ITS Disputch (ordering and maintenance of goods); QuickBooks Online (accounting and settlements with counterparties); Samsara (security and operational control of cargo). The main tasks solved by the methodology listed above are to create: corporate databases of the trucking company which is formed in real time due to the information from the cloud services listed above; appropriate software that provides automated formation of road, service and financial transactions as the basis of information logistics of the enterprise. The practical value of the methodology is: first of all, in the ability to process a large number of information transactions in a much shorter period of time; secondly, in a qualitatively new level of work with information, much less number of workers and the ability to automatically generate transactions without human intervention.
KEYWORDS. *Information logistics, database, freight broker, information transaction, temperature cargo, RFID technology.*

1. Introduction

A specific feature of the temperature freight market in the United States is the presence of a large number of freight brokers who act as intermediaries between shippers and consignees. The presence of an intermediary in most freight operations has both disadvantages and advantages for participants in the road transport market.

The main disadvantage of this organizational structure of the business is the logistical losses - primarily information and logistics, connected with the need for additional information transactions with an intermediary - a freight broker.

But such a market organization has also a significant advantage - first of all, it is competitiveness and demonopolization of the transport services market which has a positive effect on the formation of market prices and the cost of final products. Thus, the main task of improving the information logistics of road transport of temperature cargo in the United States is the need for maximum automation of all components of business information support. The consequence of this should be an increase in the speed and quality of transport and cargo operations and financial transactions, as well as a significant reduction in the cost of transportation of temperature cargo.

The formation of information and logistics support for the real business of road transport of temperature cargo in the United States is implemented on the example of a specific company-carrier AVA Carrier LLC (Nebraska). The company specializes in the transportation of temperature cargo throughout the United States and operates a fleet of approximately 25 trucks and 30 refrigerated trailers for the past 12 years. The company operates both its own vehicles and vehicles of contractors-owners, providing management and logistics of transportation.

Implementation of the transportation process at the enterprise involves the following technological sequence:

- searching and ordering cargo through the Truckstop.com cloud service;
- formation of data on cargo by the company's dispatcher in the cloud service ITS Dispatch [2];
- setting the temperature and the mode of its support in the trailer according to the cargo documents, using the Samsara cloud service;
- receiving electronic copies of cargo documents after unloading with copies of costs for payment of cargo operations in the cloud service of road loans (checks) ComData;
- formation of financial transactions in the cloud service QuickBooks Online[1];
- ancillary costs associated with the transportation of goods are realized through cloud services for fuel payments - FleetOne and for toll roads - Ipass and Ktag.

All these information resources are the basis of the information support of the company.

Based on the above, we can formulate the main tasks that were implemented by the authors:

- design and implementation of corporate database for its further use as the main tool of information logistics of the company;
- creation of software and technological support for the implementation of financial transactions with customers and contractors in automatic mode;
- creation of software and technological support for the formation of cargo documents with the ability to synchronize the databases of the freight broker and the company;
- creation of an intelligent automated system for maintaining the temperature regime of cargo transportation in order to reduce the possible risks of cargo loss.

2. Main Material Presentation

Construction and design of the corporate database involved the use of its operational formation of the above cloud services as sources. Each of these services provides technological capabilities for the use of the information by external software.

The design of the corporate database required the identification of key components that would allow the software implementation of the relationships between the relevant tables through the use of SQL SELECT statements as follows:

- INNER JOIN - to realize the connection " each to other";
- LEFT JOIN - to realize the connection “ many-to-one”;
- RIGHT JOIN - to realize the connection “one-to-many”.

The following fields of the corresponding SQL tables of the corporate database were identified as such key components:

- Cargo number - used to link the LOAD-ITS table (cargo data) with the COMDATA table (road loan data) and the INVOICES-QBO table (financial transactions with brokers);
- Track number - used to connect the tables LOAD-ITS, INVOICES-QBO, COMDATA with the table FUEL-FLEETONE (fuel consumption data), tables IPASS and KTAG (toll roads), TEMP-SAMSARA (cargo temperature).

The presence of a corporate database ensures the implementation of the following information transactions of the company:

- implementation of transactions related to the execution of cargo documents;
- implementation of service transactions related to cargo temperature control;
- implementation of financial transactions related to the transportation of temperature cargo.

Each transaction performs a certain sequence of information technology operations, which together form a complete functionality in terms of transportation of temperature goods.

Consistent execution of these transactions implements the method of improving the information logistics of the enterprise-carrier of temperature cargo [3, 5].

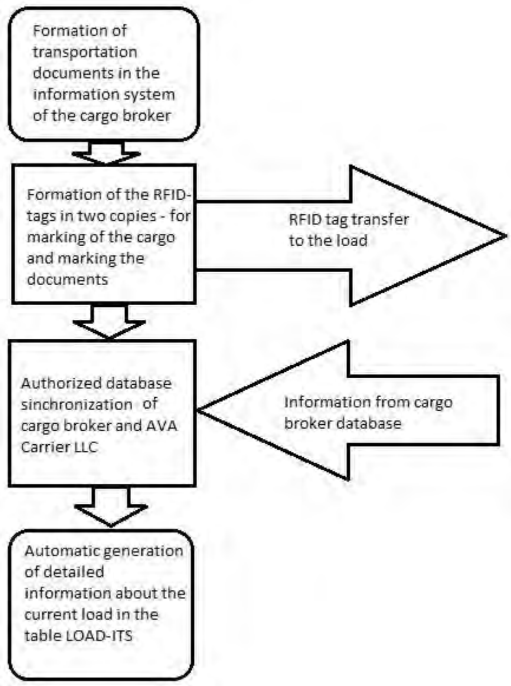

Fig. 1 Scheme of information transactions related to the execution of cargo documents

The first type of transaction is information transactions related to the execution of cargo documents. In order to do that, a system of automated registration of transportation documents is proposed. It provides for the use of RFID technology for the purpose of automatic identification of all cargo parameters. The implementation of this transaction involves the initial formation of cargo documents for the transportation of a particular cargo in the following sequence:

1. formation of transportation documents in the information system of the freight broker with the obligatory printing of a copy for the driver;
2. formation of RFID-mark of cargo in two copies - for marking of cargo and for marking of transport documents on cargo (formation of information on the temperature mode of cargo transportation is obligatory);
3. automatic generation of detailed information about the current cargo in the corporate database in the LOAD-ITS table due to the authorized synchronization of the databases of the freight broker and AVA Carrier LLC.

The scheme of information processing during the implementation of information transactions related to the execution of cargo documents is given in Fig. 1.

The second type is service information transactions related to cargo temperature control. The implementation of these transactions involves solving a rather complex technological problem - the creation of an autonomous automated control system for refrigeration and isothermal equipment of refrigerated trailers without human intervention, but with its intellectual capabilities.

As for the intelligent component of the automated control system of refrigeration and isothermal equipment of refrigerated vehicles, an important improvement is the creation and practical implementation of serial equipment algorithms and software that implements the possibility of self-learning system in real conditions of transportation of goods.

To do this, the cargo is equipped with an RFID tag [8], which contains data on the temperature modes of transportation of this cargo. To obtain this information, a refrigerated vehicle is also equipped with an RFID reader, which automatically reads data from the RFID tag of the cargo and transmits it to the on-board computer of the vehicle (usually an Android device).

The formation of a cargo RFID tag is done using software for creating cargo documents, which, in their turn, are also equipped with a temperature RFID tag. The availability of electronic data on the vehicle's temperature modes of transportation allows you to programmatically set the temperature of the refrigerator vehicle without human intervention and to constantly monitor the temperature during the transportation of this cargo in automated mode.

Implementation of an intelligent automated system for monitoring the temperature of the cargo and the body of a refrigerated vehicle with the ability for the system to self-learn in real conditions of transportation of goods involved the use of RFID-tags and RFID-tags in the middle of the body, equipped with temperature sensors DATS-612T) with the formation of the appropriate electronic archive (a file of temperature states of a certain type of cargo in the on-board computer of a specific refrigerated vehicle).

The intelligent component of the automated temperature control system of the cargo and body of a refrigerated vehicle with the possibility of self-learning of the syste m in real conditions of transportation of goods involved the creation of a mathematical neuro-fuzzy model in MathLab Fuzzy Logic ToolBox [7] with its software implementation on the on-board computer of the refrigerated vehicle.

Neuro-fuzzy simulation was subject to the useful operating time of the refrigerator required to create or maintain a certain temperature of the type of cargo. The input variables of the model are the initial temperatures of the cargo, in the middle of the refrigerator body, the weight of the cargo, the volume of the refrigerator body, the required cargo temperature. The required temperature and weight of the load must be recorded in the RFID tag of the load, and the initial temperatures of the load and in the body of the refrigerator are measured by existing equipment. The volume of the body of the refrigerator depends on the specific model of the vehicle. It is important that all design changes related to the installation of the necessary equipment occur without outside participation and apply to all existing models of refrigerators.

For the purpose of parameterization we will consider the connection of input and output variables of the model of the control time of the efficient work of the refrigerator.

Here is a list of input fuzzy variables [5]:

X_1 – temperature in the body of the refrigerator (reference);

X_2 – cargo temperature (reference);

X_3 – refrigerator body volume;

X_4 – temperature in the body of the refrigerator (current);

X_5 – temperature of cargo (current);

X_6 – weight of cargo.

Output fuzzy variable:

$\boldsymbol{Y}$ – the efficient time of the refrigerator to achieve the reference temperature in the body of the refrigerator.

It is assumed that all fuzzy variables are linguistic variables with the following term intervals [4, 6]:

$\{\boldsymbol{Y_j}\}$ – the set of term intervals of the variable $\boldsymbol{Y}$;

$\{\boldsymbol{X_{ij}}\}$ – the set of term intervals of the variable $\boldsymbol{X_i}$, $\boldsymbol{i} = \overline{1,6}$, $\boldsymbol{j} = \overline{1,8}$, where $\boldsymbol{i}$ – the number of input variables of the model; $\boldsymbol{j}$ – the number of term intervals of the corresponding variable.

Taking into account the above variables and their relationships in the model of temperature control of the refrigerator, we'll consider the following function $\boldsymbol{\varphi(x)}$, which summarizes the control process:

$$Y = \varphi \left(X_1, X_2, X_3, X_4, X_5, X_6\right). \tag{1}$$

The following diagram describes the technological sequence of the service transaction of automated intelligent control of the temperature of the cargo in the refrigerator vehicle using the above fuzzy neuro-mathematical model (Fig. 2):

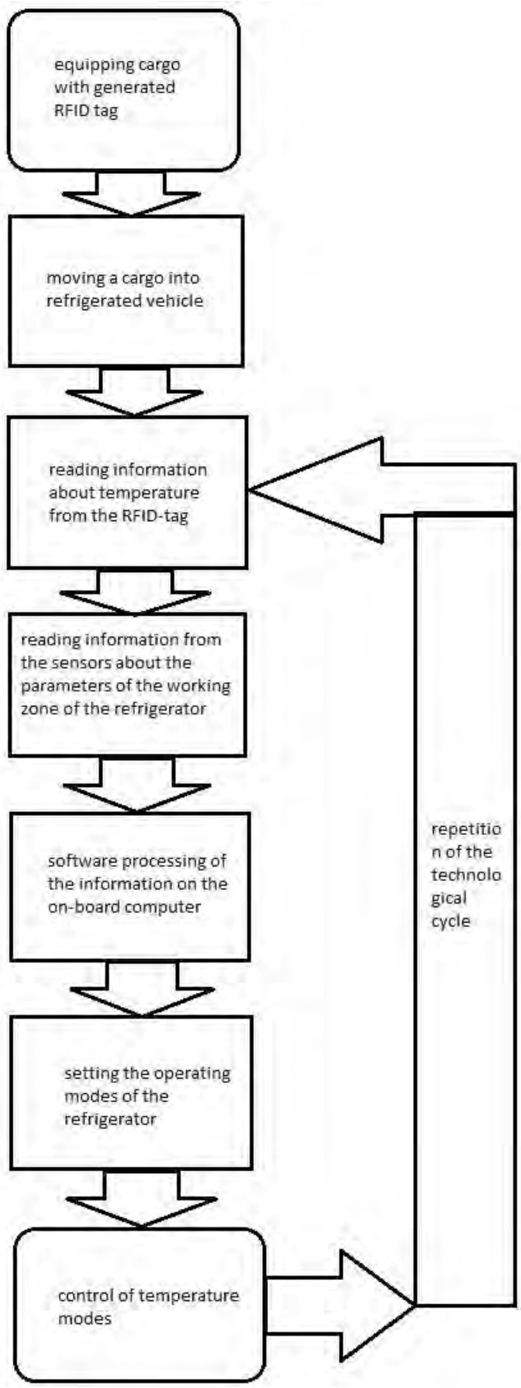

Fig. 2 Scheme of realization of service information transaction

The third type is financial transactions which are represented by two types:

- transactions of settlements with customers-brokers in the form of an invoice in QBO;
- transactions of settlements with executors-carriers in the form of ACH-document in QBO.

The software implementation of the financial transactions involved the use of standard capabilities of the QBO file interface for automatic generation of relevant transactions. The structure of the file interface for automatic invoice generation for payments with brokers is as follows [1]:

[Invoice No.] [Customer] [Email] [Terms] [Invoice Date] [Due Date] [Load Number] [Unit#] [Paid by Check] [Product/Service Description] [Qty] [Rate] [Amount] [Send later] [Subtotal] [Total] [Attachments]

The structure of the file interface of automatic ACH generation for settlements with vehicle owners is as follows:

[Ref no.] [Payee Payment] [Account] [Payment Date] [Payment Method] [Category] [Description] [Amount] [Memo] [Total]

The sequence of execution of the above information transactions corresponds to the numbering of their description, but as a result of information and logistics improvement is a real coincidence in time, i.e. the parallel execution of financial transactions with freight and service ones. This is the result of the developed software and technological solutions and is a sign of the successful information logistics and meets the goal.

3. Conclusions

The improvement of information logistics of the temperature carrier in the US market is based on the example of AVA Carrier LLC, so it takes into account the experience, needs and relevance of the tasks of a real representative of this market with 12 years of experience. To do this, the following tasks have been solved:

- a corporate database for further use as the main tool of information logistics of the company has been created;
- software and technological maintenance for the implementation of financial transactions with customers and contractors in automatic mode has been created;
- created software and technological maintenance for the formation of cargo documents with the ability to synchronize the databases of the freight broker and the company has been created;
- an intelligent automated system for maintaining the temperature regime of cargo transportation has been created in order to reduce the possible risks of cargo loss.

Separate information transactions have provided the solution of the main tasks of improving the company's information logistics at the information technology level with the possibility of combining them into a single methodology.

The set and completed tasks allowed:

- to improve the execution of information transactions related to the execution of cargo documents, reducing the time of their execution and thus ensuring the possibility of further information automation of all operations of primary input, maintenance and printing;
- to improve the implementation of service information transactions related to the control of cargo temperature, which reduces the risk of loss and damage to cargo due to violations or errors in compliance with the temperature regimes of cargo transportation;
- to improve the execution of financial transactions with customers and performers in automatic mode which reduced the time for their formation from 15 to 1 minute and reduced the number of performers from 4 to 1 employee.

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Development of Transport and Logistics Complex of Kazakhstan in the Context of the Program “Digital Kazakhstan”

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Abstract

The state of the transport and logistics complex (TLC), which is one of the key sectors of the economy of Kazakhstan and the main directions of development of transport in the long term up to 2030 are considered. The aggregated directions of scientific and technological development of the railway industry in the context of digitalization are shown. The prospects for the development of railway transport in the context of digital transformation are considered in detail. The national company "Kazakhstan Temir Zholy" adopted the program "Digital Transformation" for 2019-2023, which combined 13 initiatives aimed at improving and transforming significant business processes. One of the priority areas of NC KTZ's development is the development of operational and technological communication (OTC) and the implementation of digital trunking radio communication standard TETRA. It is noted that digitalization of TLC has brought the following benefits: -no paper records and physical storage of photo evidence; -improved quality and speed of obtaining data on violations; -no need for additional communication by mail or phone calls, etc.
KEY WORDS: *transport and logistics complex, digitalization, railway transport, digital transformation, business processes, end-to-end digital technologies.*

1. Introduction

One of the goals of the state in the sphere of transport is to create a modern transport and logistics complex on the territory of the Republic of Kazakhstan, providing cost-effective and technologically diverse transport links between industries, settlements, regions and industries, both within the country and between Kazakhstan and foreign countries.

The transport and logistics complex (TLC) is one of the key sectors of Kazakhstan's economy, affecting national income and, accordingly, the welfare of society. Efficient transport not only accelerates production processes and strengthens interregional and international economic ties, but also replenishes the state budget.

Global experience shows that the dynamic growth of the national economy leads to a significant increase in the volume of freight and passenger flows both on domestic and international transport routes. The growth of industrial production by 1% causes the growth of transportation volumes by 1.5-1.7% [1]. The development of TLC has a multiplicative effect on the economy, contributing to an increase in domestic and foreign trade. However, if the transport infrastructure is poorly developed, the productivity and efficiency of the TLC declines, constraining the socio-economic development of the country and its regions.

The development of the transport and logistics complex should outpace the growth of cargo and passenger traffic in all modes of transport. To achieve this goal, it is necessary to solve a large number of problems, which can be grouped into key areas. According to the analysis, the main directions of transport development in the long term until 2030 are:

– improving the system of state regulation and management;
– increasing transit potential and its effective use;
– maximum assistance to the development of domestic entrepreneurship, reduction of costs in domestic, export and import transportation;
– development of infrastructure;
– development of science and technology;
– ensuring transport security;
– training and retraining of personnel;
– multimodal transport technologies.

The long-term development of the TLC is of strategic importance for Kazakhstan, which ranks ninth in the world in terms of area. The favorable geo-economic location of Kazakhstan creates favorable opportunities for economic bonuses due to the development of international transit transportation of goods and passengers. The main advantage is the reduction of time for transit transportation of goods and passengers in half compared with the sea route and up to a thousand kilometers in comparison with transit through the territory of Russia [2].

2. Methodology

Let us consider in detail the prospects for the development of railway transport in the context of digital transformation, since railway transport plays a predominant role in the TLC of the Republic of Kazakhstan. Table presents the main directions of scientific and technological development railway industry in the context of its digitalization.

Table
Aggregated directions of scientific and technological development of the railway industry in the context of digitalization

№	Name of direction
1.	Implementation of innovative systems of automation and mechanization of transportation processes
2.	Resource, Safety, Risk and Reliability Management at the Life Cycle Stages of Railway Transport Facilities
3.	Development and implementation of advanced technical means and "end-to-end" technologies for railway transport infrastructure development of advanced technical means and "end-to-end technologies" for railway transport infrastructure (railway automation and telemechanics, electrification and power supply, innovative information and telecommunication technologies, etc.)
4.	Development of transport and logistics systems in the common transport space
5.	Implementation of information systems for railway transport management

In addition to the above directions, digital solutions need to be applied in the following areas:
– research on automated, interoperable and interconnected advanced traffic control systems;
– increasing the capacity of the railway track by implementing automated train control systems;
– improvement and optimization of train tracking systems;
– development and application of monitoring systems and methods for collecting large volumes of data;
– increased standardization and unification of information systems;
– development of intelligent passenger mobility management platforms.

In 2019, the national company "Kazakhstan Temir Zholy" adopted the program "Digital Transformation" for 2019-2023, which combined 13 initiatives aimed at improving and transforming significant business processes. And the first initiative of the program is industrial security. As part of the "Digital Transformation" program KTZ implements the project "Implementation of IT solutions in the field of occupational health and safety, industrial and environmental safety» has developed and is implementing an automated integrated system for the management of industrial safety processes - ISP (including a mobile version), which includes all major processes for the management of industrial safety.

The digital mobile platform of ISP has three advantages that the current system cannot provide in part or in full - mobility, validity and speed. The first advantage means that the use of a mobile app allows violations to be recorded absolutely everywhere. The second - the ability to attach photos and videos allows objective confirmation of violations, and the third - the digitization of applications helps avoid wasting time filling out paper documents and speeds up the exchange of data between departments of the company. In general, digitalization has brought the following benefits:
– no need to keep paper records and physical storage of photo evidence;
– improved quality and speed of obtaining data on violations;
– no need for additional communication by mail or phone calls, etc.

3. Results and Discussions

The following priority technologies in the context of digitalization of the railway industry are proposed.

1. *Implementation of intelligent systems for automation, optimization and mechanization of internal business processes.*

As part of this direction, railway companies should actively implement new means of interaction with customers in the digital space. The most common way of digital interaction with the customer is the creation of mobile applications. Their functionality allows the electronic purchase and booking of tickets, laying out "door-to-door" routes using various categories of transport (buses, trains) [3].

The use of digital technologies is aimed, among other things, at introducing "smart" tickets, which can be stored in the user's mobile device. Such tickets provide unified access to different types of transport. As part of mobile applications, a customer feedback system is implemented, which allows companies to manage the quality of services provided [4].

In order to improve the quality of the user experience, "service-assistant" (or "service-assistant") applications should be created. For travelers, these platforms provide opportunities to simplify door-to-door travel, accompany for the traveler, they provide door-to-door assistance throughout the entire journey, consideration of personal preferences, dealing with unexpected situations, organizing interaction with different types of transport involved in the process of movement.

For commercial companies, these platforms provide an opportunity to reduce time and money costs by forming the best route by analyzing a large number of parameters and to select the optimal values. The development and implementation of these platforms allows carriers to simplify the process of using companies' services by providing a convenient user experience through the analysis of big data, the use of artificial intelligence, machine learning and providing recommendations to end users on their basis.

The main effects of the implementation of this direction of digitalization are reduction of time for data processing, increase of fault tolerance, increase of productivity and consumer loyalty.

In addition, the active use of business applications in internal processes should be practiced, linking digital employees' devices into a single information network, the use of business intelligence software, and encouraging employees to work with digital tools.

2. *Management of resources, safety, risks and reliability at the stages of the life cycle of railway transport facilities by means of digital systems*.

The active introduction of digital technologies not only opens up new business opportunities, but also entails new risks associated with cybercrime. As part of information and cyber security, digital systems are integrated into unified automated complexes, software is continuously improved, and the practice of monitoring, maintenance and remote configuration of digital systems and equipment, the use of tools to counter cybercriminals [5].

Specific security measures include user identification and authentication, firewalling, delimitation of user access, delimitation with open networks, encryption data transmitted outside the control area, logging of users and administrators' activities, regular software updates and use of open-source software, anti-virus protection of information resources, information security management, use of the principles of auxiliary and redundancy principles.

In order to reduce the influence of the human factor in emergencies, as well as to reduce injuries at work, modern technologies are used, including various navigation systems, which, in turn, are required to provide shunting automatic locomotive signaling. Active introduction of sensorics, digital facilities condition monitoring tools, and nondestructive testing technologies (without decommissioning of the facility) is underway.

The use of "smart" sensors, advanced analytical software and information exchange systems information exchange systems to monitor the condition of equipment in real time, implementation of high-precision coordinate systems, and terrain design systems will make it possible to monitor the movement of high-speed trains. Laser and infrared detectors are also placed near the railway track, which evaluate the condition of the axles and bearings of a moving train, and "smart" cameras.

The implementation of digital monitoring of railway facilities makes it possible to improve safety, reduce the lifecycle cost of rolling stock and infrastructure, reduce downtime cars, promptly identify and eliminate technical problems, distribute maintenance personnel more efficiently, increase economic and operational efficiency and labor productivity.

3. *Development and implementation of advanced technical means and "end-to-end" digital technologies for rolling stock and infrastructure.*

The key solutions of this scientific and technological area are automated systems for constructing operational traffic schedules, route planning systems, digital platforms for multimodal (intermodal) transportation, digital platforms for transportation process management, auto guidance (autonomous rolling stock), intelligent dispatcher control systems, unmanned technologies for transportation process management, including loading/unloading processes, "machine vision" (a segment of artificial intelligence technologies, the essence of which consists in obtaining and processing real images in order to solve applied tasks without human involvement).

Auto-guidance will increase throughput by reducing intervals between trains and help reduce energy consumption for train pulling, due to the use of optimal algorithms and the absence of human influence on rolling stock control. It is worth noting that machine learning technologies are used to analyze the situation using data from sensors. Alternative technologies are high-precision means of locomotive location and an electronic 3D map.

Digital simulation systems for rail transport infrastructure represents one of the key technologies for creating a new type of railway system due to the significant development of sensor technology, the amount of information to be processed, and the computing power of computers. The technology is capable of improving railway company operations and is key, on a par with intelligent systems using the Internet of Things, to create an efficient multimodal and intermodal logistics system.

Intelligent systems using the Internet of Things in the process of monitoring the condition of rolling stock and railway infrastructure, if successfully implemented in the operational of railway companies will make it possible to optimize maintenance [6]. Subsequently, successful implementation of Internet of Things technologies will significantly automate the management of rolling stock and railway infrastructure.

One of the priority areas of development of the railway industry is the development of operational and technological communication (OTC), designed to organize instantaneous connection with subscribers to control the technological process and regulate the activities of railway facilities. In modern conditions to OTC networks such conditions as reliability, flexibility of the network, simplicity of network design, speed and error-free establishment of connections between subscribers and economic efficiency are presented [7].

In today's world there is an active and steady transition from analog transmission systems to digital transmission systems. Today, most wired transmission systems have switched to digital transmission systems, which in turn are compatible with existing analog transmission systems. As for the train radio systems, most of the railway line uses analog systems in the SW range, which, despite its longevity, have a number of drawbacks, as examples are the formation of interference directly on the antenna, the impact of weather conditions, wear and tear of portable and transportable radios, the high cost of maintenance.

Examples of solutions to these problems are: the introduction of foreign radios on a more modern element and technology base, orientation in the organization of station and repair-operational radio communication on trunking radio systems or systems with a cellular structure, which can be implemented on the basis of foreign-made equipment, also a promising direction is the use of satellite communication, the introduction of digital trunking radio standard TETRA [8].

TETRA is an open standard for digital trunked radio communications developed by the European Telecommunications Standards Institute ETSI. It is primarily a modern digital standard, developed on the basis of GSM technology and focused on the creation. communication systems that effectively and economically solve the problem of flexible communication between different groups of users with multi-level prioritization of calls and information security.

The TETRA standard uses TDMA-Time Division Multiple Access together with FDD-Frequency Division Duplex technology. The type of radio channel modulation - relative differential phase shift keying π 4 ∕ DQPSK. Forward Error Correction (FEC) and Cyclyc Redundancy Check (CRC) techniques are used in channel coding to detect transmission errors in the radio channel and to correct them.

Today there are three methods of channel division: FDMA, TDMA and CDMA.

FDMA - Frequency Division Multiple Access is a way of using radio frequencies when only one subscriber is in the same frequency range, different subscribers use different frequencies within a cell. It is an application of frequency division multiplexing (FDM) in radio communications. Therefore, until the initial request is complete, the channel is closed to other communication sessions. Full-Duplex FDMA transmission uses 2 channels, one for transmitting and one for receiving. FDMA was used in the first generation (1G) of analog communications and this principle is implemented in GSM (together with TDMA), AMPS, NAMPS, NMT, ETACS (American standard).

TDMA stands for Time Division Multiple Access. Reliable operation of local nodes is achieved with the introduction of TDMA technology. The principle of the new interface is to divide the channel into time limited slots (Time Slot). The number and duration of the channels is determined by the number of connected subscribers. Such a connection is characterized by reliability and high stability, as within the allotted time the user has access to the whole bandwidth. The data packet in the intermediate storage is divided into blocks, sorted and fills the time slot in the next order. As soon as the time is exhausted, there is a cessation of transmission for that user and a transition to the next client (after a short timing), the third, the fourth, etc.

CDMA (Code Division Multiple Access) is a code division multiple access method. This method differs from the other two most common methods of division of channels FDMA and TDMA by the fact that the codes in contrast to time and frequency are not an explicit resource of the communication channel. Despite the complexity of implementation, this method has been used in radio communications for quite some time, because it has very attractive advantages, which do not have other methods of multiple access.

Unlike analog systems, where you can observe a gradual degradation of voice quality with increasing distance, in digital systems, speech quality can be considered invariably high and independent of the distance from the base station.

Transmission and switching of signals in digital form allow to implement equipment on single hardware platforms. This allows to dramatically reduce the labor intensity of equipment manufacturing, significantly reduce its cost, energy consumption and dimensions. In addition, the operation of the systems is significantly simplified and their reliability is increased.

Obviously, there is a distance threshold at which the error level exceeds the correcting ability of the code and communication becomes impossible. Digital systems give a noticeable advantage in coverage and speech quality. Fig. 1 shows a comparative graph of the degradation of transmission quality in coverage and voice quality of MOS for analog and TETRA systems.

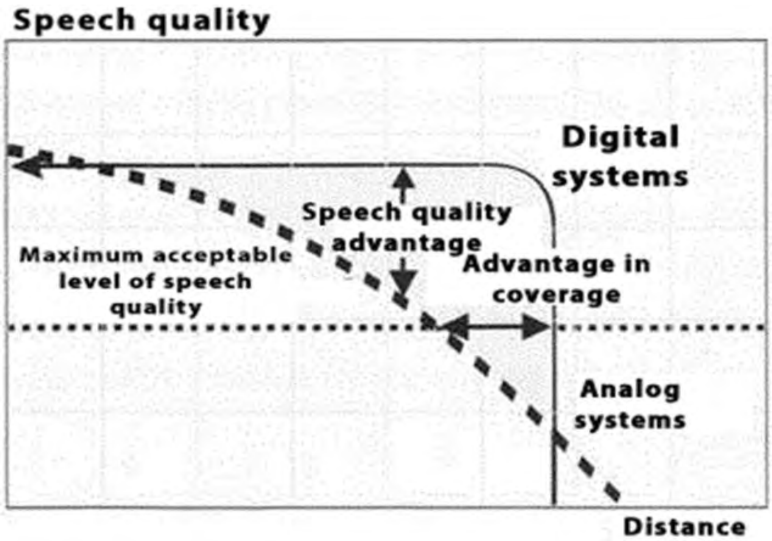

Fig. 1 Comparative graph of transmission quality versus distance for analog and digital systems

The main users of the TETRA standard are law enforcement agencies, the railway industry, airports, etc.

4. Conclusions

The trends of digitalization of the railway industry presented above are deepening due to the processes of globalization, internationalization of digital transformations in the field of doing business.

The rail industry is becoming more and more open and seamless. Digitalization in the railway industry is carried out not only through the introduction of new technologies, but also through the rethinking of traditional business models, adaptation to the digital environment of the post-industrial economy.

It can be predicted that the results of the application of economic forecasting methods and system analysis of revenue growth forecasts from the introduction of "end-to-end digital technologies" will indicate the positive dynamics of the development of the railway network technology market. The abundance of new products and solutions on the market points to the intensive digital transformation of the industry. An important feature of the applied and prospective digital technologies in the railway transport is the high level of synchronization and mutual linking of achievements from different areas, which allows for significant synergies.

The vast majority of modern digital technologies are already used or planned to be introduced in the railway of the national company Kazakhstan Temir Zholy. One of the priority areas of NC KTZ's development is the development of operational and technological communication (OTC) and the implementation of digital trunking radio communication standard TETRA.

It should be noted that due to the dynamic development of the digital sphere and digitalization, railway organizations of all countries will need to constantly update assessments, forecasts and action plans, and in this regard, a prerequisite is a regular analysis of best practices, identifying prevailing trends and trends to further take them into account when addressing their specific tasks, due to the characteristics of their activities and corporate strategy.

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Investigation of the Active Suspension in Small Cars

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Abstract

The paper investigates the issues related to the comfort riding of city-type cars. A city-type car was chosen as the object under investigation. The issue in standard cars is that proper assurance of the spring-to-unsprung mass ratio presents a complex task, as the car mass is not large. Moreover, load mass may affect total sprung mass, contribute to changes in the sprung-to-unsprung mass ratio, and, consequently, affect the suspension characteristics. The car under investigation features the McPherson suspension, but it does not provide riding comfort; hence, an active variable stiffness suspension is investigated for different loading cases. The study has shown that the characteristics, which almost do not change for all the loading cases, can be generated by changing the suspension parameters (stiffness and damping). The car moves on different road microprofiles (gravel road, uneven, and even asphalt concrete pavements), and vibration amplitudes are generated by using the active suspension, with the sprung mass moving at lower vibration frequency than the unsprung mass. The article analyses the suspensions used in the cars, and an application has been developed using the Matlab programming language. The application generates the amplitude-frequency characteristics for the quarter model of the car suspension, provides graphic depiction of the dynamic suspension model movements for different pavements and different loading cases.
KEY WORDS: *small car, active suspension, McPherson, Matlab*

1. Introduction

Recently, small urban cars have gained popularity around the world, with their low fuel consumption, air pollution characteristics, and reduced parking problems. However, this type of car also has negative characteristics. One of these is the comfort of the ride. The light weight of city cars (typically up to 1000kg) makes it more difficult to adapt the suspension of a standard mid-range car. Currently, the most popular suspensions still used in city cars are the McPherson strut independent suspension or the double wishbone independent suspension. It is known that these types of suspension do not serve their purpose properly. Also, for a small city car, the mass of the load has a significant influence on the overall mass of the car, which can affect the ratio of damped to undamped masses and can have a significant effect on the suspension performance.

Active or adaptive suspension is a computer-controlled suspension system that varies the stiffness of the shock absorber according to the road surface or dynamic characteristics. The damping force of the suspension can be controlled and measured. In this system, each quarter of the suspension can be individually controlled. Active suspension dampens vehicle body movements according to road conditions, and the suspension stiffness and damping are corrected over time. The active suspension is equipped with a direct action force generator that optimally distributes the effects of road irregularities on the suspension to achieve the best damping characteristics, thereby improving the vehicle's ride and handling stability.

The quarter model consists of an amortised mass (body quarter) and an undamped mass (wheel), springs between the body and the wheel (k_s) and between the wheel and the road (k_t), and a damping element between the body and the wheel (b_s) [1, 2].

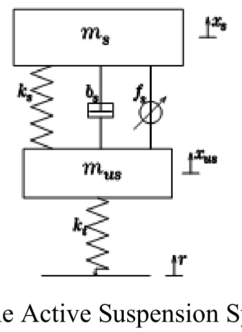


Fig. 1 Quarter of the Active Suspension System Model [1, 2]

To solve the linear active suspension system, the equations are written down and solved using the Lagrange method:

$$\frac{D}{D_t}\left[\frac{\partial T}{\partial \dot{q}_t}\right]-\frac{\partial T}{\partial \dot{q}_t}+\frac{\partial U}{\partial q_t}=Q_t\,; \tag{1}$$

$$\begin{cases} m_s\ddot{x}_s+b_s\left(\dot{x}_s-\dot{x}_{us}\right)+k_s\left(x_s-x_{us}\right)-f_s=0; \\ m_s\ddot{x}_{us}+b_s\left(\dot{x}_{us}-\dot{x}_s\right)+k_s\left(x_{us}-x_s\right)+k_s\left(x_{us}-x_r\right)+f_s=0; \end{cases} \tag{2}$$

$$\begin{cases} \ddot{x}_s+\dfrac{1}{m_s}\left[b_s\left(\dot{x}_s-\dot{x}_{us}\right)+k_s\left(x_s-x_{us}\right)\right]=\dfrac{f_s}{m_s}; \\ \ddot{x}_{us}+\dfrac{1}{m_{us}}\left[b_s\left(\dot{x}_{us}-\dot{x}_s\right)+k_s\left(x_{us}-x_s\right)+k_s(x_{us}-x_r\right]=\dfrac{-f_s}{m_{us}}, \end{cases} \tag{3}$$

where m_s − amortised mass (kg); x_s − the displacement of the suspension (m); x_{us} − the wheel displacement (m); x_r − the height of the road roughness (m); k_s − stiffness of the suspension spring; b_s − suspension damping; f_s − controller force.

The non-linear suspension system improves the vibration damping performance of vehicle suspension systems by electronically controlling the suspension. As the suspension is located between the body and the wheel, it has a significant influence on ride comfort. Active suspension monitors and optimises road conditions to ensure the best suspension performance and comfort [3]. The active suspension graph in Fig. 2 shows the displacement of a non-linear spring.

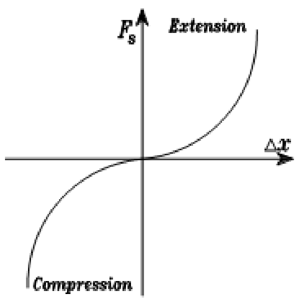


Fig. 2 Displacement graph for a non-linear spring [4]

Force calculation:

$$F_s=k_{ls}\left(\Delta x\right)+k_{ns}\left(\Delta x\right)^3, \tag{4}$$

where: k_{ls} and k_{ns} − spring stiffness.
The displacements are calculated as follows:

$$\Delta x=\left(x_s-x_{us}\right). \tag{5}$$

Solving the Lagrangian equations will yield nonlinear equations for the active suspension system [4].

$$\begin{cases} m_s\ddot{x}_s+b_s\left(\dot{x}_s-\dot{x}_{us}\right)+F_s-f_s=0; \\ m_s\ddot{x}_{us}+b_s\left(\dot{x}_{us}-\dot{x}_s\right)+F_s+k_s\left(x_{us}-x_r\right)+f_s=0. \end{cases} \tag{6}$$

The aim of this work is to develop a program to investigate the active suspension of a city car, to graphically represent its performance under different road and load conditions, and to perform a suspension test with the program at a vehicle speed of 10 m/s for the following load cases: car with driver; car with driver and passenger; fully loaded car. The road microprofiles used in the work are: gravel road; rough asphalt and smooth asphalt.

2. Car Suspension Test

In order to find out the effects of road roughness on the dynamic quarter model of a car, the road profile must be analysed. Since road roughness is generally expected to be random, many sources in the literature use statistical analysis techniques. In this case, the classical roughness description scheme is used. The average height of the roughness is calculated by selecting the position of the zero line.

$$\bar{h}=\lim_{L_h\to\infty}\frac{1}{L_h}\int_0^{L_h}h\left(x\right)dx\,. \tag{7}$$

The profile is recalculated by moving the zero line to height $\bar{h}$. The dispersion can then be determined.

$$\sigma_h^2 = \lim_{L_h \to \infty} \frac{1}{L_h} \int_0^{L_h} h_0^2(x)\,dx\,, \tag{8}$$

where $h_0(x)$ is the height of the bumps from the new zero line (m); L_h is the length of the measured section (m).

Table

Profile of the road [3]

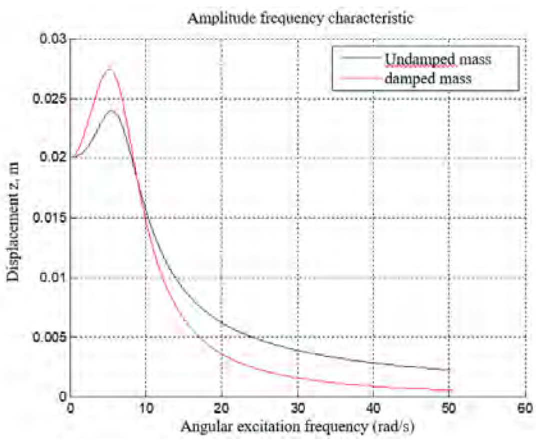
Type of road surface	Roughness variance σ_q (mm)	Characteristic wavelengths (m)
Smooth asphalt concrete	3.492	50 – 52
Uneven asphaltic concrete	12.437	75 – 77
Gravel	13.667	45 – 47

The road profile was measured using a VAS-21 vibration analysis and processing system, a PicoScope 3424 signal converter, two low-frequency and two mid-frequency sensors. Data were recorded in real time on a computer, recorded, and processed using the software PICOSCOPE 5.13.7 software [5-6].

The measurements were carried out in 2021 in Kaunas. The uneven, potholed asphalt-concrete pavement was surveyed on Jonavos St. between Varnių Bridge and Šiaurės Avenue. Smooth asphalt concrete pavement was investigated on the Via Baltika road between the Mastaičiai viaduct and the Garliava intersection. The test was carried out at speeds of 50, 60, 70 and 80 km/h. The measurement time was 50s. Sensors were mounted on suspension arms to measure the vibrations of the undamped mass [2, 7, 8].

2.1. Amplitude-Frequency Characteristics

The quarter model of the car is investigated under different load cases. The excitation amplitude is 20 mm. The resulting amplitude-frequency characteristics for the front quarter of the car suspension are given in the figure below.



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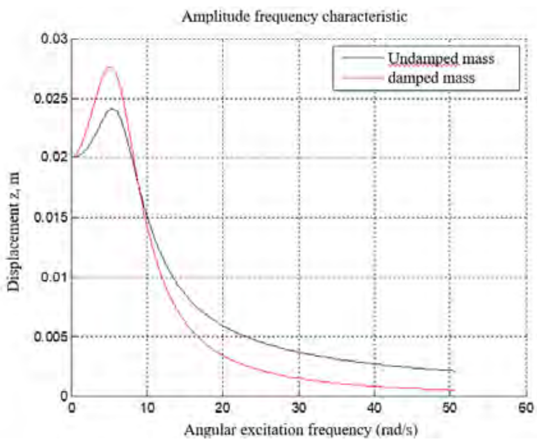

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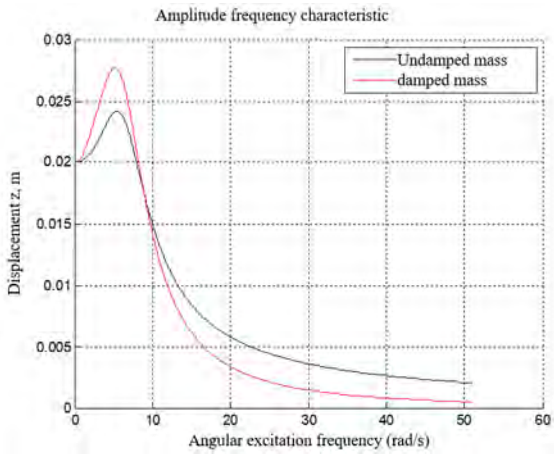


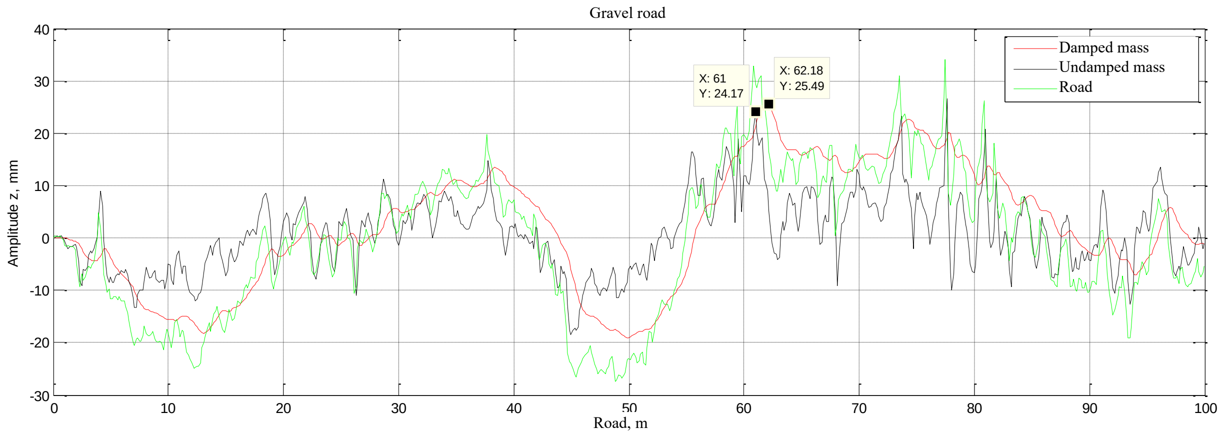
c

Fig. 3 Amplitude-frequency characteristics of the front suspension quarter: a – with driver only; b – with driver and passenger; c – with full load

We can see that the amplitude-frequency characteristics of the damped and undamped masses vary only slightly as the load case changes. This is due to the fact that we have an active suspension system, so that as the load changes, the suspension parameters - stiffness and damping - change accordingly. It can be seen that the damped mass reaches an amplitude higher than the unamplified mass at lower angular excitation frequencies, but as the frequency increases further, the damped mass oscillates faster than the unamplified mass.

2.2. Suspension Test on Gravel Roads

A study of the front axle suspension quarter model is carried out for different load cases when the car is driven on a gravel road at a constant speed of 10 m/s.



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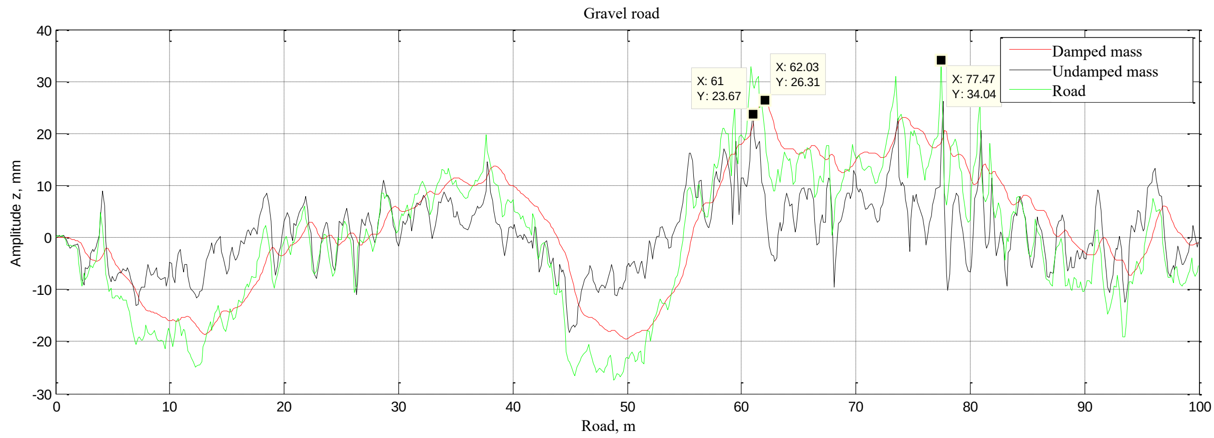

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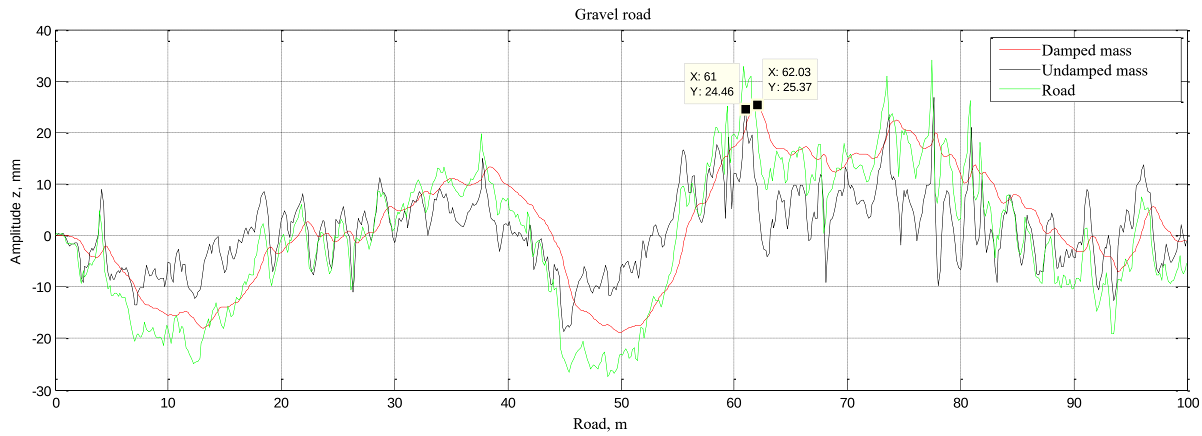

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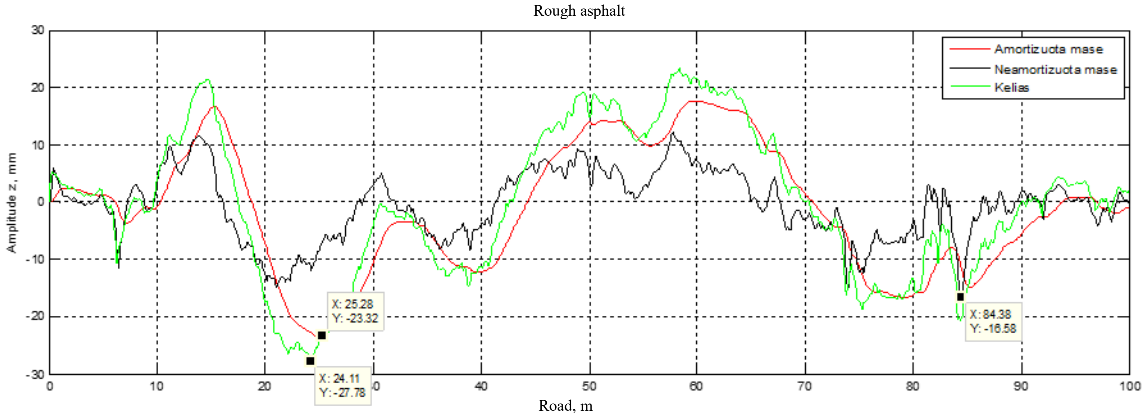
Fig. 4 Movement diagram for the damped and undamped masses of a quarter model of the front axle suspension of a car: a − car with driver; b − car with driver and passenger; c − car fully loaded

Fig. 4 shows the evolution of the undamped and amortised masses of the front axle suspension quarter-model with respect to the road. The maximum height of the bumps on a gravel road is 34 mm. When only the driver is in the car, the maximum amplitude of the damped mass is 26 mm. The amplitude of the damped mass reaches this amplitude when the height of the bumps reaches 32 mm. At the same gravel road roughness height, the undamped mass has a maximum oscillation amplitude of 23 mm.

2.3. Suspension Test on Uneven Asphalt Concrete

Rough asphalt concrete is a road where the variance of the roughness is close to that of a gravel road, reaching 12,437 mm.

A study of the front axle suspension quarter model is carried out under different loading cases at a vehicle speed of 10 m/s.



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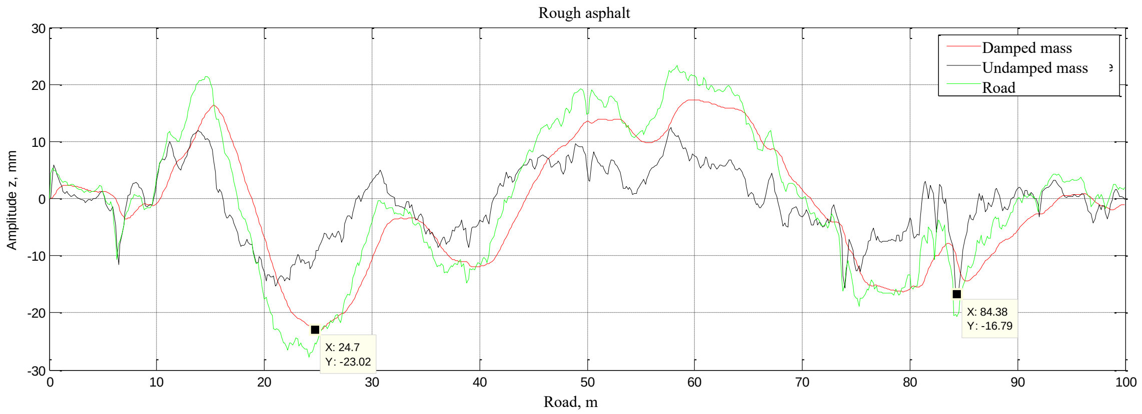

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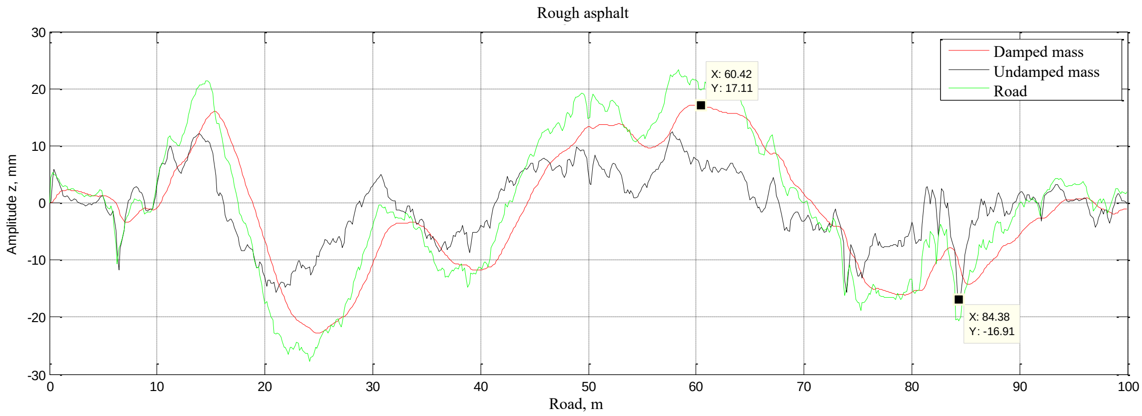

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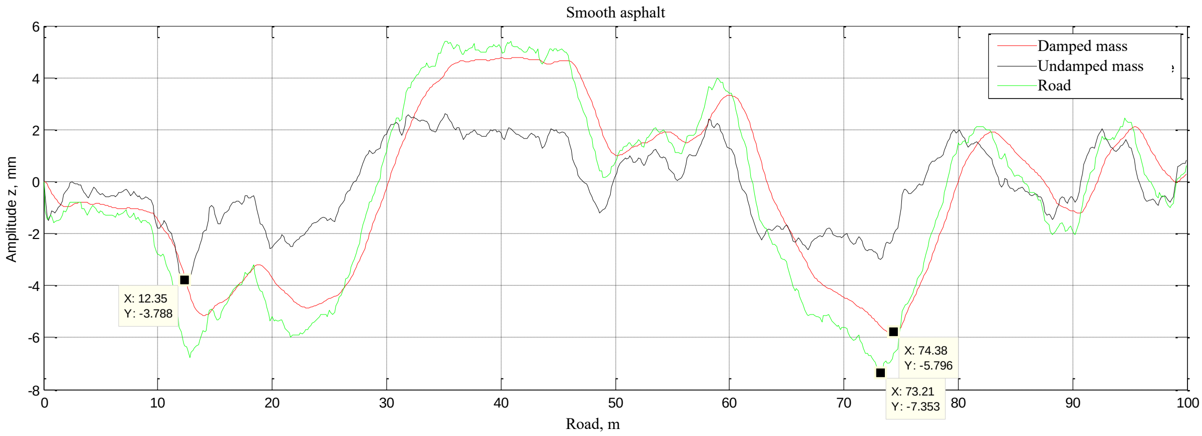
Fig. 5 Movement diagram for the damped and undamped masses of a quarter model of the front axle suspension of a car: a − car with driver; b − car with driver and passenger; c − car fully loaded

Fig. 5 shows the variation of the movement of the undamped and damped masses of the front axle suspension quarter-model with respect to the road. The maximum height of the bumps in uneven asphalt concrete is 27 mm. When the car is driven at 10 m/s by the driver in Fig. 5, a, the maximum amplitude of the damped mass is 23 mm. This amplitude is reached when the roughness of the height of the asphalt pavement reaches its maximum point. The maximum amplitude of the undamped mass is 16 mm. This value is reached when the roughness of the asphalt pavement reaches 20mm.

2.4. Suspension Test on Smooth Asphalt Concrete

Smooth asphalt concrete is a road with a roughness variance close to that of a gravel road, i.e. 3.492 mm. The test shall be carried out at a vehicle speed of 10 m/s.

A study shall be carried out on the quarter model of the front axle suspension under different load cases.



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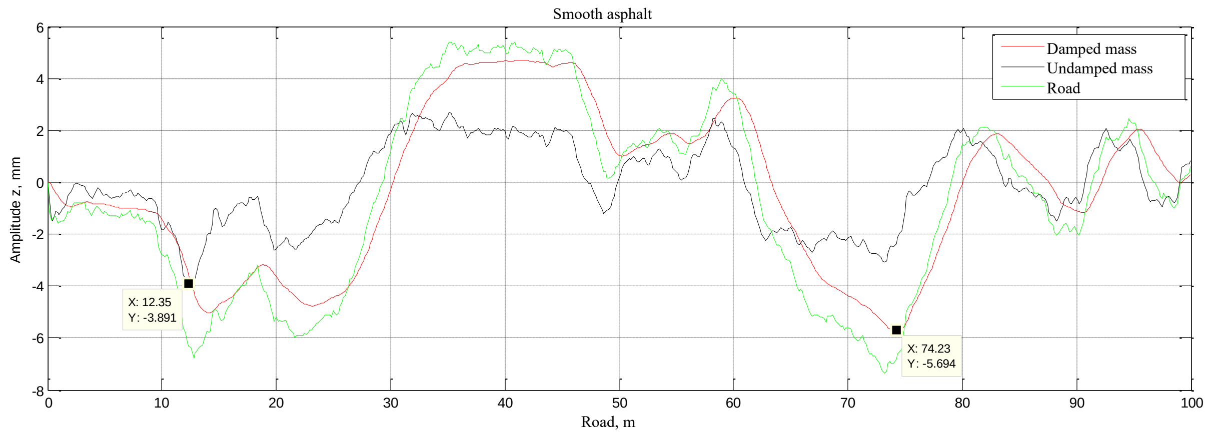

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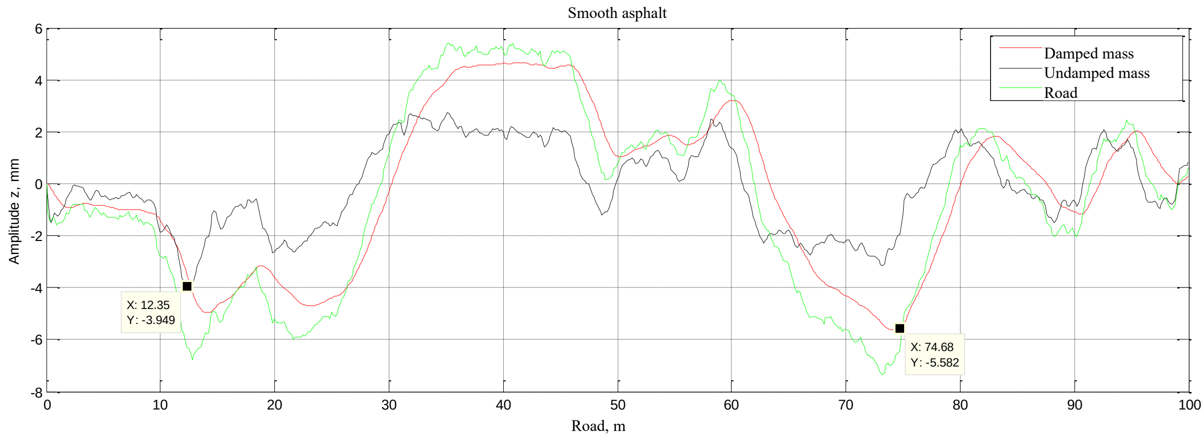

c

Fig. 6 Movement diagram of the damped and undamped masses of a quarter model of the front axle suspension of a car: a – car with driver; b – car with driver and passenger; c – car fully loaded

Fig. 6 shows the variation of the movement of the undamped and damped masses of the front axle suspension quarter-model with respect to the road. On smooth asphaltic concrete, the maximum height of the bumps is 7 mm. At a speed of 10 km/h, the amplitude of the oscillations is higher for the damped mass. When the vehicle is driven by the driver (Fig. 6, a) the maximum amplitude of the damped mass is 5 mm. This amplitude is reached when the height of the asphalt bumps reaches a maximum point. The maximum amplitude of the undamped mass is 4 mm. This value is reached when the roughness of the asphalt concrete reaches a height of 6 mm.

When the vehicle is fully loaded (Fig. 6, c), the maximum amplitudes reached are 6.5 mm for the damped mass and 2.9 mm for the undamped mass.

In this case, on a smooth asphalt-concrete surface, the differences in suspension oscillations between the front and rear axles are not as pronounced as in the previous cases. In the quarter-model suspension test with driver and with both driver and passenger, the amplitudes of the oscillations of the damped and undamped masses on the rear axle did not change, even though the damped mass did change (increase). Compared to the amplitudes of the front axle suspension oscillations, the amplitude of the amortised mass of the rear axle suspension is 2 mm higher and that of the undamped mass is 2.5 mm lower.

As the vehicle is loaded more, the amplitude of the damped oscillations of the rear axle mass decreases and the amplitude of the unamplified mass increases.

2.5. Suspension Test Over a Deceleration Hump

A deceleration road hump is a means of reducing speed on dangerous sections of the road. The dimensions of a speed reduction road hump are: height 50 mm; width 900 mm. When driving a city car over the deceleration road hump, the maximum amplitude of the undamped mass is 14mm. The amplitude of the undamped mass oscillation is 42 mm. We can see that the undamped mass moves below zero after passing the deceleration hump and reaches its maximum negative amplitude of 14mm. After passing the deceleration road hump, both the amortised and undamped masses reach their equilibrium point after 2.5 m.

The amplitudes of the oscillations of the damped and undamped masses of the quarter model of the front suspension of the vehicle under test, when the vehicle is driven by the driver only, are shown in Fig. 7 and the settling time of the oscillations of the damped masses in the front axle suspension quarter model is shown in Fig. 8.

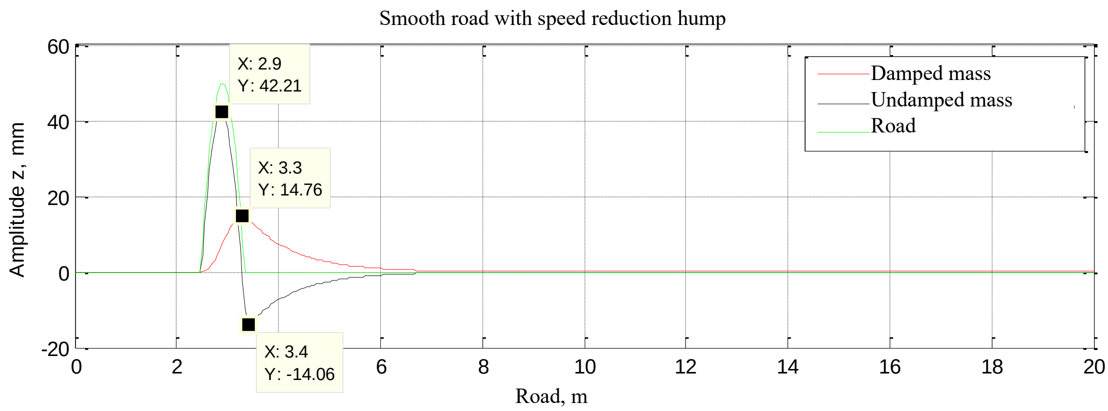

Fig. 7 Response of the quarter model of the automotive front suspension to the deceleration road hump

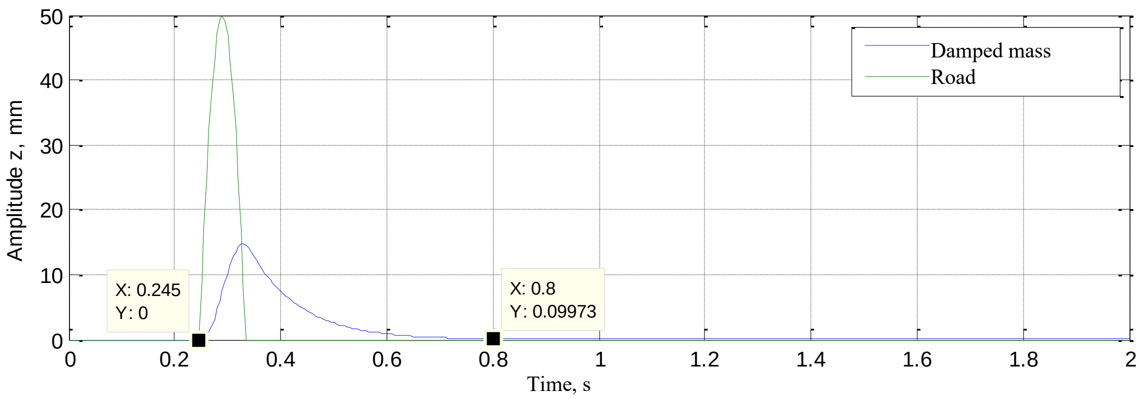

Fig. 8 Settlement time of the oscillations of the damped mass of the quarter model of the small car suspension

Fig. 8 shows that the front mass of the car reaches its equilibrium point in 0.55 s after passing the 900 mm wide deceleration hump.

The oscillation amplitudes of the damped and un-damped masses of the rear suspension quarter model for the driver-only vehicle are shown in Fig. 9.

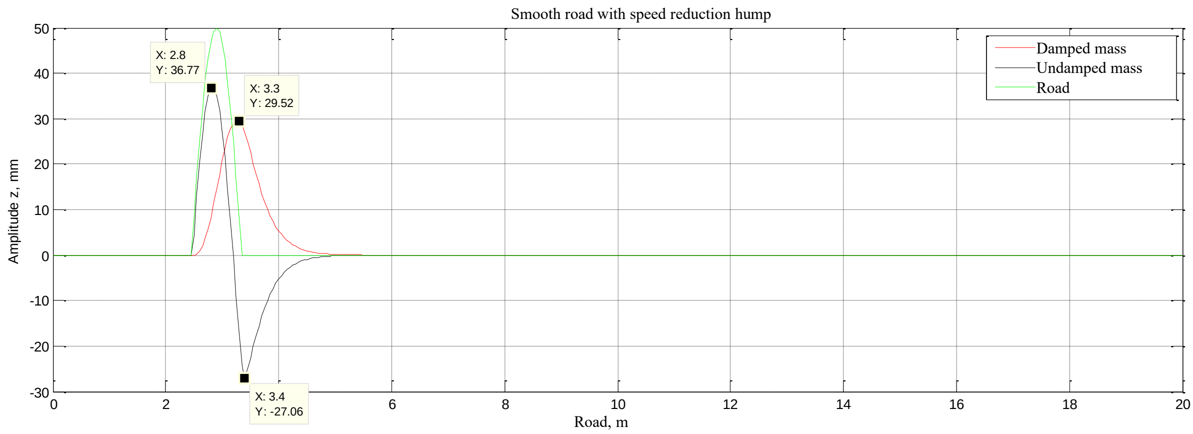

Fig. 9 Response of the small car front suspension quarter model to the deceleration hump

When the rear of a city car is hit by a deceleration road hump, its damped mass reaches a higher amplitude than the damped mass of the front of the car. The maximum amplitude of the damped mass of the quarter car model is 29 mm. The undamped mass has a positive oscillation amplitude of 36 mm and a negative amplitude of - 27 mm. The amortised and undamped masses reach their equilibrium point at a distance of 1,2 m. Thus, the rear-axle quarter-suspension model settles twice as fast as the front-axle quarter-suspension model. The settling time of the damped mass in the rear axle quarter suspension model is shown in Fig. 10. Fig. 10 shows that the front mass of the car reaches its equilibrium point in 0.27 s after passing the 900 mm wide deceleration hump.

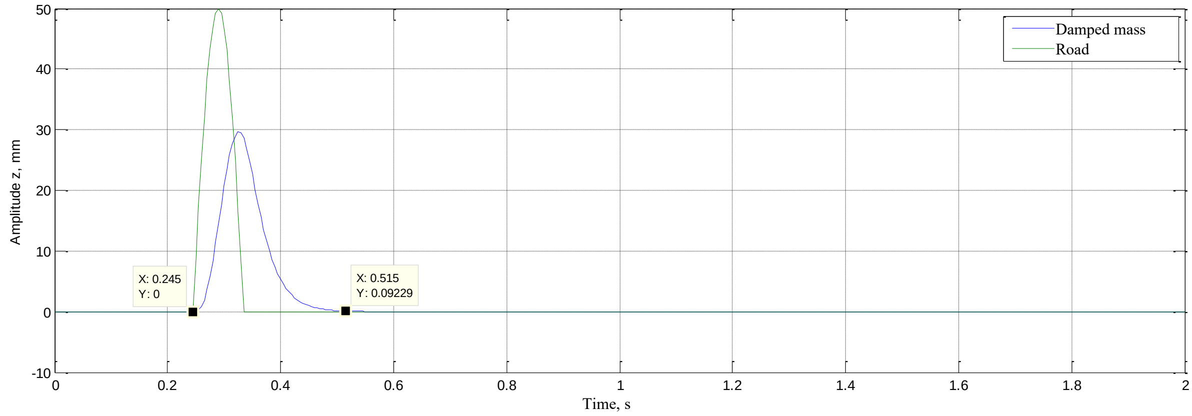

Fig. 10 Settlement time of the oscillations of the damped mass of the quarter model of the small car suspension

3. Conclusions and Recommendations

Current passenger car suspensions and their constituent elements have been analysed. A Matlab program has been developed to present the amplitude-frequency characteristics of the suspension and to graphically represent the dynamic motions of the suspension model.

It was found that the mass distribution of the front suspension of the car under study differs by 10% when the car is with the driver only and when the car is fully loaded. The mass distribution for the rear axle of the car differs by 40% when the car is with the driver only and when the car is fully loaded. This sharp change in the mass distribution is due to the fact that, when the car is fully loaded, a large proportion of the mass is borne by the rear part of the car, as a heavy load (50 kg) is placed in the boot of the car and two passengers are placed in the back of the car.

A dynamic suspension quarter is developed. The study has shown that by changing the suspension parameters, i.e. by making the car suspension active (adaptive), it is possible to maintain the amplitude of the damped masses' glow and the ride comfort. The study was carried out at a speed of 10 m/s on different types of roads. On a gravel road, the amplitudes of the glows are up to 26 mm for the shock-absorbed mass and 23 mm for the unabsorbed mass. On rough asphaltic concrete roads, the oscillation amplitudes are 23 mm for the damped mass and 16 mm for the undamped mass. On a smooth asphalt road, the small car has a vibration amplitude of 5 mm for the damped mass and 4 mm for the unamplified mass. A study was also carried out with the car on a deceleration hump. When the car is driven by the driver alone, it was found that the damped mass of the front part of the car reaches twice the maximum amplitude of the oscillations as that of the rear part of the car, but the time to return to the equilibrium position is twice as long.

To improve the comfort of the ride of this type of car, it would be optimal to use an active suspension capable of adapting to different loading conditions. In terms of value for money, the most appropriate suspension option would be to use air suspension elements that allow easy adjustment of the main suspension parameters in such small urban cars.

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Software Tool for Identification and Classification of Soft Targets of Transport Infrastructure

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Abstract

This article is focused on our research dealing with the protection of the transport infrastructure. We create the software tool which is used to identify and classify soft targets of the transport infrastructure, which will enable the identification and evaluation of individual soft goals using industry-specific decision criteria. These criteria consider, among other things, the attractiveness of these soft targets and are understood as time-varying. The result was realized in the form of a web application, which is operated within the protected environment of Tomas Bata University in Zlín. The content is based on the document Methodology of identification and protection of soft targets of transport infrastructure which was presented during the conference last year [1].
KEY WORDS: *soft targets, transport infrastructure, protection, software tool*

1. Introduction

This article presents our research in the area of soft targets. Nowadays, the protection of soft targets is a significant area in security and safety. The attacks, especially the violent attacks, show that the danger is all around us, and we must prepare for this.

In the last years, we are focused on two areas – the transport infrastructure [1-3] and the cultural events [4-7]. The deal is to create the methodologies and then the software tools, which help in the planning of the security measures and increasing the security.

In this article, we describe the software tool for the identification and classification of soft targets of transport infrastructure. The first step in the planning of security measures is thinking about a chosen object, current security, identification of assets, threats, and risks. In the case of the protection of soft targets, the protected assets are people (employees, visitors etc.). The methodology, presented last year [1], deals with the process to determine which objects are the soft targets. The software helps people to better orientate themselves in the created methodology and allows them to manage access to objects according to a set level of access. Thanks to this, it is possible to have an overview of objects to which, for example, the manager is authorized, compare them with each other and work with the results of the analysis.

The article describes the whole process of creating a web application, from the technologies used, through the determination of access levels to the structure of working with the tool.

2. Software Tool for Identification and Classification of Soft Targets of Transport Infrastructure

The software tool is used for the identification and classification of soft targets of transport infrastructure, which will enable the identification and evaluation of individual soft targets using industry-specific decision criteria. These criteria take into account, inter alia, the attractiveness of these soft targets and are understood as time-varying.

The result was realized in the form of a web application, which is operated within the protected environment of Tomas Bata University in Zlín. The content is based on the document Methodology of identification and protection of soft targets of transport infrastructure.

The web application is available at the link: https://mekkecile.fai.utb.cz/nastroj-pro-identifikaci-a-klasifikaci-mekkych-cilu/

2.1. Web Application Creation

The outputs of the project were implemented using HTML [8], PHP [9], JS [10] and MySQL [11] technologies. The resulting application is hosted via CMS WordPress at the web address https://mekkecile.fai.utb.cz/nastroj-pro-identifikaci-a-klasifikaci-mekkych-cilu/. Active and responsive forms are solved as an on-page application with application logic created using PHP. All calculations are performed on the server-side and the application does not interfere with the client's browser.

The relational database MySQL was chosen for data storage. The data is stored in tables that extend the

WordPress database backend, and all data operations are validated by the security features of WordPress itself. This ensures the security of the application against future attacks. Validation functions are updated together with the WordPress carrier application.

The data model extends the functionality of WordPress user rights by user groups according to the project (see Access levels). New users can only register for a basic account without any permission from existing objects. These types of users just receive a login to the system and wait for the approval of the site admin.

The assignment of higher permissions is subject to the explicit intervention of the site administrator. The user can only change the password. Passwords are stored in unreadable and secure (hashed) forms.

The forms themselves have validation functions implemented to control the entry of the required data. Without them, the calculation will not be performed and the user will be informed where the error occurred. However, the data already entered by the user remains in the form.

The WordPress carrier application is kept up to date. Application and runtime management takes place min. 2x a month. In the event of a serious WordPress vulnerability, immediately. The entered data is regularly backed up and its continuity over time is ensured.

2.2. Access Levels

Prior registration is required to use this software tool. It is used to determine the hierarchy of people who use the application, so they can store, manage, etc.

The following rights levels are set within the application (Figs. 1-4):

- Admin
- Supervisor
- Gestor
- User

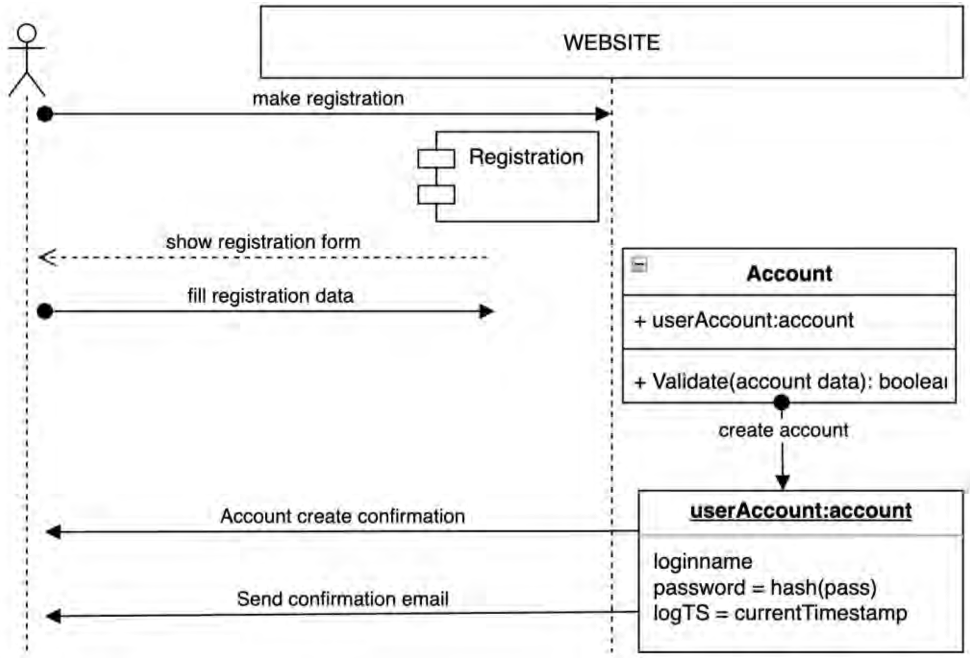

Fig. 1 User registration

Admin (one embedded local account):
- Web application management;
- The right to generate login details;
- Able to create a membership in next roles for registered user.

Supervisor - Ministry of Transport:
- Access to all entered data;
- It is not possible to change the entered data;
- It is not possible to generate access.

Gestor - a superior body that will have more objects under it:
- Entering basic information about yourself - the user will then choose this manager (eg Czech Railways);
- Access to all entered data;
- It is not possible to change the entered data;
- It is not possible to generate access.

User:

- Entering data about one specific object (must have rights on it);
- Preview only your specified object;
- Possibility to change data;
- The ability to delete data.

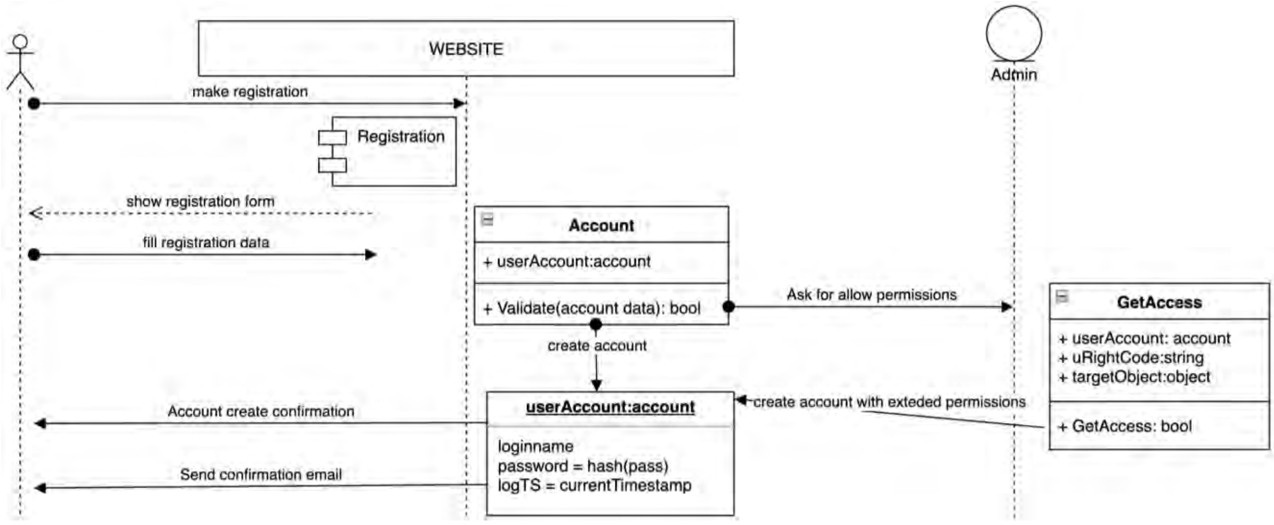

Fig. 2 Gestor registration

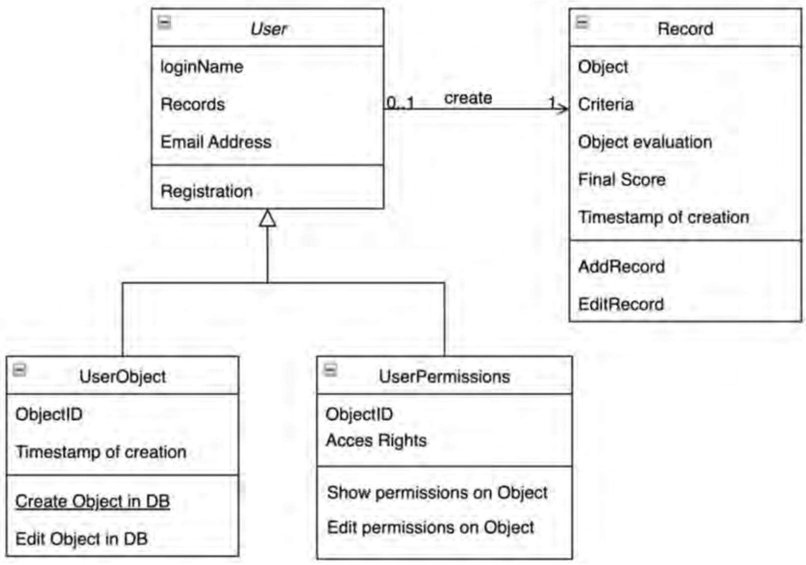

Fig. 3 Scheme of activities after login - User

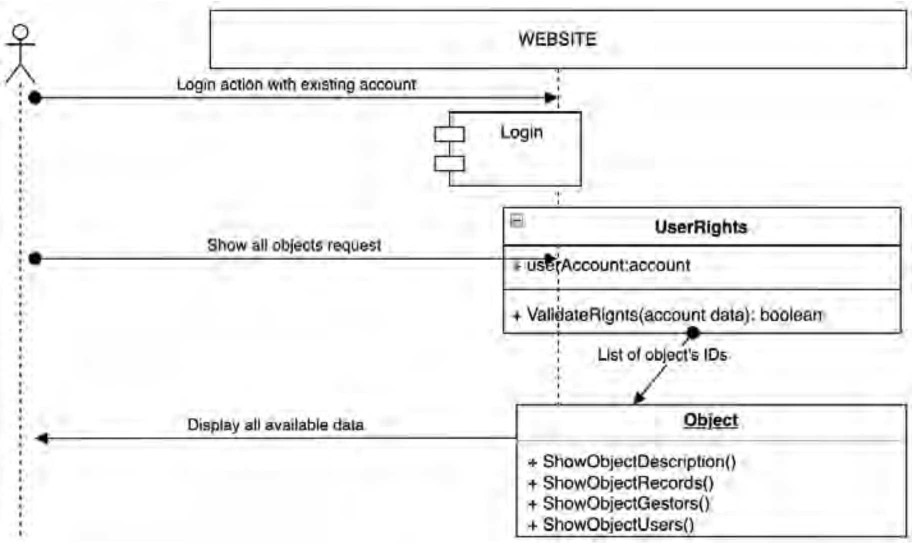

Fig. 4 Display of all objects by the supervisor

2.3. Structure of Web Application

The web application consists of several parts:

1. Home page of the web application
2. Introductory page of the project
3. Registration
4. Login
5. Tool for identification and classification of soft targets
6. User profile
7. Contacts

2.4. Tool for Identification and Classification of Soft Targets

The software tool itself is divided into two parts:

- Passenger road transport (SOD)
- Rail passenger transport (ZOD)

The algorithm for identification and classification of selected soft targets and at the same time for determining the riskiness of the selected element is represented by the following sequence of logical and interconnected steps (Fig. 5):

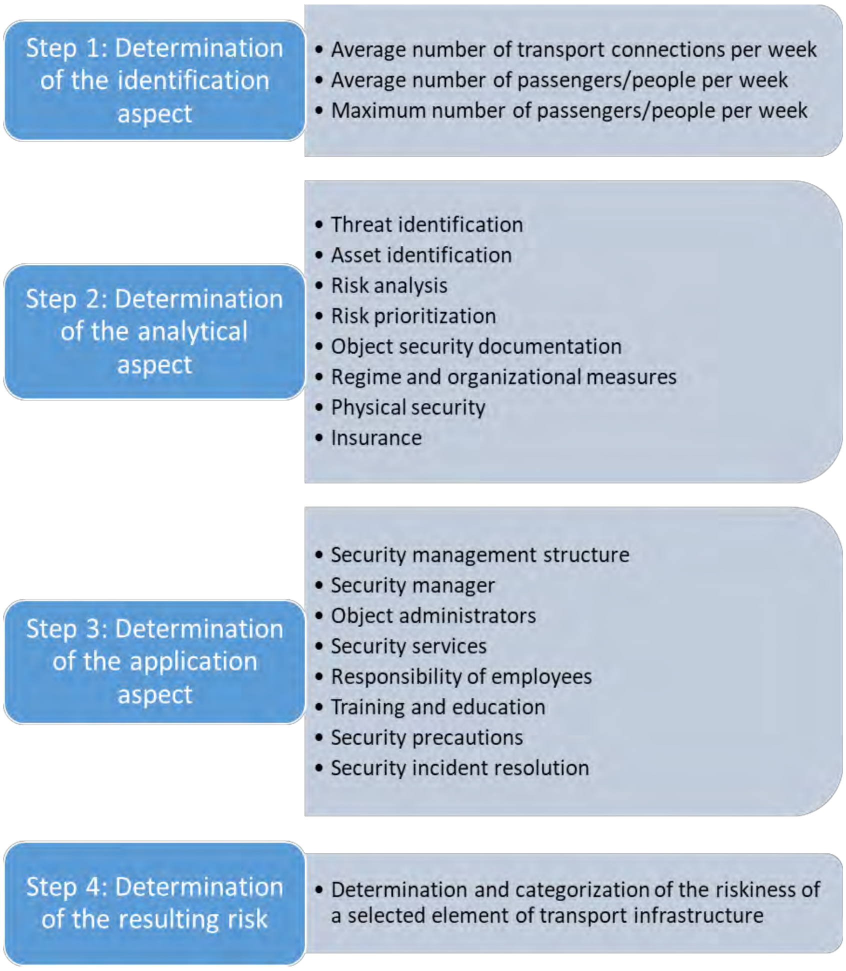

Fig. 5 The algorithm for identification and classification of selected soft targets

4. Conclusions

The article described the creation of a software tool that aims to extend and make accessible our methodology for identifying and classifying soft targets in transport infrastructure. The tool should be simple, and easy to use. The next step is the connection with the interactive map, where it will be possible to draw the analyzed objects, filter them according to the specified criteria, etc.

The web application is available at the link: https://mekkecile.fai.utb.cz/nastroj-pro-identifikaci-a-klasifikaci-mekkych-cilu/

Acknowledgement

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Mobile System for Determination of Quality Indicators of Wagon Movement under Operating Conditions

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Abstract

The organization of freight trains in Ukraine is an important factor in the integration of the country's railway transport into the European system. Currently, there is a situation that requires significant renewal of the freight car fleet with modern wagons to meet the requirements of freight traffic. Another significant shortcoming of the railway transport of Ukraine is the limitation of the speed of trains, which include freight cars with reduced tare in an empty state, so at the moment the issue of improving methodological and software and testing tools to assess the quality and safety of such cars. At present, laboratory cars are used in field tests related to the assessment of traffic quality, acceptance and commissioning of railway rolling stock, but the current state of development of measuring equipment allows in most cases to abandon the use of such cars in running tests of units rolling stock in favor of mobile software and hardware.
KEY WORDS*:* *mobile system, measuring equipment. freight car, traffic indicators, exploitation, dynamic tests.*

1. Introduction

Traffic safety - a set of organizational and technical measures aimed at ensuring trouble-free operation and maintenance of railway structures, tracks, rolling stock, equipment, mechanisms and devices. Important characteristics of the quality of railway rolling stock include vertical and horizontal dynamics, the coefficient of stability of the wheel from derailment, frame forces and body acceleration, which largely depend on the weight of the rolling stock and the interaction of the crew and track [7-9, 12, 14]. Therefore, the definition and evaluation of indicators that characterize the ride quality and safety should be based on in-depth studies of traffic dynamics. Operation of rolling stock and complex technical software and hardware systems are usually prone to failure. The reasons for such failures may be: non-compliance with manufacturing technology, difficult conditions of use, non-compliance with the requirements for the operation of such systems and rolling stock, aging and wear of components. Therefore, an urgent and important task is the introduction of periodic tests and diagnostics of rolling stock on the railways of Ukraine during their life cycle.

Currently, the development of measuring equipment and systems makes it possible to implement advanced instrumental and software approaches to assessing the quality and safety of trains and taking measures to prevent accidents. Successful experience in the implementation of diagnostic systems for locomotives and passenger cars justifies the need for further improvement of methods and tools for experimental assessment of dynamic qualities and indicators of quality and safety throughout the period of operation of rolling stock.

The above indicates the relevance of addressing issues of improving methods and tools for experimental assessment of quality and safety of freight cars with reduced tare, including by improving the methodological and software and testing tools.

2. Materials and Methods

To assess the quality of safety of carriage movement, locomotives and other types of rail rolling stock, there is a variety of approaches to assessing safety conditions and solving this problem.

The paper [1] describes the results of studies of the strength of the freight car. But the purpose of these studies was to assess the structural reserves, rather than indicators of the quality of movement of freight cars. The material [2] describes the prospects for improving the design of cars by increasing the service life. But it is proposed to increase the service life of the freight car by improving their design properties. In the material [3] modern methods of car dynamics and vibration theory are used to build a mathematical model for determining the accelerations in the supporting structure of the car body. Work [4] describes the improvement of the strength of the car body structure to ensure a reliable attachment to the deck of the railway ferry. The creation and use of a dynamic model that will take into account the quality of the movement of cars is not described. Estimation of the dynamics of an open car with a platform is described in [5]. The calculation is performed in MSC Adams. The work [6] describes the capacity of the railways intended for the transportation of raw materials and finished products of the metallurgical industry. Material [10] describes the influence of the rolling profile of the wheels of the bogie on the overall dynamics of the rolling stock. In this case, no attention was paid to the simulation of the corresponding wear and tear and the study of dynamic qualities. The work [11] is devoted to the description of the results of improving the dynamic qualities of rolling stock during the passage of curved sections of the track by improving the relevant structural elements. Articles [13] describe the development of the load-bearing structure of a covered freight car, the peculiarity of which is that the body elements are made of round tubes, but the paper does not describe how to determine the dynamics of the car and equipped with new generation couplings. In [15] the peculiarities of the design and manufacture of open freight cars of the new generation with a frame of round pipes, which allows to reduce costs. Work [16] describes the study of the dynamic load of the container in the combined train during transportation by train ferry.

2.1. Practical Research

The software for evaluating the obtained experimental data of traffic quality indicators was developed in the LabView software shell. The LabView software system implements the process of in-depth processing of the results of running dynamic tests to identify relationships between oscillating processes of the wagon frame, estimates of the frequencies at which there is interaction between them and the levels of interaction. The above processing of test results is to perform correlation and spectral analysis of the processes studied for different elements of the wagon frame. The values measured during the tests are added to a multidimensional time series $X(t)\begin{bmatrix} X_1(t) \\ X_p(t) \end{bmatrix}$, in which each row $X_p(t)\left[x_{p1}...x_{pn}...x_{pN}\right]$ – is a one-dimensional series of one measuring channel.

Table shows a block diagram of the developed software for evaluating the obtained experimental data of traffic quality indicators and consists of 5 main units.

Table

Flowchart software

Unit 1	Input processing parameters and location of the resulting file
Unit 2	Read binary data from primary files. Convert data from binary to text and numeric
Unit 3	Determining the data set used in further work. Ratio of GPS data to data from strain gauges and accelerometers
Unit 4	Filling the data set according to the specified processing requirements in unit 1
Unit 5	Record the resulting file in text form which is a chart

Fig. 1 shows the example of an oscillogram of the resulting acceleration measurement file.

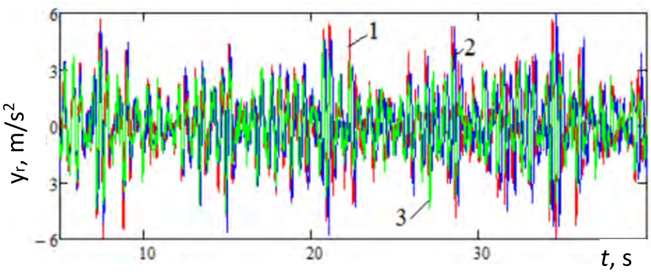


Fig. 1 Example of an oscillogram of the resulting acceleration measurement file

Next, the resulting file must be filtered with a linear digital filter. Digital Butterworth filter of the LABVIEW software shell function is used to assess the safety and quality of rolling stock movement (Fig. 2).

The Butterworth filter transfer function is shown below:

$$K(\omega) = \frac{1}{\sqrt{1 + \left(\frac{\omega}{\omega_0}\right)^{2n}}}, \tag{1}$$

where ω_0 – is the cutoff frequency (it is 1 rad / s); n – is the order of the filter.

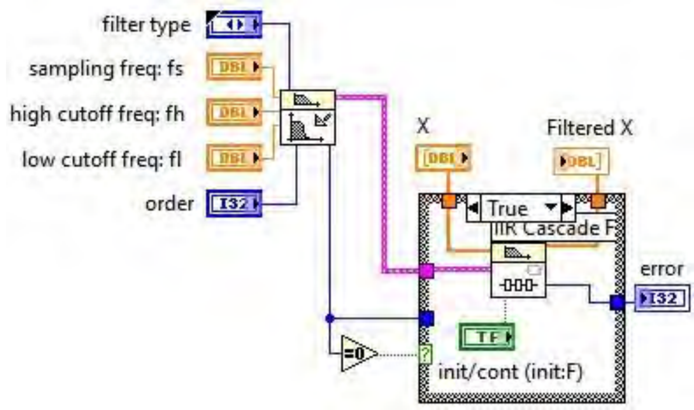
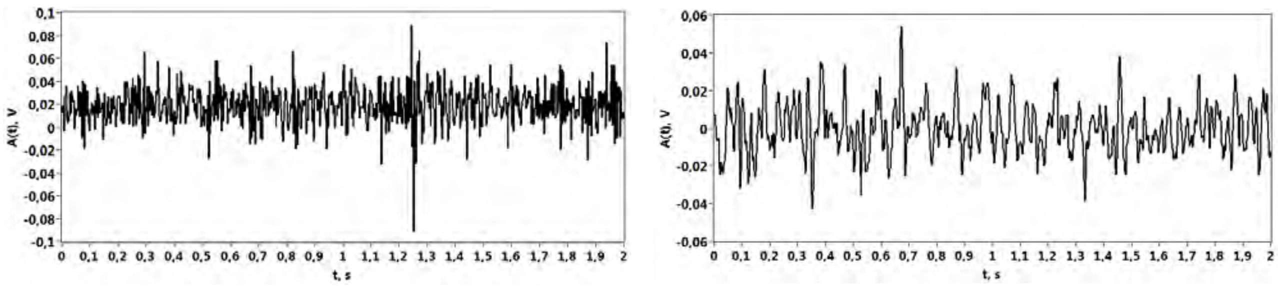


Fig. 2 Butterworth filter block diagram

The transmission factor at 0 is often1, at the cutoff frequency, regardless of the order of the filter is $1/\sqrt{2}$ = 3dB. At ω is approaching ∞ The frequency is approaching zero. The frequency of the Butterworth filter is as flat as possible at $\omega = 0$ and $\omega = \infty$.

In Fig. 3 shows the results of signal filtering, before filtering (Fig. 3, a) and after (Fig. 3, b) passing the filter.



a b

Fig. 3 Example of filter operation

2.2. Results and Discussion

The software of the mobile system of data collection and registration performs registration, storage and visualization of changes in information channels (accelerometers, strain gages). The readings of the GPS module are used to analyze the influence of speed of movement on the change of research parameters. In Fig. 4 shows a flowchart of the system of collection and registration of measured parameters.

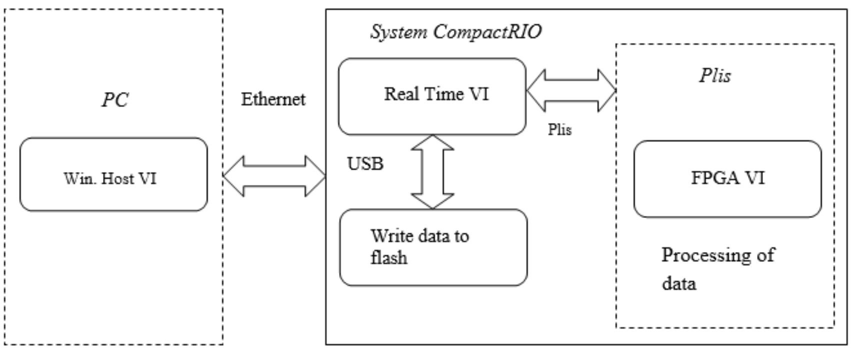


Fig. 4 Flowchart of the system

The software of the mobile system is developed according to the scheme, which divides it into three groups: virtual (HOST VI on the control PC), Real Time VI on the controller (with its own operating system) and FPGA VI on FPGA.

Functionality performed with HOST VI on a workstation with Windows software:

– storage and access to data;
– interface output.

On the controller in Real Time VI in real time the functionality is performed: - processing of registered data;

– recording process management;
– save data to controller and Flash drives.

Functionality performed in FPGA VI on PLIS:
– input and output of measurement data;
– management of the process of interaction of the mobile system;
– processing of measuring data.

FPGA is a chip, the functionality of which is determined during programming depending on the tasks. FPGA is designed to configure, synchronize, control, collect data, pre-digital signal processing and control I / O modules. The LabView FPGA is an add-on to the LabView software package, which defines FPGA logic as a virtual device instead of programming. LabView FPGA performs the process of converting a virtual device into a FPGA binary code. The result of the conversion is a binary file that determines the FPGA configuration. During program startup, the binary file is loaded on the chassis and the FPGA configuration process takes place. This file can be saved to the memory and downloaded automatically at system startup.

The hardware of the mobile system for running dynamic tests and assessment of quality and safety indicators based on the National Instruments CompactRIO solves a wide range of tasks aimed at monitoring the technical condition of rolling stock during tests and in normal operation.

The strain gauges are connected to the strain gauge module NI 9237, and the accelerometers are connected to the strain gauge module NI 9205, they scale the instantaneous values of the input voltage and analog-to-digital conversion into digital code. Digital signals on the internal bus are transmitted from the modules NI 9237 and NI 9205 to the controller NI 9012, from the output of which via the Ethernet interface bus enters the computer, where the processing, display and storage of measurement information.

The mobile system can operate in two functional modes: evaluation of quality, traffic safety and strength indicators in real time (Fig. 5) and measurement of acceleration, deformation in offline mode on rolling stock with further processing (Fig. 6). During the processing of the obtained values, the data obtained with the help of a GPS receiver are used to assess the impact of changes in speed on the controlled parameters.

Fig. 5 Real-time mobile system

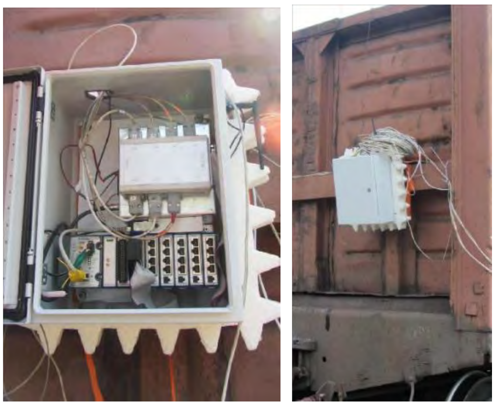


Fig. 6 Mobile system in offline mode

The general flowchart of the mobile diagnostic system is shown in Fig. 7.

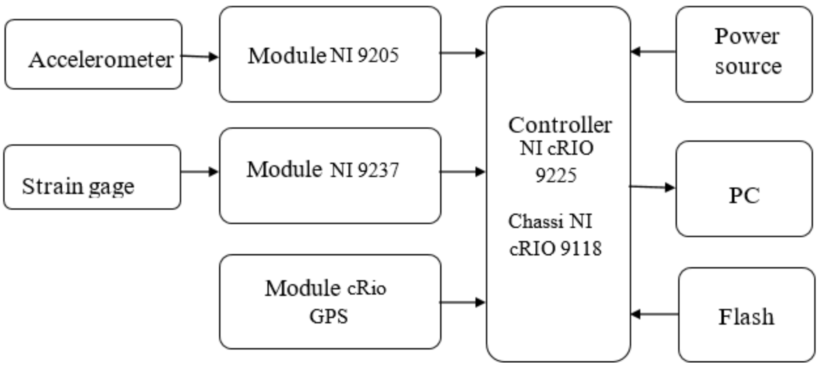


Fig. 7 The flowchart of the mobile system

3. Conclusions

According to the results of the research we can conclude:

The method of in-depth processing of the results of running tests of rolling stock is proposed. The essence is to perform spectral analysis of dynamic processes for different elements of the freight car frame, in order to identify the relationship between the oscillating processes of the wagon frame and the frequencies at which there is interaction between them. The software algorithm of the in-depth estimation of experimental indicators of quality of movement of freight cars with the reduced tare is developed.

Mathematical support of the procedure for determining the indicators of quality and safety of traffic, which allows with expanded measurement uncertainty of 2,1% (with a maximum allowable 5%) to determine these indicators by mobile systems in operation. This is achieved by using high-precision accelerometers to measure vibration acceleration and modern recording equipment

The general requirements to the mobile system on definition of indicators of quality and safety of movement of freight cars with the reduced tare in operation are formed and realized. This mobile system allows you to conduct running tests without the involvement of a laboratory car, which reduces costs and time for such tests by 25,8%.

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Analysis of Transport Pollution Air Quality Monitoring Stations in Lithuania

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Abstract

Ambient air pollution is one of the most important causes of premature human deaths. Industry and transport are among the main sources of air pollutants. Ambient air pollution is the most relevant in cities, because they have a high concentration of people. In order to accurately assess the quality of ambient air, it is necessary to constantly monitor the amount of pollutants in the air. There are seventeen stationary state-owned air quality monitoring stations in Lithuania. Some of them are designed to determine the impact of traffic pollution on ambient air quality, and they are usually installed in cities with high traffic intensity. The article analyses the locations and data of stationary state-owned air quality monitoring stations in Lithuania.
KEY WORDS: *ambient air quality, air quality monitoring stations.*

1. Introduction

According to the European Environment Agency data, air pollution is a major cause of early human death due to environmental factors. It is quite clear that this problem is most topical in cities, which have many sources of pollution (industry and transport), and are densely populated.

Industry and transport are the main pollutants in cities. Currently, the transport sector accounts for approximately 40-50% of NOx and 10-15% of PM emissions [1]. Automobile engines are constantly being improved by adapting them to tougher requirements in order to reduce pollutant emissions. However, the ever-decreasing car emissions are offset by the growth in the number of vehicles, and therefore the pollution of the transport sector and its share in the total amount of pollution remains more or less constant.

The main pollutants emitted by the transport sector are NOx and PM (particulate matter). In the transport sector, the biggest source of pollutants is road transport - about 80% of all NOx and PM emissions, and of this amount, about 40% are emitted from cars, which are the most popular means of transport in many countries and Lithuanian cities [2].

The most accurate way to evaluate air quality is to measure the concentration of different pollutants in the air. Measurements can be performed by stationary and mobile air quality monitoring stations [3]. The air quality in a certain place can change depending on various factors. These factors may or may not depend on the pollutant sources. Therefore, it is appropriate to measure the air quality permanently with stationary air quality monitoring stations. Also, in order to accurately evaluate the air quality, the location of the air quality monitoring station is a very important factor. Since the factors affecting air quality are very different and changing, it is very important to choose the right and sufficient number of air quality monitoring stations. Usually, the location of the air quality monitoring station is selected according to the intensity of pollutant sources, the concentration of people and other factors. For example, 18 stationary air quality monitoring stations operate in the city of Berlin in Germany, 12 stationary air quality monitoring stations operate in Hamburg [4].

2. Network of Air Quality Monitoring Stations in Lithuania

Currently, there are seventeen stationary ambient air quality monitoring stations in Lithuania that are state-owned. The data of state-owned ambient air quality monitoring stations is recorded by the Environmental Protection Agency. The purpose of state-owned air quality monitoring stations is different:

- five stations are installed in places with high traffic intensity and their purpose is to measure the impact of vehicle pollution on air quality;
- four stations are located close to large industrial facilities and they measure the impact of pollution from these facilities on air quality;
- five stations are urban background, they are installed in cities away from transport roads and industrial facilities;
- three stations are rural background, they are installed in non-urban areas and away from transport roads and industrial facilities.

When choosing the installation locations for air quality monitoring stations, it is important to take into account many factors that depend on the purpose of the measurements (the purpose of the station), the source of pollutants and other environmental factors. When installing industrial, urban and rural background air quality monitoring stations, the factors that determine the optimal location of the station are usually clear and unchanging. There is a bigger problem with air quality monitoring stations, which are designed to measure the impact of transport pollution on ambient air quality by selecting the installation location, because it is necessary to take into account the intensity of traffic, traffic congestion and its changes [5].

Vilnius is the capital of Lithuania and the largest city in the country. According to the data, in 2020 there were more than 0.5 million permanent residents in Vilnius [6]. There is only one state-owned air quality monitoring station for the effect of transport pollution in Vilnius city (Fig. 1), which is located in Zirmunai near Kareiviu Street (coordinates 54°42'55"N 25°17'21"E). There is high traffic intensity on Kareiviu street and traffic jams often form here.

Fig. 1 Air quality monitoring station on Kareiviu street in Vilnius city

Kaunas is the second largest city in Lithuania. According to the data, in 2020 there were about 300 thousand permanent residents [6]. There is only one state-owned air quality monitoring station for the impact of transport pollution in this city too (Fig. 2), which is located in Petrasiunai near R. Kalanta Street (coordinates 54°53'42"N 23°59'10"E). R. Kalanta street has an average traffic intensity and traffic jams rarely occur here. There are also several industrial facilities on R. Kalanta street, which emit certain pollution components and can have a significant effect on the overall ambient air pollution.

Fig. 2 Air quality monitoring station on R. Kalanta street in Kaunas city

Klaipeda is the third largest city in Lithuania. According to the data, in 2020 about 150 thousand permanent residents lived there [6].

Fig. 3 Air quality monitoring station on Bangu street in Klaipeda

In Klaipeda city, two state-owned air quality monitoring stations for the effect of transport pollution are installed, one of them is located near Bangu street (coordinates 55°42'27.5"N 21°08'28.3"E) (Fig. 3). Low traffic intensity is recorded on Bangu street, but the city centre is not far from this place, which can affect the ambient air quality. Also not far from this place is the only sea port in Lithuania, the pollution and effect of which is unquestionable on the ambient air quality.

The second air quality monitoring station in Klaipeda city, which records the effect of traffic pollution, is located near Silute highway (coordinates 55°41'24.0"N 21°10'44.9"E) (Fig. 4). There is high traffic intensity on Silute road and traffic jams often form here during rush hours. In this place, road transport has the greatest effect on ambient air quality and its pollution.

Fig. 4 Air quality monitoring station on Silute road in Klaipeda

In Siauliai city, where in 2020 there were about 100 thousand permanent residents [6], one state-owned air quality monitoring station for the impact of transport pollution is installed (Fig. 5), which is located at the intersection of Zemaite, J. Basanavicius streets and Ausra avenue (coordinates 55°56'16.1"N 23°18'29.8"E).

Fig. 5 Air quality monitoring station on Zemaite street in Siauliai

This place in Siauliai city is not characterized by high traffic intensity, but it is close to the city centre and traffic jams form here during rush hours.

Comparing the number of air quality monitoring stations in Lithuania with other Western European countries (Fig. 6), it is possible to single out an insufficient number of these stations and some air quality monitoring stations are installed in non-optimal locations.

Fig. 6 Network of transport pollution monitoring stations in Europe [4]

In general, air quality monitoring stations for the impact of transport pollution are arranged in the territory according to the following criteria:

- the most polluted areas of the city, i.e. street intersections characterized by the highest traffic intensity and frequent traffic jams;
- densely populated or frequented visited city areas;
- the environment of stationary air quality monitoring stations, i.e. terrain, buildings, greenery.

In order to more accurately present the current ambient air quality situation, it would be appropriate to install several state-owned air quality monitoring stations in major cities of Lithuania, while currently there is only one state air monitoring station in the cities of Vilnius and Kaunas. It is also important to select optimal locations where the effect of traffic pollution on ambient air quality is essential. From this point of view, it is possible to single out the state air quality monitoring stations installed on Petrasiunai street in Kaunas and Bangu street in Klaipeda, because there is no high traffic intensity and frequent traffic jams in these places. When predicting the installation locations of stationary air quality monitoring stations, it is necessary to evaluate future changes in road infrastructure and traffic intensity. If the intensity of motor vehicle traffic fundamentally changes in places where stationary state-owned air quality monitoring stations are installed, which record the impact of traffic pollution on ambient air quality, it will be appropriate to consider moving these stations to more relevant and likely more polluted areas of the city.

4. Conclusions

The most accurate way to evaluate ambient air quality is to measure it with stationary or mobile air quality monitoring stations.

In Lithuania, air quality is monitored at state stationary air quality monitoring stations, 5 of which are dedicated to determining the effect of transport pollution on air quality.

In order to accurately present the current ambient air quality, it is very important to select suitable locations where stationary or mobile air quality monitoring stations are installed.

When determining the effect of transport pollution on ambient air quality, it is important to take into account the intensity of traffic flows, resulting congestion and future changes in transport road infrastructure and traffic flows.

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Experimental Research of Ropeway Dynamics

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Abstract

Research of ropeways is carried out in several directions, one of which is the establishment of dynamic characteristics of rope systems under different operating conditions. In previous works, we proposed a mathematical model for calculating the frequency spectrum of ropeway, which is based on the representation of the ropeway traction circuit as a discrete-continuous dynamic system. The main purpose of the experimental studies is to confirm the adequacy of this model; its results are presented in this article. The considered single-span ropeway is usually used as a means of industrial transport for moving goods between production and storage facilities, in the mining industry – for transporting various materials from the place of extraction to railways and highways. Studies were carried out using experimental equipment developed by us. According to the results of the experiment, we drew the frequency diagrams, which show the change of eigenfrequencies of the ropeway traction circuit during the cars movement between stations. The total array of results includes information on the decoding of about a thousand oscillograms, which were obtained and studied according to the methodology developed by us.
KEY WORDS: *ropeway; dynamics; mathematical model; eigenfrequency; frequency spectrum; experimental research*

1. Introduction

Ropeway is a versatile transport system that has significant advantages over existing vehicles for transporting goods and people. The costs of construction and maintenance of ropeway are much lower than the corresponding values that characterize other modes of transport. At the same time, the duration of the transportation cycle is reduced due to the realization of the possibility of connecting final (and intermediate, if necessary) destinations for the shortest distance, due to the low dependence of the ropeway route on terrain. The combined consideration of these advantages confirms the technical and economic feasibility of using ropeways as a means of freight and passenger (including urban) transport.

The analysis of scientific literature showed that the researches of ropeways are carried out in several directions, one of which is the establishment of dynamic characteristics of rope systems under different operating conditions [1-4]. The similar research is being conducted for rail vehicles [5].

Any vehicle with a flexible traction body, in particular a ropeway, is a rather complex system in terms of mathematical modelling of the dynamics of its elements. It is characterized by the presence of lumped masses and elements with distributed parameters. In particular, in the problems considered in [6] the lumped masses are the motor rotor *1*, the mass of the gearbox parts brought to the output shaft *2*, the drive pulley *3*, the real or suppositive mass *5*, which characterizes the working force of the haulage rope tensioning device, and cars *6*. The concept of suppositive mass is introduced for tensioning devices of non-weight action, such as hydraulic; hereinafter, any tensioning devices will be called "tensioning load". Sections *4* of the haulage rope are elements with distributed parameters (Fig. 1). This representation of the ropeway defines a mathematical model of its elements motion in the form of a system of differential equations in ordinary and partial derivatives, which is quite cumbersome and difficult to analyze.

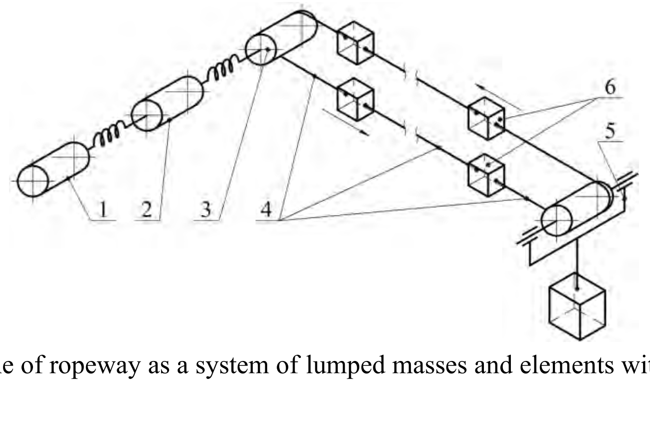


Fig. 1 Calculation scheme of ropeway as a system of lumped masses and elements with distributed parameters

To simplify the general mathematical model, you can use one of the following approaches:

1. Use the assumption that elements with distributed parameters (rope sections) are weightless [7], but this approach is acceptable only for ropeways of short length;
2. Replace the elements with distributed parameters by a system of finite number of lumped masses, which allows to make a mathematical model only from Lagrange equations of the second kind without the use of partial derivatives [8, 9];
3. Bring the masses of the subsystem "the motor rotor; the masses of the gearbox parts, reduced to the output shaft; the drive pulley" to the drive pulley, which allows you to make a mathematical model only from the equations of wave mechanics without the use of conventional derivatives [10].

The third approach was used during the theoretical studies of the ropeway frequency spectrum [6]. A mathematical model of the dynamics of the ropeway traction circuit as a discrete-continuous system consisting of lumped masses (drive pulley with the reduced masses of all rotating elements of the drive, cars, haulage rope tensioning load), interconnected by haulage rope sections as elements of distributed parameters. This model is more accurate than discrete, and allows to take into account the effect of changes in inertial and elastic characteristics of the haulage rope along its length. The developed model is compiled in general form and can be used to study ropeways of any type, purpose and field of use.

The main purpose of experimental research, the results of which are presented in this article, is to confirm the adequacy of the mathematical model for calculating the ropeway frequency spectrum, which is based on the representation of the ropeway traction circuit as a discrete-continuous dynamic system. Peculiarities of compiling and using such a model were presented and substantiated in [6].

To achieve this goal, we solved a number of problems, the main of which are the following:

1. Develop and substantiate of the experimental equipment constructive scheme;
2. Create of research methodology;
3. Manufacture, assemble and install experimental equipment and measuring system;
4. Conduct research in accordance with the created methodology;
5. Perform an analysis of the convergence of the theoretical and experimental studies results;
6. Draw a conclusion about the adequacy of the mathematical model presented in [6].

Some tasks are performed in parallel, so the presentation of the results will be combined.

2. General Characteristics of the Experimental Equipment

To confirm the adequacy of the mathematical model presented in [6], consider a single-span ropeway (Fig. 2), which consists of drive *1*, track rope anchor *2*, haulage rope *3*, track rope *4*, track rope tensioning device *5*, haulage rope tensioning device *6*, car *7*. Such ropeways are classified as pendulum, cars of which carry out reciprocating movement between the final stations. They are usually used as a means of industrial transport for the formation of dumps, for the movement of goods between production and storage facilities, in the mining industry - for transporting various materials from the place of extraction to railways and highways, ect. Pendulum ropeways can also be used to transport people, in particular as a means of passenger urban transport.

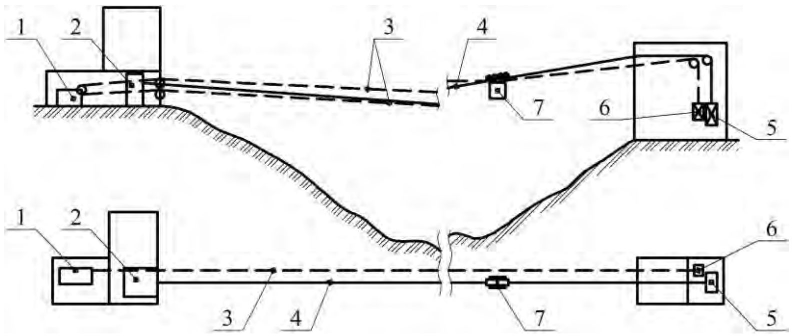


Fig. 2 Ropeway scheme

To conduct experimental studies, we will use equipment similar in design to the ropeway described above, with some changes to simplify the design and installation of its individual components and measuring equipment. This equipment (Fig. 3) has driving and tension pulleys, track and haulage ropes, cars, basic metalwork. Ensuring the force in the haulage rope required for reliable friction to the drive pulley surface is carried out by using a weight tensioning device. The tensioning device of the track rope was replaced with anchor clamps to simplify the structure of the experimental equipment, which is acceptable for ropeway of short length. Each of the pulleys are mounted on rolling bearings and rotate relative to fixed axles. Cars roll on wheels on a track rope and are rigidly connected to the haulage rope.

The experimental equipment has the following parameters:

- length of the simulated ropeway (along the car trajectory) is 2.5 m;
- drive and tension pulleys: diameter is 320 mm; weight is 15 kg;

– deflecting pulleys: diameter is 200 mm; weight is 10 kg;

– reduced weight of the tension load (taking into account the weight of the tension pulley, deflecting pulleys and the tension load) is 37 kg;

– track rope diameter is 8 mm;

– haulage rope diameter is 4,1 mm;

– car weight is variable, from 3.5 kg to 16 kg with a step of 2.5 kg (a set of loads).

To register the change in the ropeway elements acceleration we used a measuring equipment consisting of the following units:

– accelerometer (acceleration sensor) AT 1105-05; measuring range is (0… 5) g; frequency range is (0…500) Hz; measurement error is 2.5%;

– eight-channel universal amplifier QuantumX MX840A; accuracy class is 0.05;

– computer with Catman Easy software.

The results of continuous recording, which was carried out according to the following method, were stored as a tabular function by separate files of asc type.

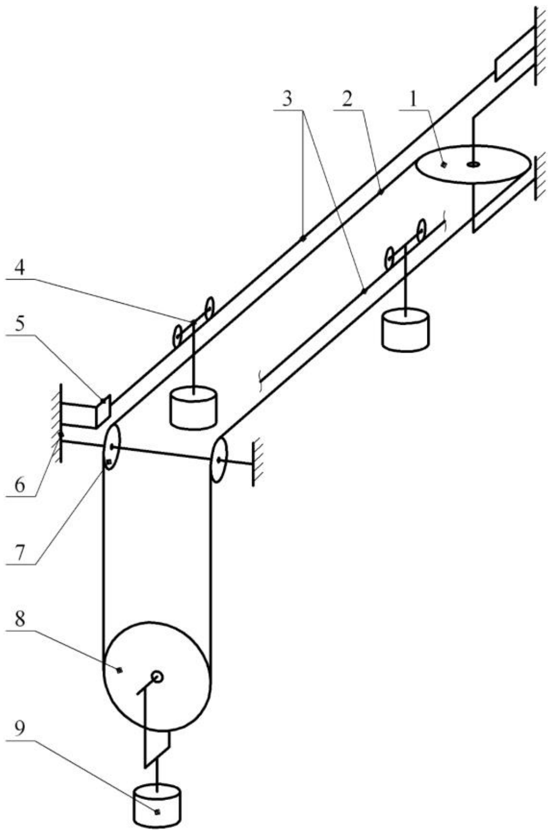


Fig. 3 Experimental equipment scheme: *1* – drive pulley; *2* – haulage rope; *3* – track rope; *4* – car; *5* – track rope anchor; *6* – supporting metal structure; *7* – deflecting pulley; *8* – tension pulley; *9* – tension load

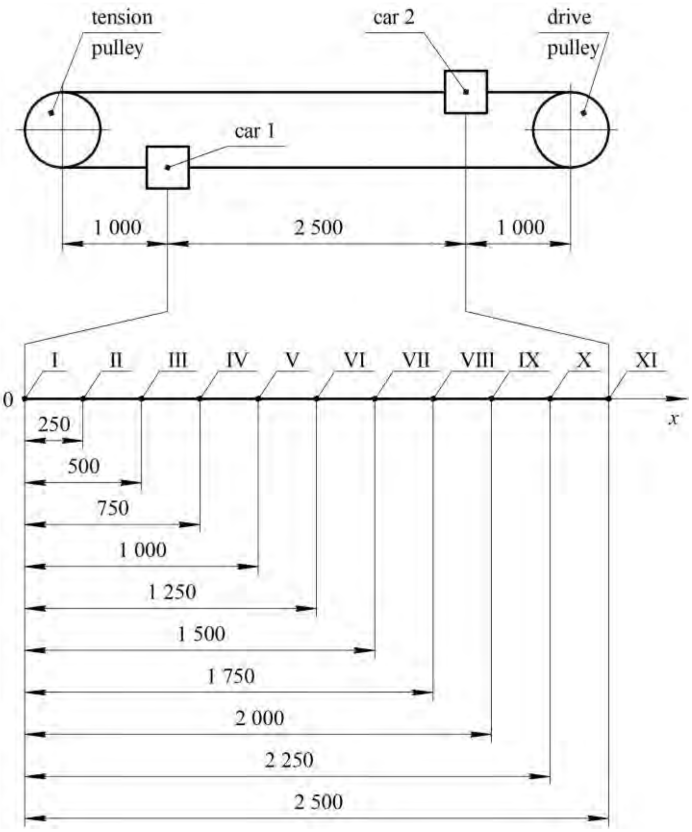


Fig. 4 Scheme of the car 1 location points during the registration of acceleration(dimensions are given in millimeters)

3. Research Methodology

Experimental studies of the ropeway frequency spectrum involve the drawing of frequency diagrams that show the change in ropeway eigenfrequencies during the movement of cars between stations. The measuring equipment used during the experiment allows to register the change in the ropeway elements acceleration as a function of time. As a result of the experiment, we obtain a number of oscillograms, by which we determine the frequency of acceleration change (the acceleration is a polyharmonic function). These values are equal to the ropeway eigenfrequencies, and therefore, by measuring in several discrete positions of the cars on the route, we built frequency diagrams.

For the experiment, we selected ten positions of the car, evenly distributed over a length of 2250 mm (Fig. 4). The eleventh position of the car is unstable under certain load conditions: if the difference in cars weight is significant (for this ropeway – more than 5 kg), there is free movement of cars in the direction of their oncoming movement under the action of its own weight. Therefore, the registration of acceleration at the point $x = 2500$ mm was not performed.

The experiment was performed for thirty-six combinations of car masses (m_1, m_2), which varied in the range from 3.5 kg to 16 kg with a step of 2.5 kg ($m_1 = 3.5$ kg, $m_2 = 3.5$ kg; $m_1 = 3.5$ kg, $m_2 = 6$ kg; $m_1 = 3.5$ kg, $m_2 = 8.5$ kg …

m_1 = 16 kg, m_2 = 3.5 kg; m_1 = 16 kg, m_2 = 6 kg … m_1 = 16 kg, m_2 = 16 kg).

Registration of change of car 1 movement acceleration was carried out in the following sequence:

1. place wagons with predetermined masses in the position specified by the x coordinate;
2. make a background recording of the change in acceleration until the moment of stabilization of the equipment (cessation of cars oscillations that occurred due to their forced movement);
3. give the drive pulley a single force pulse, which lead to its rotation so as to ensure a small movement of the car 1 in the direction of a positive change in the coordinate x; the free oscillations of car 1 were registered until they were completely attenuated and the oscillogram acquired the appearance of a background record.

This sequence of actions was repeated three times for each cars position and the combination of their masses. A total of 1080 oscillograms were recorded. The duration of recording one oscillogram (background – workflow – background) is up to 10 s. Next, the oscillograms were processed to remove “background noise” using the Advanced Grapher software. One of the processed oscillograms is shown in Fig. 5.

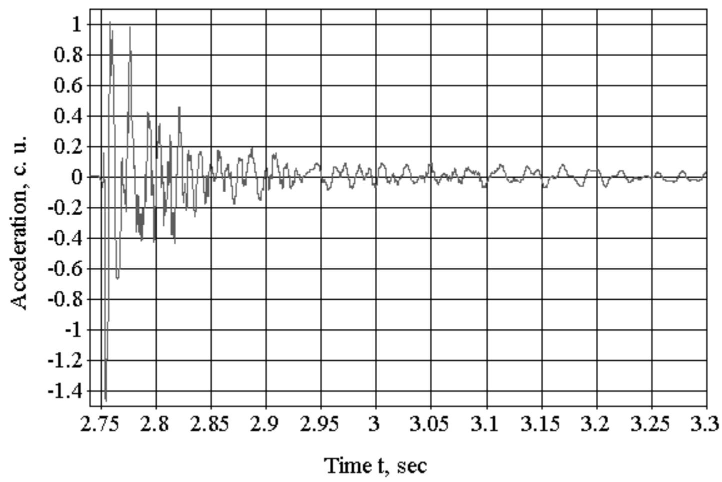


Fig. 5 Oscillogram after processing

The studied process is polyharmonic, so to establish the ropeway eigenfrequencies and compare them with the values determined analytically, we performed their preliminary calculation using the mathematical model presented in [6]. This approach made it possible to determine the approximate values of the ropeway eigenfrequencies, which must be found using oscillograms. The next step was to search on the oscillogram for the harmonics of the process under study, which are close in frequency to those determined analytically. To do this, we analyzed a fragment of the oscillogram from the moment of ropeway oscillations excitation due to the action of a single pulse. On this fragment we established the waves periods, expressed to a sufficient extent, by which we determined their frequencies:

$$\omega = \frac{2\pi}{T}, \tag{1}$$

where T – wave period.

We determined the corresponding eigenfrequencies analytically using the mathematical model presented in [6], and compare them with experimental values. The deviation is determined by the formula:

$$\Delta = \frac{|\omega_a - \omega_e|}{\omega_a} \cdot 100\%, \tag{2}$$

where ω_a and ω_e – eigenfrequency values obtained analytically and experimentally.

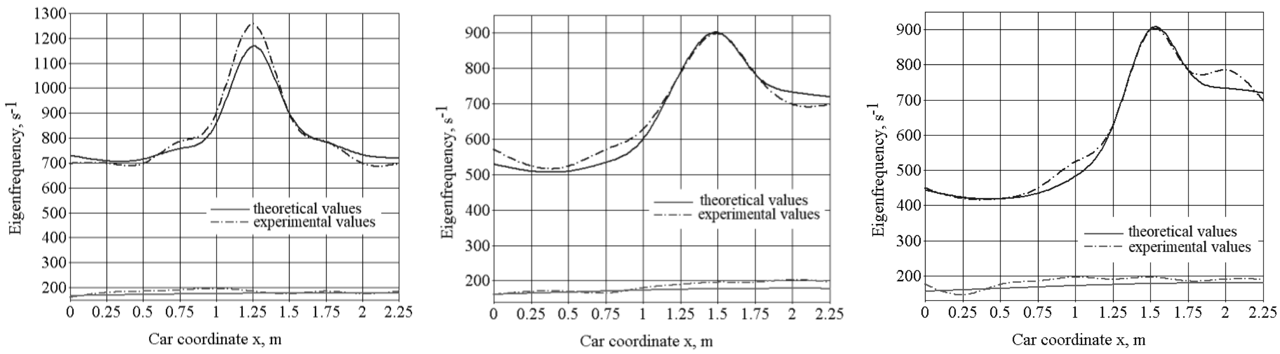
4. Analysis of Research Results

The total array of results includes information on the decoding of about a thousand oscillograms, which were obtained and studied according to the method described in the previous paragraph. To present the main results of the experiment and confirm the adequacy of the mathematical model described in [6], we consider the following combinations of initial data:

1. m_1 = 3.5 kg, m_2 = 3.5 kg;
2. m_1 = 6 kg, m_2 = 3.5 kg;
3. m_1 = 8.5 kg, m_2 = 3.5 kg.

m_1 and m_2 are cars masses, the values of which were changed by combining a certain number of loads. Other equipment parameters for all simulation cases are the same and correspond to those given in the general equipment characteristics (see above).

For each combination of masses, we performed measurements three times in each of the ten cars positions with a pitch of 250 mm (see Fig. 4). The results of the analysis of oscillograms are presented in the form of frequency diagrams (Fig. 6). On each of the graphs, two pairs of curves are shown: the first pair having a smaller amplitude characterizes the change of the first eigenfrequency, the second pair characterizes the change of the second eigenfrequency of the ropeway.



m_1 = 3.5 kg, m_2 = 3.5 kg m_1 = 6 kg, m_2 = 3.5 kg m_1 = 8.5 kg, m_2 = 3.5 kg

Fig. 6. Frequency diagrams

5. Conclusions

The difference between the results obtained analytically and experimentally is small and is characterized by deviations of experimental values of eigenfrequencies from theoretical within 14% at the points of possible influence of external dynamic processes (low frequency noise).

The results of experimental studies confirm the adequacy of the mathematical model [6] for calculating the ropeway frequency spectrum, which is based on the representation of the ropeway traction circuit as a discrete-continuous dynamic system.

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Working Drones in a Modern Airport's Daily Life

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Abstract

We can admire the beauty of flight and the need to soar as far back as the ancient epics of Daedalus and Icarus. Faith, will and determination, coupled with industrial and technological progress, have made it possible to airlift heavier-than-air equipment and to use it effectively in air transport. In this rapidly developing world, there is a growing need to increase the volume of air transport, which, in addition to the increase in the number of aircraft, will bring with it the development of airports in terms of area, quality and service. The final capacity of the human workforce generates the next challenge of what solution can be offered to replace and relieve this. The use of unmanned aerial vehicles, already used successfully in so many places, seems obvious, but the question of aviation safety is "how to integrate an unmanned and manned aircraft in the same airspace, in the same work area". In this research project we are looking at which aircraft, for which tasks and with which sensors can be the most effective part of a modern airport concept.
KEY WORDS: *Drone, infrared, electromagnetic spectrum, sensor, LoRa CSS, receiver sensitivity, link budget*

1. Introduction

Thanks to the technological advances of the last decades, unmanned systems have undergone a huge evolution, which is uninterrupted and even tumultuous. These devices are almost identical to human-piloted aeroplanes and helicopters in their design and operation [1]. Drones are flying robots that can take off with a few grams to several tonnes of take-off weight, can fly up into the air, can be less than 100 metres from their base, and can even cross continents. Nowadays, rigid, rotary and even flapping-wing versions have evolved, flying at low speeds or even faster than the speed of sound. The fixed-wing model is similar in design to an aeroplane, where the lift is generated on the forward wings as the aircraft rises into the air. As far as the rotorcraft are concerned, their operating principle is the same as that of helicopters, i.e. the rotor blades used - as wings - generate the necessary lift by rotation [2].

Unmanned, remotely or autonomously operated aircraft carrying lethal or non-lethal payloads are also considered drones [3]. They collect the information they need to operate from their environment, use sensors to detect their position and, as a result of a decision-making process, correct their operation, position and movement in three-dimensional space [4], [5]. However, ballistic or semi-ballistic vehicles, cruise missiles, artillery projectiles, torpedoes, mines and satellites are not considered drones [6].

So the role of UAVs is growing in air, ground and maritime operations. From drones, bomb disposal robots to mini-submarines, from ship-borne reconnaissance helicopters to high-altitude precision attack aircraft, most require human intervention to carry out or prepare for their mission [7].

Observing the history of the development of unmanned aircraft from the point of view of exploitation, it can be said that their life cycle can be divided into three parts. The first, in which various destructive devices were mounted on it, used as weapons, and intended to destroy the forces and assets of the opposing side. The next use, as a targeted aircraft, was for peacetime training of air defence forces, providing them with realistic conditions. And the third area, where various sensors have been installed to enable the device to acquire and transmit information from the air, helping to make decisions at different management levels and in different areas of use [8]. In the course of evolution, robotic devices will provide the individual with more and more opportunities, convenience and information horizons, leading to autonomous task execution by having one operator coordinate the manoeuvres of several aircraft simultaneously, as our "grown-up, autonomous" device "does not require" constant supervision [9].

Understanding the emerging "problem", several international aviation and aviation safety organisations, as well as national authorities, independently of each other, began to investigate the regulatory issues of unmanned aircraft systems, which are becoming increasingly important in almost all areas of life. As a flying device, the integration of drones into the airspace is a major challenge for aviation authorities. Apart from legal "interpretation" and classification into usable categories, the trajectory, direction and technical development of drones and the capability, appearance, equipment, equipability and knowledge of the devices are unpredictable at the moment. Thanks to continuous development, huge changes can occur even in the short term, which can have a major impact on the future of aircraft and our perception of aviation [10].

2. Can Drones Make an Airport More Modern?

There are a number of essential part work processes for the safe operation of the airport. These are currently carried out by manpower and a dedicated vehicle. Drone capabilities include work and services that we believe can be efficiently performed by unmanned aerial vehicles "equipped" to do so (for example: runway control, Foreign Object Damage, bird/wildlife alert, „Follow me" function, air pollution, NBC measuring, security-protection, taxiway/runway/aircraft de-icing, aircrafts technical/damage inspection, checking airport power supplies/wiring etc.) By preparation we mean finding, calibrating and "teaching" the right sensors, accessories, fitting them to the right carrier platform, diversifying them, and developing the necessary legal environment, procedures and application methods. Hereinafter we will discuss the infrared detection and sensors that will be used as part of the sample drone elements of our project.

2.1. Infrared Detection

Infrared (IR) can also be used with drones to monitor the airport and its facilities and equipment, because the IR can show what the human eye cannot see. Let us look at the basics.

2.1.1. Electromagnetic Spectrum

The electromagnetic radiation (EMR) consists of waves of the electromagnetic (EM) field, propagating through space, carrying electromagnetic radiant energy. It is including: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays (Fig. 1).

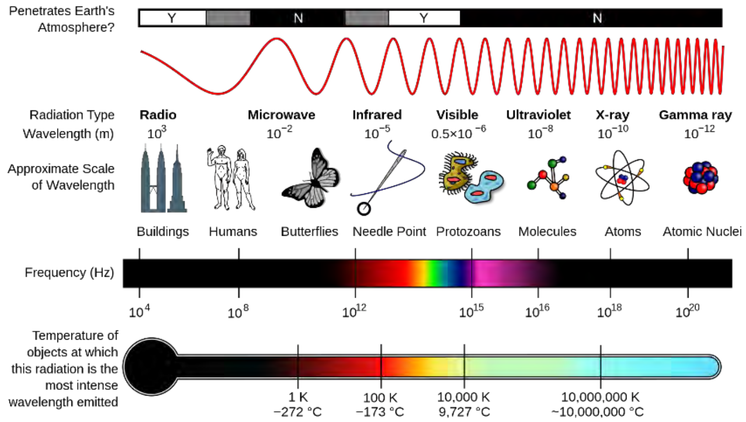

Fig. 1 The electromagnetic spectrum, showing various properties across the range of frequencies and wavelengths [11]

The electromagnetic waves are derived from the resultant of two mutually perpendicular electric (E) and magnetic (H) fields exciting each other (Fig. 2).

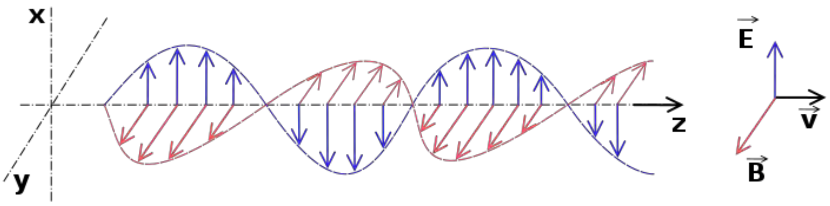

Fig. 2 Electric (E) and magnetic (B) fields [12]

The electromagnetic waves are typically described the following two physical properties: the frequency f and wavelength λ. The unit of frequency is *Hz* and its prefixed value kHz (10^3 Hz), MHz (10^6 Hz), GHz (10^9 Hz). The unit of wavelength is *m* and its prefixed value km (10^3 m), mm (10^{-3} m), μm (10^{-6} m) and nm (10^{-9} m). Electromagnetic waves travel at a speed of 299,792,458 m/s ≈ 3×10^8 m/s which is also known as the speed of light, sign letter c [13].

The wavelength and frequency are inversely proportional: that is, the shorter the wavelength, the higher the frequency, and vice versa. This relationship is given by the following equation:

$$c = \lambda f \,. \tag{1}$$

This relationship reflects an important fact: all electromagnetic radiation, regardless of wavelength or frequency, travels at the speed of light.

2.1.2. Infrared

The Infrared has 0.7 to 300 μm wavelength. This region is further divided into the following bands:

- Near Infrared (NIR): 0.7 to 1.5 μm;
- Short Wavelength Infrared (SWIR): 1.5 to 3 μm;
- Mid Wavelength Infrared (MWIR): 3 to 8 μm;
- Long Wanelength Infrared (LWIR): 8 to 15 μm;
- Far Infrared (FIR): longer than 15 μm [14].

The NIR and SWIR are also known as the Reflected Infrared, referring to the main infrared component of the solar radiation reflected from the earth's surface. The MWIR and LWIR are the thermal infrared [14, 15].

To monitor the airport and its facilities and equipment we can use IR camera working in MWIR and LWIR bands. With these cameras or drones equipped with IR cameras, we can detect deviations from normal operations e.g. excessive heating on a terminal in an industrial electrical fuse block (Fig. 3) or differences in aircraft engines and airframe structure (Fig. 4, a) or intruder to the airport (Fig. 4, b) or control the building temperature etc. This method able prevent for example a fire by detecting in time, for example the heating of a transformer or a connector, which could cause a fire later.

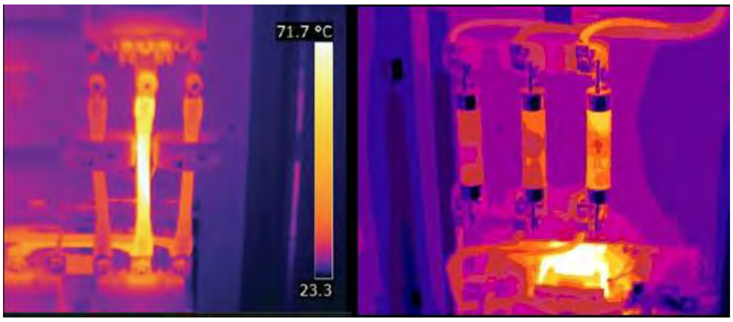

Fig. 3 Excessive heating on a terminal in an industrial electrical fuse block [15]

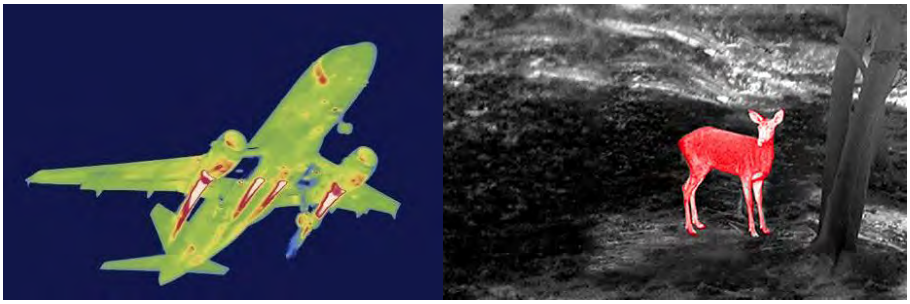

Fig. 4 Different IR photos: a – Aeroplane; b – Intruder to the airport [15]

Drones equipped with IR cameras show a visual picture so temperatures over a large area can be compared. It is capable of catching moving targets in real time. It is able to find deterioration, i.e., higher temperature components prior to their failure. It can be used to measure or observe in areas inaccessible or hazardous for other methods. It is a non-destructive test method. It can be used to find defects in shafts, pipes, and other metal or plastic parts. It can be used to detect objects in dark areas [16].

3. What to Do With On-Board Sensor Data?

In this chapter, we examine one of our future scenario, where we measure small amount of data in relatively long time intervals and in addition of storing onboard, we want to send it to a ground station. At first, the expected distance between stations (sensor node and gateway) was 10+ km, now the most feasible distance is 2 km that can become larger later on. Our sensor system is layered to ease future modifications, so to change radio system to a more optimal one is relatively simple.

The pivot point of all measurements made onboard an air vehicle is what we do with the acquired data. We can store/display it onboard or transmit it to a ground station or both.

In case we transmit it, what are the main boundary conditions? We can use existing communication infrastructure for example cellular systems that expectedly has a tower nearby and available in most places, although can be unusable while there are power outages.

Or we can use independent radio systems. When designing wireless communication (transmission), there is always the question of transmission speed, the range that can be covered, or power/energy consumption. Well, there is no objective answer to this question, as the distance depends on the electromagnetic noise generated by the environment.

We can choose two of these, because we can only optimize for two. For a more complete picture, the most important factors are: transmission range, topology, data rate, regulations, battery life, development cost, unit cost, size, mass/weight, interoperability, Quality-of-Service and scalability.

In IoT (Internet of Things) and M2M (machine-to-machine) connection technologies there are many good solution for that within reach of everyone, for example cellular system (4G/5G), Zigbee, Bluetooth, Wi-Fi and the LPWAN solutions. LPWANs are Low Power Wide Area Networks, that exist as both licensed (LTE, NB-IoT) and unlicensed (Sigfox, LoRa). As it was previously mentioned, we don't intend to use existing communication infrastructure, so we picked LoRa from the unlicensed ones. However it has its own limitations. In order to meet EU regulations the Duty Cycle of transmission is 0.1% to 1% per day (depends on the channel) [17, 18].

LoRa is stands for Long Range and developed by Semtech Company. As modulation, it uses spread-spectrum techniques as LoRa CSS (Chirp Spread Spectrum) (see Fig. 5). In EU, it uses the 868 MHz ISM[1] band.

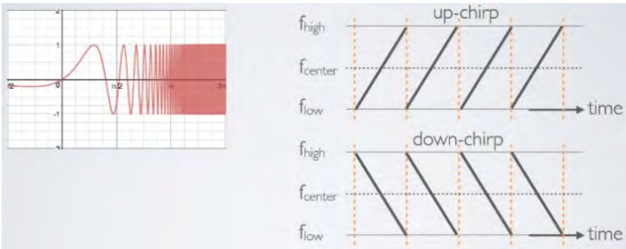

Fig. 5 Lora CSS in time and frequency domain [17]

Before using a solution, we need to examine whether the solution meets our requirements. The indicator of the quality of a radio transmission channel is the link budget that consists transmitter power (TX), free space loss (FSPL – energy loss in free space while the signal travels from transmitter to receiver), antenna gain, receiver sensitivity (RX). If we would like to estimate our service radius to check wether the solution fits our requirements, we need to investigate this parameter. We have other parameters to consider, but it stands as a rough estimate.

Regulations in EU limit some of these parameters: Transmit power is limited to 25 mW (14 dBm) and maximum antenna gain is 2.15 dBi.

Effective radiated power (EiRP) can be determined by the following equation:

$$EiRP = Transmit\ power - Cable\ losses + Antenna\ Gain = 14\text{ dBm} - 1\text{ dB} + 2.15\text{ dB} = 15.25\text{ dBm}. \tag{2}$$

For calculating FSPL, there is a widely used logarithmic formula:

$$FSPL_{dB} = 20log_{10}(d) + 20log_{10}(f) - 20log_{10}\left(\frac{4\pi}{c}\right) = 20log_{10}(d) + 20log_{10}(868) + 120 - 147.55, \tag{3}$$

where d – is the distance between the receiver and the transmitter in meters; f – is frequency in MHz (hence the +120 dB, originally it is in Hertz); c – is speed of light in vacuum. Its 97.24 dB on 2 km.

Using the receiver sensitivity equation:

$$RXsensitivity = 10log_{10}(kTB) + 10log_{10}(BW) + NF + SNR = -174 + 10log_{10}(125000) + 6 - 7.5, \tag{4}$$

where kTB – total thermal noise power is calculated at room temperature; BW – bandwidth in Hz (125000); NF – noise factor in dB (called noise figure[2], as a rule of thumb, we usually calculate with 6 dB on gateways, however in practice the value is much lower); SNR – signal to noise ratio that equals -7.5 dB using SF7 (see Table). Spreading Factor (SF) is the ratio between the symbol rate and the chip rate, which can be in the range of 7–12. Higher SF increases the SNR, transmission range, and packet airtime, therefore it decreases the data rate [19].

Using the total thermal noise power equation:

$$kTB = 30 + 10log_{10}(k \cdot T \cdot B), \tag{5}$$

where k – is Boltzmann constant $[Joules/K]$, T – is temperature in Kelvin, B – is channel bandwidth in Hertz, and there is +30 dB to get the result in dBm instead of dBW. Our -174 dBm value means the temperature is 290 K and the bandwidth is 1 Hz [20].

[1] ISM - Industrial, Scientific and Medical. Unlicensed band, the so called 868 MHz band is from 863 MHz – 870 MHz.

[2] how our device effects the signal to noise ratio negatively, thus we have worse SNR on output than in the input.

Table

SNR according to SF values [19]

SF	Chrips/Symbol	SNR	Airtime[3] [ms]	Bitrate [bps]
7	128	-7.5	56.5	5469
8	256	-10	-103	3125
9	512	-12.5	185.3	1758
10	1024	-15	371	977
11	2048	-17.5	741	537
12	4096	-20	1318.9	293

Our Rx sensitivity equals -124.5 dBm. From that we can calculate the link budget without antenna gain.

$$\text{Link budget} = \text{Rx sensitivity} - \text{transmit power}. \tag{6}$$

Given that the transmit power is 14 dBm, our link budget equals -138.5 dB. It can solve the problem and still has margin for structural attenuations. Of course this is just a rough estimate with direct line of sight, in practice there are other factors that act as attenuators (the aformentioned structural attenuations).

For placing antennas, its advised to investigate the Fresnel zone. It is a certain elliptical region of the free space between the transmitter and receiver and obstacles in this area have negative effects on signal regardless of free line of sight.

As a rule of thumb Fresnel zone (Fig. 6) should always be clear of obstruction but this can be impractical so it is said that beyond 40% blockage, signal loss will become significant [17]. So it must be at least 60% clear.

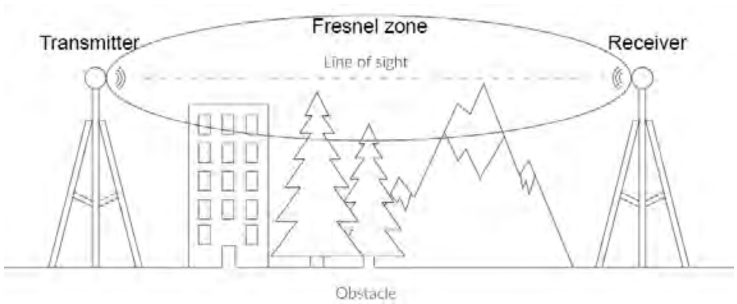

Fig. 6 Fresnel zone [21]

The radius of this zone with the 60% clearance can be calculated by the following formula (based on flat earth, does not take curvature into consideration):

$$F_1 = \frac{1}{2}\sqrt{\frac{60\% \cdot c \cdot D}{f}} = 8.656\sqrt{\frac{0.6 \cdot d}{f}} = 8.656\sqrt{\frac{1.2}{0.868}} = 10.18 \text{ m}. \tag{7}$$

In one of our scenarios, we get much more data, that we couldn't send through LoRa without breaking regulations, thus we store it onboard into non-volatile memory for later evaluation or if we needed it realtime, we would transmit it via another radio band and equipment. (These are later scenarios)

4. Conclusions

Because of the significant advantages of unmanned aircraft systems, there are numerous publications, studies and tenders on the potential of drones. In this study, the authors have reviewed and summarised the basics of infrared sensing as well as examined one future scenario where small amounts of data will need to be measured at relatively long intervals and be beamed to a ground station in addition to being stored on board. The authors' initial assumptions were that the expected distance between the stations (sensor node and gateway) would be 10+ km, but now the most realistic distance is 2 km, which could of course be greater as the project progresses. The sensor system to be used is layered to facilitate future modifications, making the radio system relatively easier to optimise. All these tools require the purchase of a heavy-duty drone (approx. 8 kg), which is needed to carry out the tasks of the project, and the market research and procurement process has started. After the arrival of the quadrocopter, its commissioning and the installation of the systems, the real measurements can follow, which until then have to be simulated, evaluated and analysed on a theoretical level, based on the theoretical foundations and initial parameters presented.

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[3] 20 bytes per packet and code rate = 4/5.

Acknowledgement

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Methods of Assessment of Ballast Contamination on Railways of Ukraine

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Abstract

Ukrainian railways use a wide variety of methods for determining ballast contamination. Some regional branches of JSC "Ukrzaliznytsia" prefer to replace the old ballast with new instead of cleaning it. Others do the cleaning of crushed stone ballast. The periodicity of such crushed stone cleaning depends on local conditions and features of cargo transportation. Ballast contamination assessment plays an important role in this matter. The essence of the research is to reduce the time for obtaining results on the assessment of ballast contamination and to simplify it for use by one or two persons, who can act as track installers.
KEY WORDS: *ballast, railway track, crushed stone, ballast cleaning, sleepers.*

1. Introduction

Railway transport plays an important role in the economic development of the country and is the basis of its transport system. However, today railway transport is becoming less competitive with other types of transport, which is connected with global economic changes and the unfavorable economic situation that has developed in the state. Effective functioning of railway transport is a necessary condition for the stabilization and development of the economy and ensuring the national security of the country.

The process of European integration requires approximation to European transport quality standards, this primarily concerns the international transport corridors of Europe and Asia and the improvement of the economic efficiency of railway transport.

One of the ways to increase the competitiveness of railway transport is to reduce costs for its infrastructure. The share of railway track infrastructure in the entire railway transport system of Ukraine is significant. This especially applies to the costs of modernization and maintenance of the railway track by railway enterprises, which is associated with large investments

In European railways, it is believed that the most effective reduction of infrastructure costs is achieved by extending the life cycle of the track. Among the methods of extending the life cycle of tracks can be [1]:

– improving the initial quality of the track in order to distance the development of unevenness by using mechanized maintenance and high-quality materials, such as elastic elements and others, which ensure better operation of the ballast layer;

– planning of repairs and ongoing maintenance activities using effective planning strategies based on continuous monitoring of the development of the geometric state of the track and the use of automated work planning management systems.

2. Analysis of Ballast Layer Work Research

Two fundamentally different types of railway track are used on the world's railways: with a ballast layer and a ballastless base. On domestic public railways with a soil subgrade (more than 99% of the track length), the upper structure of the track with a ballast layer is the only structure that is used from both technical and economic indicators [2].

The main advantages of the ballast track are:

– proven technology;
– relatively low construction costs;
– easy replacement of track elements;
– relatively easy correction of track geometry (retention);
– small adjustments to the configuration (plan) of the railway track are possible;
– good drainage properties, elasticity and noise absorption [3].

As a result, the traditional ballast track superstructure still meets the high requirements, as demonstrated by the TGV tracks in France. The profitability of using a ballast track depends, first of all, on the performance of one of its main components, namely the ballast layer.

Ballast consists of a layer of unbound coarse-grained material, which, as a result of internal friction between the grains, can perceive significant compressive stresses, but not tensile stresses. The bearing capacity of the ballast layer in the vertical direction is significant, but it is clearly reduced in the lateral direction [4].

In addition to uniform distribution, the drainage property of ballast is very important [5-6]. Contamination of the ballast layer can have external and internal causes, such as abrasion, destruction of the ballast material under the influence of atmospheric phenomena or penetration of small particles in the form of a mixture of clay (loam). A contaminated ballast layer prevents the passage of water, which, as a result, reduces resistance to sliding and freezing during frost. The most important requirements for ballast material are: hardness, abrasion resistance, good particle size distribution. The particles should be cubic in shape and have sharp corners.

3. Influence of Factors on the Operation of the Ballast Layer

Based on the review of theoretical, laboratory and natural studies, conclusions are formulated about the generally accepted ideas about the operation of the ballast layer and the influence of the main factors on it [7-9]. In general, the operation of the ballast layer and railway track is influenced by a large number of primary and secondary factors. Including:

1) 1)operational: load tension, lost tonnage, axle load, speed of rolling stock, influence of rolling stock and condition of running parts;
2) factors depending on the track design: track stiffness, sleeper profile, condition and construction of the track substructure;
3) ballast layer factors: ballast material and its granulometric composition; pressure from the sleeper on the ballast layer, or horizontal and vertical stresses in the ballast; vibration effect on the ballast layer; initial compaction of the ballast layer; ballast contamination and moisture;
4) factors depending on track maintenance: permissible stress in the ballast layer; the initial quality of the track after repair (the quality of the track geometry and the ability to maintain this quality); quality of current maintenance and methods of its implementation (mechanized straightening and tamping of the ballast layer and their periodicity, grinding of the rolling surface of the rail, etc.).

Field tests make it possible to assess the influence of operational factors on the disruption of the track geometry without considering the processes that occur in the ballast layer. Laboratory tests make it possible to assess in detail the influence of load factors on individual sleepers and ballast properties on the settlement of the ballast layer. However, the assessment of the influence of factors on the operation of the ballast layer by laboratory tests has two main drawbacks. Firstly, the result is always the settlement of a single sleeper, while the unevenness on the track is the uneven settlement of many sleepers along the track, which also depends on the bending stiffness of the rails, uneven sleeper shoring, fluctuations in the rolling stock, uneven elasticity of the subgrade, etc. Secondly, for practical calculations, it is necessary to have a relationship between the operating factors and the load factors on the ballast layer or sleeper, that is, with a known speed, load tension, axial load, it is difficult to theoretically find the load on the ballast layer, the vibration effect on it, the degree of unloading or complete unloading in the presence of backlash.

A number of other factors can also be identified, but at the moment not all of them can be taken into account. Knowledge of the mechanisms of destruction and the influence of the listed factors on the operation of the ballast layer can provide an answer regarding the prediction of the disruption of the ballast layer and related planning of track works, optimization of its operation, selection of a combination of design parameters that best meet the given operating conditions. All this can significantly reduce the costs of construction and operation of the railway track.

4. Analysis of the Disadvantages of the Existing Methods of Assessing the Work of the Ballast Layer

At present, on the railways of Ukraine, when designing track structures or setting conditions for the rotation of rolling stock, the performance of the ballast layer is assessed by calculated stresses in the ballast layer and their permissible values, which can have different levels depending on the load tension, the type of fasteners and the type of rolling stock [10]. The approach based on the allowable stress criterion, which was adopted by analogy with the strength of other track elements, does not allow to fully assess the performance of the ballast layer. The main reason for this is the lack of clear boundaries between the operational and non-operational state of the ballast layer, as it continuously changes throughout its service life. The second reason is the failure to take into account the factor of current retention, which is decisive for the service life of the ballast layer. In addition, there are a number of other factors, without knowledge of which it is difficult to evaluate the performance of the ballast layer [6].

Thus, in summary, the following shortcomings of the assessment of the ballast layer can be identified [5, 10]:

1) calculated stresses in ballast and subgrade are much closer to their permissible stresses than in other elements and do not give an answer as to how the element will behave if the stresses are exceeded;
2) the ballast layer, unlike other track elements, is an element whose failure is the gradual deterioration of the track geometry;
3) a significant impact on the work of the ballast layer of track maintenance works;

4) permissible stresses are not related to the frequency of current maintenance work and the intensity of the accumulation of non-homogeneous residual deformations;

5) in addition to permissible stresses, an important factor is the initial quality of the track and its maintenance strategy;

6) the operation of the ballast layer is influenced not only by the maximum stresses in it, but also by the level of vibration, complete or partial unloading of the ballast in the presence of backlash, and many other factors;

7) unevenness that occurs on the track, or which was allowed, has an inverse reinforcing effect on the development of unevenness due to the disruption of the ballast layer;

8) the mechanisms of the destruction of the ballast layer under the sleeper are significantly different from the mechanisms of destruction of other elements to which the theory of resistance of materials is applied: the failure of the ballast layer occurs gradually in relation to the amount of backlash, the stiffness of the track at the place of the backlash, the loads on the ballast under the backlash and the dynamic by the action of the rolling stock.

5. Development of an Express Method for Determining the Degree of Ballast Contamination

Currently, the most diverse methods of ballast maintenance are used on roads. Some roads prefer to replace the old ballast with new instead of cleaning it. Other roads are cleaning crushed stone ballast from blast furnace slag and stone. The periodicity of such crushed stone cleaning depends on local conditions.

In some cases, crushed stone cleaning is done annually, and in other cases - only once every 12 years. Some roads periodically clean the ballast only on the slopes of the ballast prism and on the track, but do not clean it in the sleeper boxes. This practice is based on the assumption that the contaminant of the ballast in the sleeper boxes will be washed out by atmospheric water through the cleaned ballast on the slopes of the ballast prism and in the track. If the ballast on the slopes of the ballast prism and in the track is contaminated, then over time the ballast in the sleeper boxes also becomes contaminated. Some roads clean ballast from both sides of sleepers and in boxes, sometimes up to 8 cm below the bottom of the sleepers. Cleaning of ballast on the slopes of the prism is usually done 20-30 cm below the sole of sleepers, and when cleaning ballast on the track - 15 ... 20 cm Cleaning of ballast in sleeper boxes is usually done to a depth slightly below the sole of sleepers in the axis of the path and approximately 7.6 cm below the sole of the sleepers at their ends. Under such conditions, the contaminant in the ballast under the sleepers is washed away by atmospheric waters to the ends of the sleepers. To drain water from the ballast on the track, transverse drainage slots are used, with their slope corresponding to the slope of the prism. The distances between the slots, which should not pass under the rail joints, are usually equal to the length of the rail.

Various methods of cleaning contaminated ballast are used on roads. On some roads, only manual ballast cleaning is used; on other roads - only crushed stone cleaning machines on the rail course and machines that do not occupy the race. These machines clean the ballast on the slopes of the ballast prism and on the track. On a number of roads, ballast from sleeper boxes is first cut by hand or with the help of special machines and placed on the slopes of the ballast prism, and then it is cleaned here by a mechanized method. Ballast cleaning is done by roads or by own forces or under contracts with relevant companies.

The contaminant released during ballast cleaning dries quickly and usually turns into a material that is easily blown away by the wind. If the contaminant is thrown on the edge of the ground bed, it can be captured by the eddy currents of air that occur when trains pass, and, falling on the ballast, clog it again first of all on the slopes of the ballast prism, preventing the drainage of water from it.

In this regard, the contaminant must be thrown far below the slope of the embankments. When cleaning the ballast in the recesses, the contaminant must be removed beyond their limits. The contaminant can be left on the sides of the trenches only temporarily, for 1 ... 2 days.

Ballast cleaning in tunnels has specific features. The rise of the path in tunnels to clean ballast is limited by the conditions of the dimensions of the tunnel from above.

In long tunnels, the ballast is usually not only dirty, but also wet; therefore, many roads do not attempt to clean it, as it is difficult to separate the sticky contaminant from the crushed stone mass. In such cases, the ballast is completely removed and replaced with a new one. In short tunnels, the ballast is often dry and therefore easy to clean. Ballast cleaning is done manually on some roads.

In tunnels with good ventilation, special machines are used to cut ballast from the sleeper boxes and throw it to the sides on the slopes of the ballast prism, where it is cleaned with rubble-cleaning machines of the "Mole" type, or it is loaded with grab cranes on a rail run into wagons and taken out of the tunnel. On one road, for ballast cleaning in tunnels, a rail-mounted rubble-cleaning machine is successfully used, which cuts rubble from under the sleepers and from the slopes of the ballast prism, cleans it and puts it back on the road, and the contaminant is loaded with the help of conveyors into semi-wagons attached to the rubble-cleaning machine.

With this cleaning of crushed stone, the path is lowered by 1 cm, which allows you to make three lifts of the path to new ballast in the future.

In places where manual cleaning of crushed stone is planned, local conditions should be carefully studied, because with the existing high cost of labor, it is sometimes more profitable to replace contaminated ballast with new ones instead of cleaning it by hand. Manual cleaning of crushed stone is done according to the following technology. First, the crushed stone is loosened with a pick at the ends of the sleepers to a depth of about 15 cm below the bottom of the sleepers. Then the ballast is taken on forks and, by shaking, the contaminant is separated from it. Cleaned crushed stone is placed in the middle of the path, where it is used when raising the track. The brought clean crushed stone is unloaded on the slopes of the ballast prism. In those cases when the crushed stone in the sleeper boxes is very dirty, it is cut with picks and shovels slightly below the bottom of the sleepers. Manual cleaning of crushed stone is inefficient, very expensive and tiring for the workers. In addition, no matter how carefully the crushed stone is cleaned on the forks, some amount of the contaminant remains in it or in the process of cleaning it gets back into the path. The average rate of production of one worker on cleaning crushed stone by hand is about 4.9 m of path in an eight-hour working day. At one time, manual rubble cleaning was used on many roads using the following technology. The dirty crushed stone was loosened with picks and shoveled onto the sieves installed at an angle on the side. The contaminant fell on the roadside and was then dumped on the slopes of the embankment, while the clean crushed stone rolled down the inclined surface of the screens to the base of the ballast prism and was then placed on the road. Works based on this technology had a high cost and low productivity. Therefore, in order to reduce the cost of work and increase productivity, screens began to be installed on railway platforms. Contaminated crushed stone was thrown onto these sieves with the help of grab cranes on the rail course. Clean crushed stone was rolled back to the road on inclined screens, and the contaminant that passed through the screens remained on the platforms

6. Conduct of Research on Ballast Contamination

Conducting an experiment

To carry out the express method for determining the contamination of the ballast layer, two sections of track were taken: Section A (119 km of even and odd track), Section B (135 km of odd track).

Characteristics of the site A

Fraction: 25 ... 60 mm.

Cleaning was performed by RM-80 in 2018.

The missed tonnage is 876 million gross tons. Load volume – 38.3 million gross tons per year.

Track category - II. Track type: P65, non-contact.

Fastening: double track – KB; odd track – KPP 5.

Speed: V_{pas} – 80 km/h; V_{load} – 60 km/h;

Characteristics of the site B

Fraction: 40 ... 70 mm.

Cleaning was performed by RM-80 in 2015.

The missed tonnage is 259,2 million gross tons. Load volume – 53.8 million gross tons per year.

Track category - II. Track type: P65, non-contact.

Fastening: double track – KB; odd track – KPP 5.

Speed: V_{pas} – 100 km/h; V_{load} – 80 km/h;

During the research, a sieve with 0.5 (mm) holes was used, and electronic weights up to 2 kg, and with a measurement step of 1 gram.

The essence of the research is to reduce the time for obtaining results on the assessment of ballast contamination, and to simplify it for use by one or two persons, who can act as track installers. During the research, 20 samples were taken on each section of the track, 10 in the sleeper box, and 10 in the end of the sleeper at a depth of 20 cm, with different characteristics of the track and with differences in plantings.

After sieving, the following numerical values were obtained (Tables 1-6).

Table 1

Site A is even

Even track in the sleeper box		
Sample weight (g)	Net weight (g)	Contamination, %
989	886	10,4
993	898	9,6
987	896	9,2
999	899	10,0
989	888	10,2
994	894	10,1
995	896	10,4
999	902	9,7
999	901	9,6
1007	900	10,6
1002	904	9,8
989	887	10,3

Table 2

Site A is even

Even track at the end of the sleeper		
Sample weight (g)	Net weight (g)	Contamination, %
1006	972	3,4
1001	969	3,2
988	960	2,8
996	965	3,1
991	964	2,7
997	965	3,2
996	964	3,1
994	967	2,7
1003	974	2,9
986	960	2,6

Table 3

Site A is odd

Odd track in the sleeper box		
Sample weight (g)	Net weight (g)	Contamination, %
996	911	8,5
999	920	7,9
1002	926	7,6
1001	919	8,2
999	907	8,4
998	917	8,1
994	901	8,1
997	917	8,0
997	919	7,8
991	913	7,9
990	915	7,6

Table 4

Site A is odd

Even track at the end of the sleeper		
Sample weight (g)	Net weight (g)	Contamination, %
997	976	2,1
1003	989	1,4
1004	984	2,0
989	975	1,4
996	979	1,7
994	977	1,5
992	976	1,6
988	964	1,9
987	969	1,8
993	972	2,1
995	976	1,9

Table 5

Site B

Odd track in the sleeper box		
Sample weight (g)	Net weight (g)	Contamination, %
987	925	6,3
993	926	6,7
989	929	6,1
1006	937	6,9
992	934	5,8
997	937	6,0
991	929	6,3
1001	939	6,2
989	924	6,6
993	932	6,1

Table 6

Site B

Odd track at the end of the sleeper		
Sample weight (g)	Net weight (g)	Contamination, %
986	969	1,7
1003	988	1,5
997	986	1,1
993	979	1,4
993	977	1,6
996	984	1,2
991	977	1,4
994	981	1,3
986	976	1,0
995	983	1,2

According to the experimental data, numerical values were obtained on 3 sections of the track.
6...8 man-hours per 1 km of track were spent on the work.
We will compare the contamination in the sleeper box and at the end of the sleeper (Figs. 1-3), and the graphs are drawn for 10 pickets with the most characteristic values.

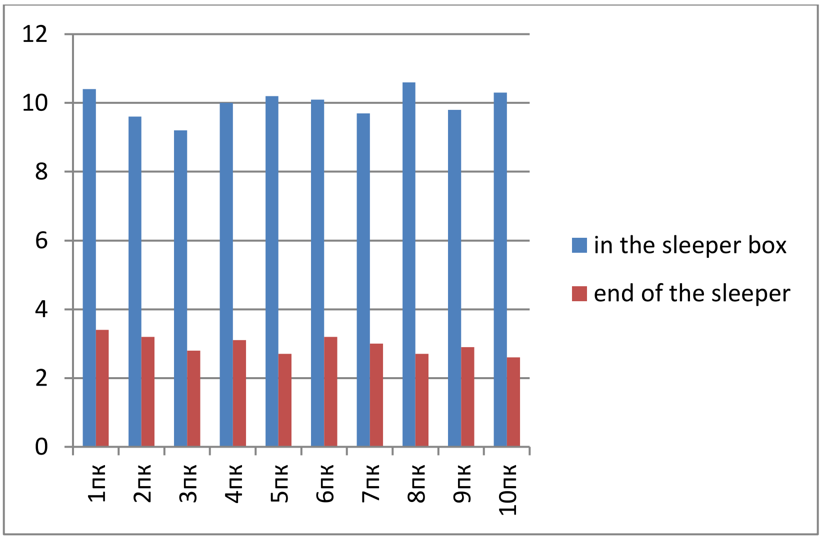

Fig. 1 Comparison of ballast contamination in the sleeper box and at the end of the sleeper

To this graph (Fig. 1), it can be concluded that the contamination of the ballast in the sleeper box is greater, almost 3 times, than in the end of the sleeper.

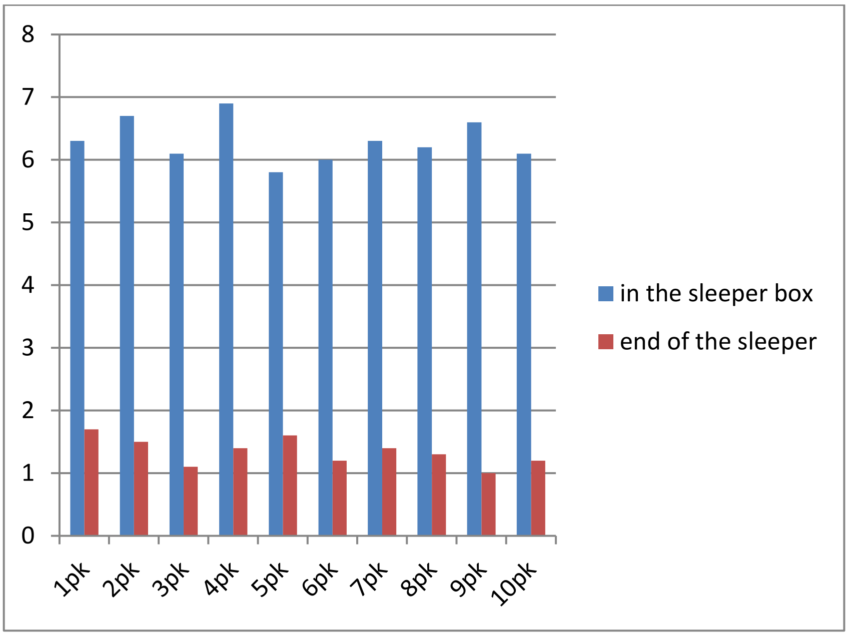

Fig. 2 Comparison on the site with the crushed stone fraction 40-70

This graph (Fig. 2) makes it possible to testify that with a fraction of 40 ... 70 mm, the contamination in the sleeper box is greater than in the end of the sleeper.

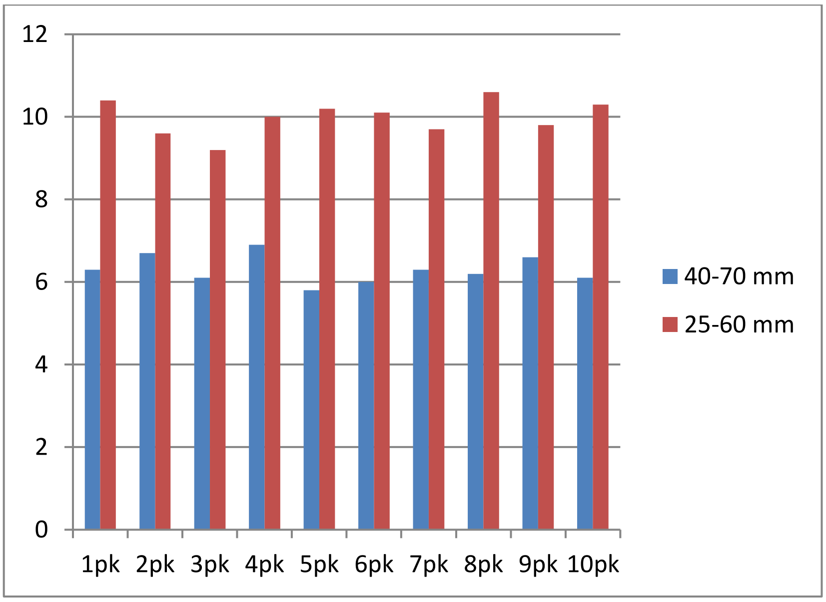

Fig. 3 Comparison of contamination of track sections with 40 ... 70 mm and 25 ... 60 mm ballast

On this graph (Fig. 3) we can see that the section of the track works better on ballast with a fraction of 40 ... 70 mm than on a fraction of 25 ... 60 mm.

During the implementation of the express method for determining ballast contamination, it was determined that 1 km of track, 1 track fitter can check the contamination of 1 km of track in 1 working day.

7. Conclusions

During the implementation of the express method, the following conclusions were made: the maximum contamination at the end of the sleeper is 3.4%; the maximum contamination in the sleeping box is 10.4%; contamination at the end of the sleeper is less than contamination in the sleeper box; time spent on carrying out the express method is 4 ... 8 man-hours per 1 km.

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Numerical Analysis of the Strength of the Crankshaft of a Four-Stroke Internal Combustion Engine

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Abstract

In this paper is presented a numerical dynamic strength analysis of the crankshaft under load acting in a specified operational point of compression ignition engine. The such point was determined for the maximal force of combustion gases; and additionally inertia forces resulting from the rotational speed of the crankshaft were taken into consideration. The analysis was performed in order to evaluate the distribution of the stresses, and to determine critical areas on the crankshaft where the concentration of the stresses could occur.
KEY WORDS: *crankshaft, compression ignition engine, Finite Element Method, FEM.*

1. Introduction

The crankshaft, as an element of the crank mechanism, through the piston, piston pin and connecting rod, takes over gas forces generated by the combustion process in the cylinder, and next converts these forces into torque transmitted further through components of the transmission system to the road wheels of the car. Due to the significant increase in power output of contemporary power units, due to emphasis on the limitation of fuel consumption, and compliance with ecology requirements imposed on combustion engines, nowadays these engines belong to very heavy-duty loaded thermal machines, subjected to significant thermal loads as well as mechanical loads caused by increase of mean effective pressure [3]. Additionally, rotational speed of internal combustion traction engines has increased as well, and can reach value up to 5000 rpm in case of compression ignition engines, while in case of spark ignition engines even up to 9000 rpm. Values of the forces acting on the crankshaft are function of many factors such as crank radius, dimensions and mass of connecting rod, dimensions and mass of piston. The gas forces and the inertia forces result in compressive, torsional and bending loads acting on components of crank system. Arisen stresses cause dangerous concentration of the stresses occurring in areas of base of fillets, like for instance transition areas between crank arms and crankpins [1].

The Finite Element Method (FEM) was used to estimate stresses occurring in the crankshaft and occurring in specified points of combustion engine operation. Numerical simulation belongs to quick and economical methods of verification of crankshafts subjected to predetermined loading. The FEM method is often used to solving engineering problems on stage of development, production and operation [4, 5]. The method itself is based on division of a physical objects into finite number of elements connected with nodes. Interactions between the nodes are described in form of interpolating functions [2].

2. Object of the Analyses and Scope of the Calculations

This paper deals with analysis of the crankshaft of compression ignition engine for light road traction, parameters of the engine are presented in the Table 1. The crankshaft was modelled using the NX software, while to evaluation of compressive stresses and the stress according to von Mises theory one used ANSYS Workbench software with Transient Structural module.

Table 1

Technical data of the engine

Type of the engine	compression ignition engine, CR system, turbo supercharger
Layout/number of cylinders	in-line engine / 4
Swept volume	1248 ccm
Maximal power output	55.2 kW at 4000 rpm
Maximal torque	190 Nm at 1500 rpm

The crankshaft was manufactured from alloy steel for carburizing with the following parameters: density = 7870 kg/m^3, Young's modulus = 210000 MPa, Poisson's ratio = 0.3, yield strength = 520 MPa, and ultimate tensile strength = 800÷950 MPa. In course of the simulations the crankshaft was subjected to load of the gas force in

TDC position having value of 44 000 N, and was rotated at rotational speed in range from 1000 to 4500 rpm. The gas force was evaluated for maximal fuel dose. Size of the mesh amounted to 1 mm. The crankshaft was suppressed using Cylindrical link on the main journals, allowing possibility of rotation of the crankshaft itself.

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3. Construction of the Numerical Model

Solid model of the crankshaft was built in the NX program, and next, using .stp format serving for data exchange between CAD systems, the model was exported to the ANSYS WORKBENCH software. The calculations were performed in the Transient Structural module which is used to evaluating dynamic response of the system under loads changing in time. Size of a single element of the mesh was determined for 1 mm using the Uniform function (Fig. 1 and Fig. 2), which does not improve the mesh in terms on distances or curvature of geometry. The mesh is composed from 6845909 nodes and 1608812 elements. After applying the mesh on geometry of the shaft, method of suppressing and suppressing positions of the crankshaft together with loading force were applied – i.e. boundary conditions. The crankshaft was suppressed using the Cylindrical link on the main journals, allowing possibility of rotation of the crankshaft itself, what results from real conditions of crankshaft operation. The gas force which was placed on crankpin had amounted to 44,000 N (in the TDC) and was applied to surface of the crankpin in the angular range from 0 to 120 °CA. Additionally, the crankshaft was loaded with centrifugal force (inertia one) resulting from its rotational speed. Range of the rotational speed was from 1000 to 4500 rpm. Calculation points are summarized in the Table 2.

Fig. 1 Meshed model of the crankshaft

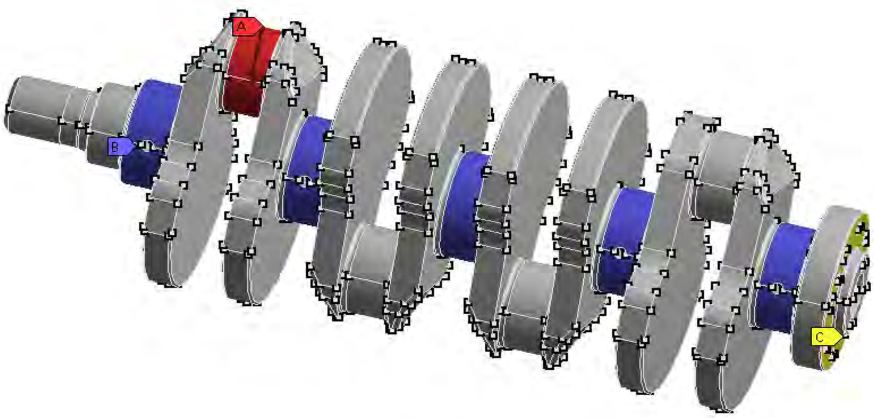

Fig. 2 Boundary conditions applied on the crankshaft. Crankshaft main bearings are suppressed, the load 44000 N is applied on top of the crankpin surface

4. Results of Numerical Calculations

Due to complex geometry of the crankshaft, the FEM calculations allow for assessment of areas that are most exposed to damage, and places of stress concentrations. Exemplary results are shown on the Fig. 3 and Fig. 4. The results collected here are displacements and stresses (Table 2). Maximal deformation took place in the middle of the crankpin (Fig. 3), the highest stresses occurred in transition radius areas between crank arms and crankpin, and between crankpins and main journals (Fig. 4).

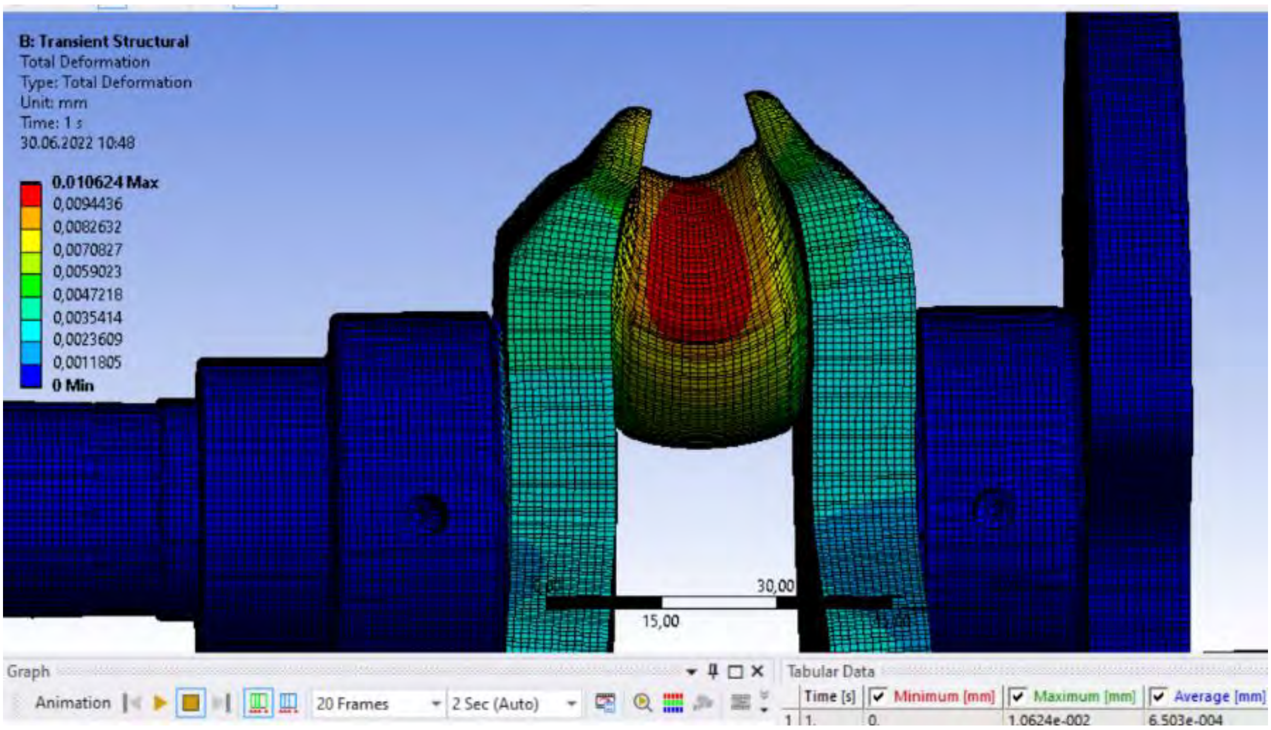

Fig. 3 Total deformation for 1000 rpm (in scale)

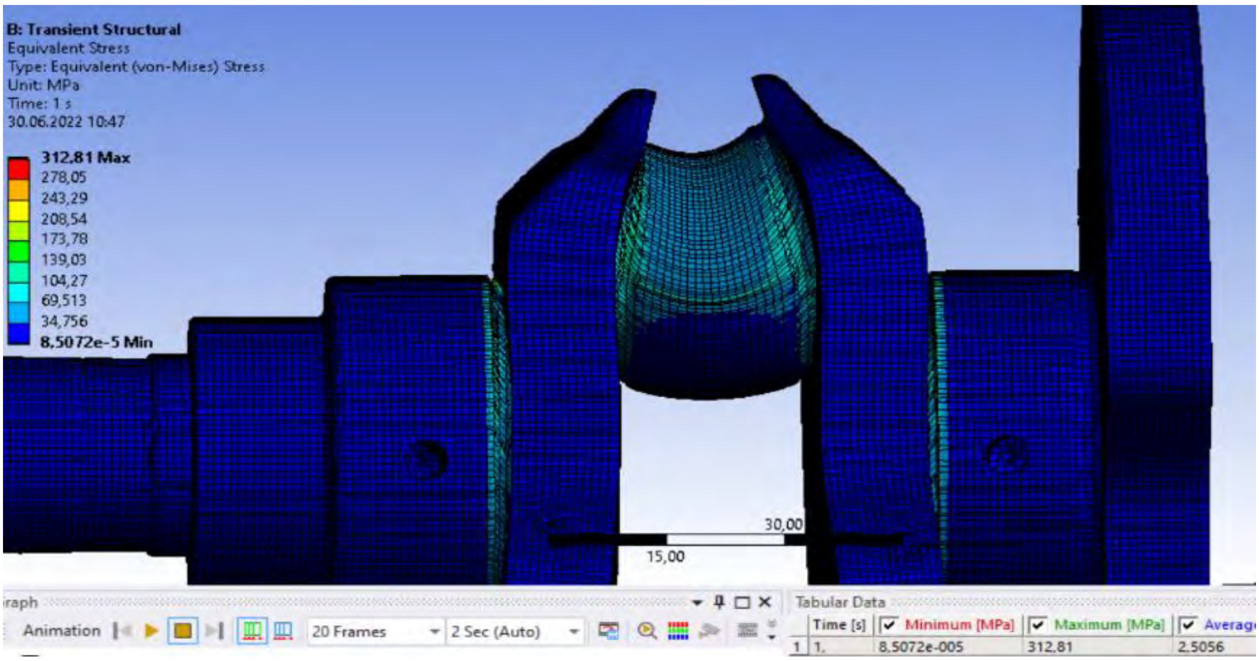

Fig. 4 Equivalent Stress for 1000 rpm (in scale)

Table 2

Results of numerical analysis

Rotational speed, rpm	Displacement, mm ($\cdot 10^{-2}$)	Stress, MPa
1000	1.0624	312.81
2000	1.0557	310.94
3000	1.0446	307.84
3500	1.0374	305.82
4500	1.0197	300.85

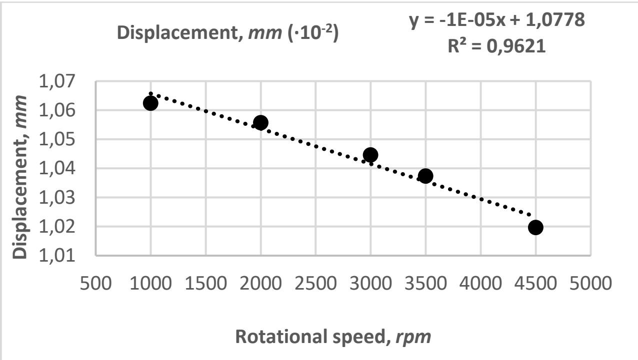

Fig. 5 Specification of the results - displacements

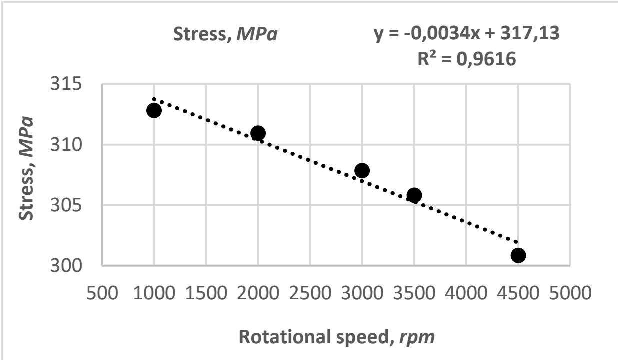

Fig. 6 Specification of the results – stress

5. Conclusions

The engineering tool implemented in this study allows for stress analyses of various design solutions for crank mechanisms of combustion engines.

Results of the numerical calculations allow for confirmation of relieving effect of inertia forces on the crankshaft. Together with an increase of rotational speed from 1000 rpm, to 4500 rpm, at constant force acting on the crankpin and equal to 44 000 N, displacement of the middle of the crankpin decreased from $1.0624 \cdot 10^{-2}$ mm to $1.0197 \cdot 10^{-2}$ mm (Fig. 5). Simultaneously, maximal stress according to von Mises theory also decreased from 312.81 MPa to 300.85 MPa, i.e. with 3.9% (Fig. 6).

The authors continue already undertaken an analysis of the effects of engine control parameters on the loading of the crank mechanism, inclusive of the effects of temperature on the structural components of the engine.

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Simulation of the Influence of the Rolling Surface Profile on the Stability of Wheel Pair Movement on the Railway Track

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Abstract

According to the results of experimental studies of technical parameters of the rolling surface of wheel pairs and the impact on the parameters of intermediate rail fasteners to ensure the longitudinal stability of rail threads, interaction modeling is performed. The research on the influence of geometrical characteristics of a surface on the interaction of a rail and a wheel and their influence on the level of longitudinal forces of interaction between elements of a track and wheels of rolling stock in operation on the railways of Ukraine are analyzed. After the beginning of operation of wheel pairs with the increased value of hardness the optimum ratio of the hardness of rail and wheel steel was broken. From various sources on the interaction of the rail and the wheel, it is known that the best wear resistance in the friction pair is found in metals with approximately the same hardness. Based on the obtained data, calculations were performed and their analysis was carried out with the development of recommendations for further operation.
KEY WORDS: *rail track, stability, horizontal forces, longitudinal forces, intermediate fastenings.*

1. Introduction

Railway transport of Ukraine is a developed industry with a strong infrastructure. In addition, the Ukrainian railways have rather difficult operating conditions, which are characterized by combined train traffic, in which both passenger trains and freight trains run on the same highways. All this complicates the operating conditions. Therefore, the problem of interaction of rails with wheels is quite relevant today. The reason for the loss of stability of rail crews "lies" in the place of contact of the wheel with the rail - more precisely, in the ratio of forces generated in the area of contact interaction of the wheel with the rail. However, even for fairly simple calculation schemes of rail crews, the general picture of the influence of the characteristic parameters of the system on its dynamic qualities is unknown, because the conditions of steady motion are extremely cumbersome and practically unsuitable for qualitative analysis. This paper proposes an approach that involves transferring the results of the analysis of the stability of rectilinear motion of a pair of wheels on a rail track (with some design limitations) to the model of a rolling stock.

2. Influence of Nonlinear Creep on the Stability of Rectilinear Motion of a Wheel Pair with a Conical Profile

To find the conditions of stability of rectilinear motion on a rail track of a wheel pair with a conical profile, elastically connected to the frame in the transverse and longitudinal directions, we use the method of Lyapunov functions, which allows to estimate the influence of nonlinear creep (Carter creep model) [1]. For the direct conduct of experimental research, a method of performing work on existing sections of the railway track has been developed. A laser profilometer was used to measure the parameters of wheel pairs [2-3].

Wheelset is considered as a mechanical system with two degrees of freedom of Fig. 1: y, ψ - transverse deviation of the center of mass of the wheel pair relative to the centerline of the track and the angle of rolling, respectively (coordinates y, ψ determine the position of the wheel pair in the horizontal plane relative to the inertial coordinate system moving at a constant speed along and across the track line) [4]. The main experimental researches were carried out on the seamless track within the main sections of the railway, the structural analysis of territorial transport systems on the basis of classification methods was carried out. During operation, the elements of the intermediate rail fastening are subjected to constant dynamic impact in the process of which there are residual deformations [5-6]. We will consider that the wheel has one point contact with a rail, and the point of contact does not change the position concerning a rail that is possible only at rather small values of lateral shift of wheel pair. The deviation was within 4 mm on both sides of the wheelbase. The coordinates of the points were taken from the obtained values of the scanned surface with a laser profilometer.

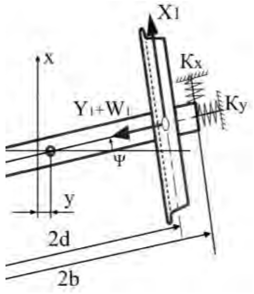


Fig. 1. Scheme of forces acting on the wheel during movement

In this case, the equations of motion will take the following form:

$$\begin{cases} m\ddot{y} = -2k_y y + Y_1 + Y_2 + W_1 + W_2; \\ J\ddot{\psi} = -2k_x b^2 \psi + (X_1 - X_2)d + (W_1 - W_2)d\, sin(\psi), \end{cases} \tag{1}$$

where y – lateral deviation of the center of mass of the wheelset from the longitudinal axis of the track; ψ – swaying angle; m, J – mass and central moment of inertia about the central vertical axis; k_x, k_y – stiffness coefficients of elastic elements of axle box suspension in the longitudinal and transverse directions; k_1 – creep ratio; k_{ri} – coefficients (polynomial) that determine the geometry of the profile; γ – taper of the wheel profile ($\gamma = k_{r1}$); $2d$ – the distance between the wheels; $2b$ – shoulder "elastic" pair (the distance between the longitudinally located elastic elements of the axle box suspension).

The strength of creep as a function of relative pseudo-slip is determined by the formula:

$$F_i = f_i \varepsilon_i \left[1 + \left(\frac{f_i \varepsilon_i}{k_f P_i} \right)^2 \right]^{-1/2}, \tag{2}$$

where P_i – wheel load in [kN]; f_i – pseudo-slip coefficient; k_f – coefficient of friction, relative slip, which is determined by the formula:

$$f_i = 235P_i - 2.4P_i^2 + 0.01P_i^3 \quad (i = 1,2). \tag{3}$$

The longitudinal and transverse components of the relative pseudo-slip based on expression 2 are determined according to the formulas

$$\begin{cases} \varepsilon_{ix} = (-1)^i \dfrac{d\psi}{\upsilon} - \dfrac{\Delta r_i}{r_0}; \\ \varepsilon_{iy} = \dfrac{\dot{y}}{v} - \psi, \end{cases} \tag{4}$$

where y – the magnitude of the perturbation; Δr – taper of the wheel profile; v – speed.

The conical profile of the wheel generates the so-called gravitational stiffness - the lateral component of the reaction occurring at the points of contact of the wheel and rail; P_i – vertical components of reactions at the points of contact of the wheel with the rail (we will consider equal on the left and right wheel). The experimentally obtained geometric data on the geometry of the profile (worn) wheel pair in the form of a polynomial of the fourth degree are included in the mathematical model. In the linearized equations of perturbed motion there is a destabilizing moment of gravitational stiffness forces (this does not change the qualitative structure of the equations, can be "suppressed" by the choice of elastic elements in the longitudinal direction). Coefficients of rigidity k_x, k_y elastic elements are chosen so that the subsystems corresponding to the phase variables y, ψ, had matching natural frequencies

$$\frac{2k_y}{m} = \frac{2k_x b^2 - 2P_1 d\gamma}{J} = \tau. \tag{5}$$

Zero values of phase variables correspond to undisturbed motion of a wheel pair $y = 0$, $\psi = 0$. Nonlinear equations of perturbed motion of a pair of wheels with respect to new variables p, q (slippage in the transverse and longitudinal directions, respectively, relative slippage, creep forces will have the character of saturation function). The quadratic Lyapunov function was used to determine the critical velocity. From the condition of positive definiteness, Lyapunov functions obtained the expression of critical velocity $V_{kr} = \sqrt{\tau d r_0 / \gamma}$. At $V < V_{kr}$ undisturbed motion of the wheel pair is asymptotically stable, and the nonlinear nature of the creep forces does not impose restrictions on its area of attraction, when $V > V_{kr}$ rectilinear motion of the wheel pair is unstable. Assuming that the slip is identically zero, then the so-called kinematic oscillations or undisturbed motion in this case is stable. Assumption ($p = 0$, $q = 0$) implemented only when $V = V_{kr}$ – corresponds to the critical Lyapunov case of a pair of purely imaginary roots. The amplitude of the kinematic oscillations in the lateral ratio is proportional to the square root of the ratio of the average radius of rolling to the conicity of the surface of the wheel. The magnitude of the perturbations of the variables y, ψ, sold during operation belong to a limited set D, it is necessary to assess the area of attraction of undisturbed motion, which would ensure the absence of unwanted contact of the wheel flange with the rail.

To estimate the region of attraction, we turn to dimensionless variables (the expression of the Lyapunov function has the dimension of acceleration) for dimensionlessness selected parameters V, d. Where $\bar{R}$ the maximum radius of the circle that lies entirely in D, that is $\overline{y^2} + \overline{\psi^2} = \overline{R^2}$. When considering a four-dimensional sphere of the same radius $\bar{y}^2 + \psi^2 + \bar{p}^2 + \bar{q}^2 = \overline{R^2}$ it is established that its projection on the plane $\bar{y}$, ψ did not go beyond the radius $\bar{R}$.

3. Influence of Force Structure on the Stability of Rectilinear Motion of a Wheel Pair with a Conical Profile

To determine the influence of the force structure on the stability of the rectilinear motion of a wheel pair with a conical profile, consider the structure of forces acting on the wheel pair in the presence of elastic connection with the frame in the longitudinal and transverse directions. The equations of linear approximation have the form:

$$\begin{cases} m\ddot{y} = -2k_y y - 2\dfrac{f_{kr}}{V}\left(\dot{y} - V\psi\right); \\ J\ddot{\psi} = -k_x b^2 \psi - 2 f_{kr} d^2 \left(\dfrac{\dot{\psi}}{V} + \dfrac{\gamma y}{d r_0}\right), \end{cases} \tag{6}$$

where V – speed; y lateral deviation of the center of mass of the wheel pair from the longitudinal axis of the track.

We distinguish symmetric and obliquely symmetric components of the forces acting on the wheel pair based on formula (6) $A\ddot{x} + D\dot{x} + Ex + Fx = 0$, where A, D, F − symmetric matrices, E − obliquely symmetric matrix (matrix of positional nonconservative forces). That is, the forces of the creep are included in the matrix of potential forces and in the matrix of positional forces, hence their "complex" effect on the stability of rectilinear motion. In this case, the forces of the creep entered only the matrix of positional forces. The influence of non-conservative positional forces on the stability of rectilinear motion depends on the totality of acting forces. If $\bar{F} = 0$, then zero system solution $A\ddot{x} + D\dot{x} + Ex + Fx = 0$ unstable at arbitrary values of parameters (there is a structural instability). This follows from the instability theorem for autonomous systems - the sign-changing function due to the system of excited motion has a sign-constant derivative.

4. Approximate Determination of Self-Oscillations of the Lateral Ratio of the Wheel Pair in Straight Sections of the Track

In the mathematical model we will enter the geometrically obtained geometric data on the geometry of the profile (worn) wheel pair. The appearance of a component of gravitational stiffness in the case of a worn wheel profile will lead to a violation of the "symmetry" of elastic characteristics in the transverse and longitudinal directions, which may affect the characteristics of self-oscillations and conditions of soft - rough loss of stability. This section will analyze such situations.

When the lateral deviation of the wheel pair from the track axis, a contact pad of the wheel rim is formed on the surface of the rail head. reinforced concrete sleepers. Rolling of a wheel on a rail at a modern level of development of science [7] is considered as rolling of one cylindrical surface of radius r_1 пon the other cylindrical surface the radii of the wheels will be different - the difference of the radii Δr arises due to the conicity of the surface of the new wheel, its structural curvature or acquired curvature for the worn profile of Fig. 2.

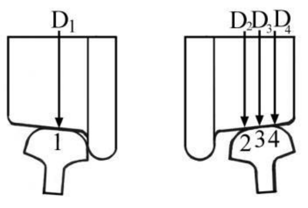


Fig. 2 The scheme of change of diameters of wheels within a point of contact of wheels with rails

The effective conicity of the wheel profile generates the so-called gravitational stiffness of the lateral component of the reaction that occurs at the points of contact of the wheel and rail, the scheme of changing the radius of the wheel pair within 4 mm is shown in Fig. 3. Vertical components of reactions at the points of contact of the wheel with the rail (taken equal on the left and right wheel).

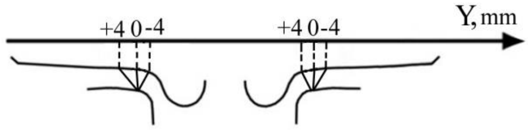


Fig. 3 Changing the radius of the wheel of the wheel pair

The equations of perturbed motion of a model of a wheel pair with a curvilinear profile (the wheel profile is approximated by a polynomial of the 3rd degree) in a rectilinear section have the form:

$$\begin{cases} m\ddot{y} + \left(2k_y + 4P_1k_{r2}\right)y + 2k_1\left(\dfrac{\dot{y}}{v} - \psi\right) + 8P_1k_{r4}y^3 = 0; \\ J\ddot{\psi} + \left(2k_xb^2 - 4P_1s\gamma\right)\psi + 2k_1d^2\left(\dfrac{\dot{\psi}}{v} + \dfrac{\gamma y}{dr_0}\right) + 2\dfrac{dk_1k_{r3}}{r_0}y^3 = 0. \end{cases} \tag{7}$$

From the system of Eq. (7) for the corresponding moments of time after the corresponding mathematical simplifications the formula for determining the amplitude was obtained:

$$a^2 = \frac{8\dfrac{k_1^2k_{r1}}{m_2dr_0} - \dfrac{1}{2}\delta^2 - 8\dfrac{k_1^2t_s}{m^2v^2}}{\alpha_4\left(4\dfrac{k_1^2}{m^2v^2} + \delta\right) - 4\dfrac{k_1\alpha_3}{m}}, \tag{8}$$

where the coefficients t_s, δ are determined from expressions:

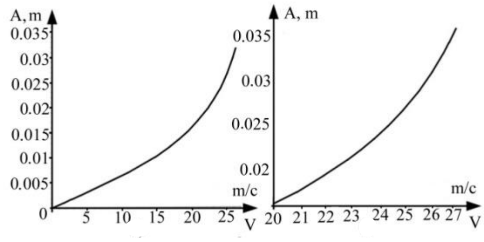
$$\begin{cases} t_s = \dfrac{t_1 + t_2}{2}; \\ \delta = t_1 - t_2. \end{cases} \tag{9}$$

The approximate ratio of the amplitude makes it possible to determine the conditions of existence of the periodic mode of self-oscillations. It is established that v_{kr} speed value, which is determined by the condition $a^2 = 0$ (v_{kr} coincides with the critical speed of rectilinear motion), then there is a slight loss of stability. If $v > v_{kr}$, , or $a^2 = \infty$ this condition is not met, there is a severe loss of stability. When accurately determining the square of the amplitude, the value of the critical velocity will no longer determine the asymptote. With a slight loss of stability, the amplitude curve passes below the "approximate", maintaining the qualitative nature of the latter; in case of severe loss - passes above the "approximate", but acquires a different character (there is a turning point). The turning point divides the amplitude curve into two parts: the first corresponds to unstable self-oscillations; the second is stable. Therefore, at certain subcritical velocities there are two limit cycles (internal unstable, external stable), and at supercritical speed only one stable (as in the case of mild loss of stability, but the amplitude of self-oscillations is much larger than in the case of mild loss of stability). A special case ($t_1 = t_2 = t$).

Thus, with these limitations on the parameters of the system, the nature of the loss of stability (soft or hard) is due only to the geometry of the wheel profile. However, the conditions for safe loss of stability are guaranteed by inequality

$$\frac{\tau}{k_{r1}} > \frac{8d^2P_1k_{r4}}{k_{r3}\left(J + d^2m\right)}. \tag{10}$$

Let us first consider the case of a free wheel pair ($\tau = 0$) with moderately worn profile. From relation (8) it follows that the wheel pair will go to the self-oscillating mode, the amplitude of which will depend on the speed of relaxed motion. To calculate the self-oscillations of the wheel pair, all the necessary data are taken and a graph of the amplitude of the self-oscillations of the lateral relationship from the longitudinal speed, taking into account the average degree of wear of the rolling surface of the wheel pair Fig. 4. Coefficients of rigidity k_x, k_y elastic elements will be chosen so that the subsystems corresponding to the phase variables y, ψ had matching natural frequencies (we also assume that for the central moment of inertia the relation $J = md^2$). Zero values of phase variables correspond to undisturbed motion of a wheel pair $y = 0$, $\psi = 0$.



a b

Fig. 4 Dependence of the amplitude of self-oscillations of the lateral ratio of the free wheel pair on the average worn condition of the band a) graph of complete dependence, b) its fragment

Let us write down the most complete equations of perturbed motion of a wheel pair up to the members of the third order of smallness with respect to new variables (slips in the transverse and longitudinal directions, respectively):

$$\begin{cases} \dot{y} = p + V\psi, \\ \dot{p} = \left(\dfrac{V^2\gamma}{dr_0} - \tau\right) y - \dfrac{2k_1}{mV} p - \dfrac{V}{d} q - \alpha_4 y^3 + 2\dfrac{k_3 p}{mV^3}\left(p^2 + q^2\right); \\ \dot{\psi} = -\dfrac{V\gamma}{r_0} y + \dfrac{1}{d} q; \\ \dot{q} = \dfrac{V\gamma}{r_0} p + \left(\dfrac{V^2\gamma}{dr_0} - \tau d\right)\psi - \dfrac{2k_1 d^2}{JV} q - \alpha_3 y^3 + \beta y^2 \psi + 2\dfrac{k_3 d^2 q}{JV^3}\left(p^2 + q^2\right). \end{cases} \tag{11}$$

In expression (11) coefficients α_3, α_4 and β are determined by formulas:

$$\begin{cases} \alpha_3 = 2\dfrac{d^2 k_1 k_{r3}}{Jr_0}; \\ \alpha_4 = 8\dfrac{P_1 k_{r4}}{m}; \\ \beta = \dfrac{6P_1 d^2 k_{r3}}{J}. \end{cases} \tag{12}$$

The zero solution of the system (it corresponds to the undisturbed motion of the model - rectilinear) is stable only to a certain speed (critical speed). At a critical speed, the linear part of the system allows splitting - an isolated subsystem relative to variables p, q asymptotically stable on the linear approximation, relatively variable y, ψ cthe system of linear approximation is only stable (there is a critical case of a pair of purely imaginary roots). The question of stability can be solved only taking into account nonlinear terms (determined by the sign of the first nonzero coefficient according to the Lyapunov method). The stability of undisturbed motion in the critical case is determined by the sign of the first nonzero Lyapunov coefficient. Under the accepted assumptions, the stability condition is reduced to a simple relation (which does not include system parameters associated with the nonlinear nature of the creep forces and the destabilizing moment of gravitational stiffness forces).

$$V_{kp}^2 < \frac{k_1 d \alpha_4}{m\alpha_3}. \tag{13}$$

If we assume further that the rigidity of the system in the transverse direction occurs only due to the gravitational component, the conditions of dangerous-safe loss of stability will be determined only by the "geometry" of the rolling surface of the wheel. destabilizing moment of gravitational stiffness and nonlinearity of creep forces). Therefore, self-oscillations exist at supercritical velocities (according to the Andronov-Hopf theorem, the origin of self-oscillations occurs at $V = V_{kp}$); a stable limit cycle in this case limits the growth of perturbations, which corresponds to a safe loss of stability. When the condition is violated, the limit cycle limits the area of stability of undisturbed motion even at subcritical speeds, narrowing the interval of operating speed; at supercritical velocities, the growth of perturbations will be unlimited - a case of dangerous loss of stability. From the consideration of the refined model it follows that taking into account the destabilizing moment of gravitational stiffness forces cannot change the local (in the vicinity of the critical velocity) picture of the amplitude curve. The nonlinear nature of creep forces also cannot affect the qualitative picture of the amplitude curve in a small neighborhood of critical speed, ie this approach makes it possible to obtain clear from the point of view of analysis of the effects of dangerous - safe loss of wheel pair stability in the most general assumptions. In addition, it should be noted the work of Ukrainian scientists - Prof. M. Kurgan and D. Kurgan [8-10], who developed a methodology for calculating the railway track in interaction with high-speed rolling stock, which will undoubtedly contribute to the introduction of high-speed and, in the long run, high-speed train traffic in Ukraine.

5. Model Approach to the Analysis of Stability of Movement of Rail Crews

The reason for the loss of stability of rail crews "lies" in the ratio of forces arising between the wheel and the rail. The latter have a complex structure in terms of mathematical classification and include dissipative, gyroscopic, potential and non-conservative positional forces. That is why there are various scenarios for losing or maintaining the stability of undisturbed movement. However, the conditions of stability in general are extremely cumbersome and unsuitable for qualitative analysis. The meaning of the working hypothesis is that the total stiffness that is "transmitted" to the wheelset from the side of the cart in the longitudinal and transverse directions, will satisfy the same ratio, but the coefficient of proportionality is unknown. Assume that the critical speed of rectilinear motion of the cart is known, for example, obtained by numerical method for some set of parameters. Then from the ratio that determines the critical speed of the wheel pair, can be determined "hypothetical" parameter ("integral" stiffness, which is created by the entire structure of the cart):

$$\tau = K\frac{2k_y}{m_1} = K\frac{2k_x b^2}{J_1}. \tag{14}$$

In this paper, a model approach is proposed, which is based on the transfer of the results of the analysis of the stability of the rectilinear motion of a pair of wheels on the model of the trolley scheme of the trolley is shown in Fig. 5.

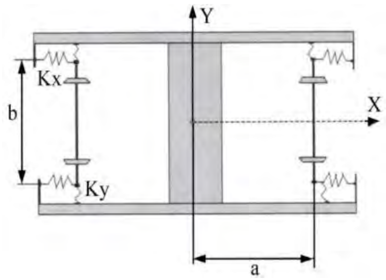


Fig. 5 Estimated model of the cart

Determination of the critical speed of the trolley model was performed on the basis of numerical analysis in the Maple system. Meaning τ=3820 s^{-2} corresponds to the critical speed $V_{cs} \approx 59$ м/с; the maximum critical speed of the cart (140.5 m/s) is reached at value of the resulted rigidity $\tau \approx 55000$ s^{-2}. Knowing the profile of the wheel within the undisturbed position of the point of contact with the rail and the generalized characteristics of the elastic suspension, based on the model approach can predict the dynamic behavior of the cart - to determine dangerous - safe nature of the loss of stability of rectilinear motion and estimate the amplitude. When using the model of creep according to Carter or Kalker, the corresponding sequence of steps does not change, but in the first case there are comprehensible from the point of view of qualitative analysis defining relations:

1) numerical determination of the critical speed of the trolley model based on the Rauss-Hurwitz test;
2) determination of the reduced (total) stiffness transmitted to the wheelset from the side of the trolley in the longitudinal and transverse directions, from the ratio;
3) determination of conditions of dangerous-safe loss of stability and amplitude of self-oscillations from the approximate ratio. Below are the results of numerical - analytical analysis of self - oscillations of the lateral ratio of the wheel pair of the passenger car trolley model in the case of the linear theory of creek according to Kalker; the critical speed of rectilinear motion was V_{kr} = 59 m/s. In the model approach, the amplitude of self-oscillations is A = 0.0048 м (speed V = 80 m/s). In the case of a dangerous loss of stability, the amplitude at speeds V = 80 m/s is A = 0.082 m. When changing the speed parameter in a wider range (at a sufficiently high supercritical speed) there are significant differences in the dynamic behavior of the subsystem (it corresponds to the wheel pair) and the whole system (cart model).

6. Conclusions

With a certain choice of parameters of the axle box suspension, the critical speed of rectilinear motion of the wheel pair is almost independent of the values of the creep coefficients.

Based on the analysis of the nonlinear model of the wheel pair, the influence of the parameters of the nonlinear profile; the other two coefficients determine the amplitudes of self-oscillations and the size of the stability region (the real margin of stability of the wheel pair in a straight line).

The analytical ratio that determines the critical speed of the wheel pair can be used to determine the stiffness of the rail track used in the model approach.

The amplitudes of self-oscillations of the trolley model can be approximated on the basis of analytical relations obtained on the basis of subsystems using the real geometry of the rolling surface of the wheel.

Restrictions on the maximum wear (hire) of a pair of wheels can be related to the magnitude of the amplitude of self-oscillations that precede the occurrence of two-point contact at the maximum operating speed of the crew. As a result of experimental and theoretical studies and theoretical calculations, it was found that the most effective ways to increase the running life of wheelsets are parameters when the thickness of the ridge is more than 26.5 mm, and the steepness of the ridge is not less than 6.0 mm; it is offered to leave hire during turning to 1.8 mm.

The results of critical speed calculations show that with increasing conicity of the skating surface, its value decreases; at speeds up to 120 km/h. lateral forces transmitted from the wheel to the rail are sufficiently stabilized and do not exceed the set values, and at speeds greater than 120 km/h. significantly increase and approach the maximum allowable. The ratio of the stiffness of the axle suspension and the condition of the rolling surface of the wheelset has a significant effect on the value of lateral force.

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Post-Stall Correction for Vortex Lattice Method

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Abstract

The traditional vortex lattice method (VLM) is a highly efficient tool for pre-stall aerodynamic computations. A lot of authors have contributed to the development of non-linear VLM, which can be used to model post-stall flight conditions efficiently. This work provides an overview of the different varieties of non-linear VLM, the proposed applications of these methods, and possible future developments and use cases.
KEY WORDS: *vortex lattice method; computational aerodynamics; stall prediction*

1. Introduction

Vortex lattice method (VLM) is a popular low-order computational aerodynamics method for calculating the aerodynamic characteristics of wings in subsonic flight. It is computationally efficient and accurate for wings with low sweep but cannot be used for post-stall calculations [1]. To use VLM in this extended regime, corrections need to be made based on viscous aerofoil data. This method was first implemented in 1988 by Tseng and Lan [2] to model the aerodynamic properties of fighter aircraft at high angles of attack. This model was used by van Dam et al. [3] to develop a method for rapid prediction of the maximum lift coefficient of transport aircraft.

In 2003, Mukherjee et al. [4] proposed a new method to link viscous aerofoil data with the VLM, based on local aerofoil decambering. This concept was later developed further by Mukherjee and Gopalarathnam [5] to evaluate performance of multiple-lifting-surface configurations and adapted by Wu et al. [6] for modelling and design of flight control systems. More recently, this method was extended to model the stall of finite swept wings by Hosangadi et al. [7] and adapted by Parenteau et al. [8] for design and optimization of a jet transport aircraft wing, including the high-lift system.

In this article, an overview of the current methods of non-linear VLM will be presented and directions of possible future development will be proposed.

2. Regular Vortex Lattice Method

A description of the regular VLM will be provided here. The lifting surfaces of the aircraft are divided into panels both chord-wise and span-wise. Each of these panels are assumed to have an attached ring vortex, with the trailing edge panels also having a horseshoe wake vortex attached. The general view of the ring vortex lattice is presented in Fig. 1. Each panel also has an integration (or collocation) point at the centre of the three-quarter chord line.

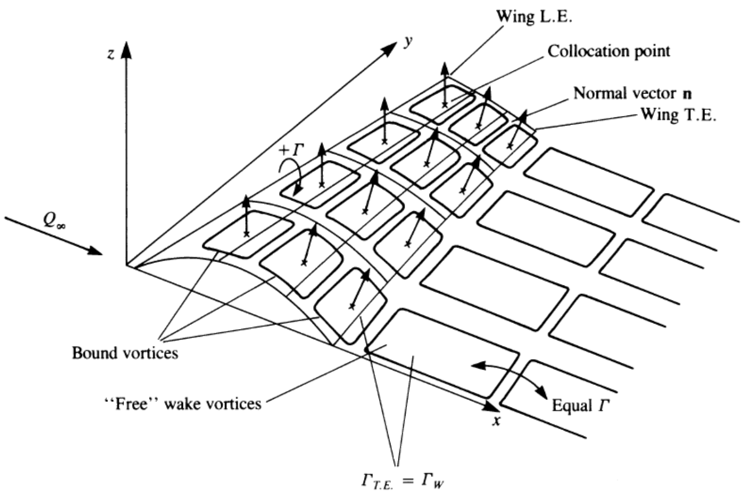


Fig. 1 Schematic of a vortex lattice of a thin lifting surface [1]

Each of the ring vortices induces some velocity in every integration point of the mesh. The velocity induced at integration point i by ring vortex j can be calculated:

$$w_{ij} = \Gamma_j v_{ij}, \tag{1}$$

here Γ_j is the strength of vortex j, and v_{ij} is the velocity that a unit strength vortex j would induce at integration point i. The value of v_{ij} depends only on the relative position of the integration point and the vortex and can be calculated using the Biot-Savart law. The total velocity induced at an integration point by all vortices would be the sum:

$$w_i = \sum_{j=1}^{N} \Gamma_j v_{ij}, \tag{2}$$

here N is the total number of panels. The induced velocity at each integration point must satisfy the no-penetration condition:

$$V_\infty \sin\left(\alpha + \theta_i\right) = -w_i, \tag{3}$$

here V_∞ is the free-stream velocity, α is the angle of attack of the wing and θ_i is the angle of the panel. This condition means that there can be no airflow perpendicular to the panel.

From Eq. (2) and Eq. (3) a linear system of equations can be created and solved for Γ, giving the vortex strength at each panel. Then, the lift and drag at each panel is given by

$$\Delta L_i = \rho V_\infty \Gamma_i \Delta y_i; \tag{4}$$
$$\Delta D_i = -\rho w_{ind,i} \Gamma_i \Delta y_i,$$

here ρ is the air density, Δy_i is the span-wise length of the panel and $w_{ind,i}$ is the induced velocity at each panel. The total lift and drag of the wing is then calculated by summing the lift and drag of each panel.

3. Variations of Non-Linear Vortex Lattice Method

Currently, there are two main approaches to non-linear VLM, an older method based on local angle of attack correction, and a more recent method based on local aerofoil decambering. In this section, an overview of both approaches is presented, as well as a description of a further correction for swept wings.

3.1. Angle of Attack Correction Method

The angle of attack correction method is based on iterative correction of the local angle of attack at different wing stations, until the local lift calculated by VLM agrees with 2D viscous aerofoil data [2]. At the start of the solution, a regular inviscid VLM solution is calculated. Then, it is assumed that the flow is attached and that the correction angle of attack $\Delta\alpha$ equals zero. Afterwards, the induced angle of attack at all span-wise locations is calculated [2]:

$$\alpha_i = \alpha_n - \sin^{-1}\left(\frac{c_{l,3D}}{c_{l\alpha}}\right) - \alpha_0 - \Delta\alpha, \tag{5}$$

here α_n is the geometric angle of attack, $c_{l,3D}$ is the local lift coefficient calculated using VLM, $c_{l\alpha}$ is the aerofoil lift slope and α_0 is the aerofoil zero-lift angle of attack.

An aerofoil lift coefficient $c_{l,2D}$ at the α_n - α_i angle of attack is then extracted from the aerofoil viscous aerodynamic data, and a ratio of lift coefficients is calculated [2]:

$$f = \frac{c_{l,2D}}{c_{l,3D}}, \tag{6}$$

based on which the new $\Delta\alpha$ is calculated [2]:

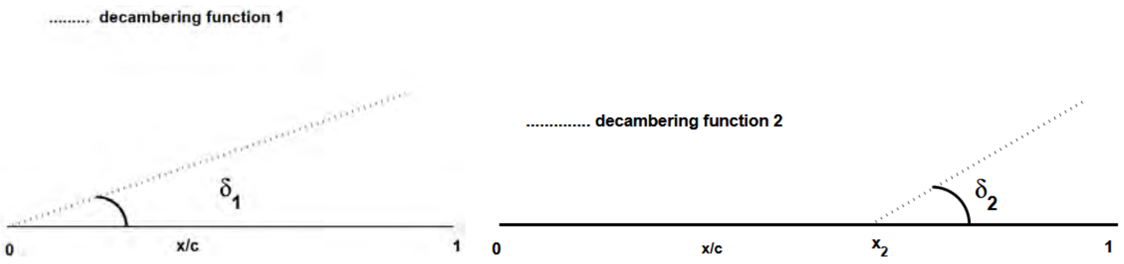
$$\Delta\alpha = \alpha_n - \sin^{-1}\left(f \sin\left(\alpha_n\right)\right). \tag{7}$$

This value of Δα is the used to re-solve the VLM equations, and the process is repeated iteratively until the total lift coefficient of the wing converges to a fixed value.

3.2. Aerofoil Decambering Method

A more modern method of adjusting VLM results based on 2D aerofoil aerodynamic data is based on decambering, where the top surface of the local aerofoil is iteratively rotated to decrease its' camber until the 3D local lift and pitching moment fits the 2D aerofoil data [4]. The main advantage of this method compared to angle of attack correction is that it fits not only the local lift, but also the local pitching moment to aerofoil data, thus providing a more accurate solution, especially for pitching moments.

The local aerofoil is decambered using a function with two variables, δ_1 and δ_2. The effect of these variables is shown in Fig. 2. δ_1 controls the decambering of the whole top surface, rotating it around the leading edge of the aerofoil (Fig. 2, a), and δ_2 controls the decambering of the trailing part of the top surface, rotating it around a chosen point, usually located between 50% and 90% of the chord (Fig. 2, b).



a b

Fig. 2 Geometry of decambering [4]

At the beginning of the calculations, initial values of δ_1 and δ_2 are assumed, the VLM calculation is performed, effective angles of attack at each chord-wise section are calculated using [4]

$$\alpha_{eff} = \frac{C_l}{2\pi} - \delta_1 - \delta_2 \left(1 - \frac{\theta_2 + \sin(\theta_2)}{\pi} \right), \tag{8}$$

here C_l is the local lift coefficient of the aerofoil and θ_2 is the angular chord-wise location at which the second decambering function takes effect. The difference between section lift coefficient C_l and moment coefficient C_m predicted by VLM is compared to those from viscous aerofoil data at α_{eff}. Then, using the Newton iteration algorithm, a gradient of section C_l and C_m based on δ_1 and δ_2 is calculated, and the values of δ_1 and δ_2 are adjusted for the next iteration. The iterations are repeated until VLM section and viscous aerofoil lift and moment coefficients are equal within a specified tolerance.

3.3. Wing Sweep Correction of Non-Linear Vortex Lattice Method

In more recent works, a further correction method to account for wing sweep and the resultant span-wise flow was developed. This correction can be used both with the angle of attack correction method [8] and decambering method [7]. Instead of using viscous 2D aerofoil data to adjust the VLM results for post-stall conditions, 2.5D aerofoil data of an infinite swept wing is used, accounting for span-wise flow effects. Such data is commonly acquired using a Reynolds-averaged Navier-Stokes (RANS) solver.

As well as using swept aerofoil data, a further correction to Eq. (7) must be made to account for wing sweep: [8]

$$\Delta\alpha = \alpha_n - \sin^{-1}\left(f \sin(\alpha_n) \right) \cos(\theta), \tag{9}$$

here θ is the angle of the wing sweep line. This correction is done to account for the change in the theoretical lift slope for swept wings.

4. Applications of Non-Linear Vortex Lattice Method

4.1. Current Applications

Several works have focused on the practical applicability of the non-linear VLM. The main uses are those which require iterative aerodynamic analysis at high angles of attack, such as control law design, wing geometry optimization and conceptual performance analysis. For these purposes, using a CFD solver would be prohibitively computationally expensive, so lower-order computational aerodynamics methods must be used.

Non-linear VLM has been implemented into the aircraft design process by several authors. Van Dam et al. [3] suggest using an angle of attack correction based method for conceptual design of high-lift systems. The authors use the model to analyse several aircraft configurations equipped with leading and trailing edge flaps and compare the computational results with experimental data. In most cases, the calculated maximum lift coefficient agrees very closely with experimental data. The authors suggest that such a computationally inexpensive method could be used at the initial stages of aircraft design to design a simpler high-lift system which satisfies the project requirements.

Another work, by Parenteau et al. [8], examines the possibility of using non-linear VLM to optimize the wing of a jet transport aircraft for both low and high speed flight. The authors used the angle of attack correction method with additional correction for wing sweep. The wings were optimized for maximum lift and maximum lift to drag ratio for cruising flight, with the maximum allowed outboard stall location as an additional constraint. The optimization variables were wing twist distribution, sweep angle, geometry of the double-tapered planform and the high-lift system design. It was successfully demonstrated that non-linear VLM can be used effectively with gradient-free optimization methods (such as evolution based optimization), for which CFD-based methods are too computationally expensive.

A different use for non-linear VLM is proposed by Wu et al. [6]. The authors use a decambering based method to design control laws for the longitudinal motion of F-16 aircraft, particularly for the transition from pre-stall to post-stall flight. The authors successfully demonstrated the viability of non-linear VLM for control law design.

4.2. Future Applications

One area for which non-linear VLM could be adapted in the future is aeroelasticity modelling. Currently, time-based aeroelasticity models often rely on linear unsteady formulations of VLM [9-11], limiting their scope to pre-stall conditions. Such models are valid in most cases of aeroelasticity, because flutter usually occurs at high speeds and low angles of attack. However, some problems of aeroelasticity, such as aeroelasticity of fighter aircraft at high angles of attack and low-stiffness low-speed aircraft time-domain aeroelastic modelling, require post-stall aerodynamic models. For such cases, an unsteady non-linear VLM would have to be developed, including both the viscous coupling of VLM with aerofoil data and kinematic contribution terms.

5. Conclusions

The vortex-lattice method is a useful and widely used low-order computational aerodynamics, combining low computational cost with good accuracy for a wide range of pre-stall problems.

The traditional VLM was extended by several authors to the post-stall regime, using either an angle of attack correction or a decambering method for coupling with viscous aerofoil data.

A correction method to account for wing sweep in non-linear VLM is described by several authors, which can be used in conjunction with both viscous coupling methods.

The use of non-linear VLM for conceptual aircraft design, optimization, and control law design has been proposed in some articles, demonstrating the usefulness of the low computational cost of this model for these purposes.

In the future, a development of an unsteady non-linear VLM would enable efficient modelling of high angle of attack aeroelasticity cases, such as fighter aircraft manoeuvring and low-speed low-stiffness aircraft aeroelastic modelling.

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Electric Conversion of Small Wheeled Military Vehicle

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Abstract

Military reconnaissance and special operations vehicles have undergone a major transformation in the last few years. Often are used as a light, high mobility vehicles which can carry small teams of soldiers and necessary equipment. Transforming conventional drive based on combustion engine into fully electric can bring more advantages for special military units. Electricity gives these vehicles the ability to move without unmasking the noise of the combustion engines. This paper presents the options of such transformation with MATLAB Simulink simulation of one configuration with results of vehicle range and dynamics.
KEY WORDS: *reconnaissance vehicle, electric vehicle, LiIon accumulator*

1. Introduction

Modern technologies, such as electric vehicles [1-3] bring new possibilities for armed forces all across the world. As we could see, unmanned electric vehicles, both aerial and ground are fully integrated into reconnaissance units these days. This modern technology gives reconnaissance units the irreplaceable advantages of e and not be seeing, hearing and not being heard. Special operations forces perform different tasks and vehicles with minimal noise unmasking can facilitate these operations. The aim of this paper is to find possible theoretical ways of power drive conversion from fossil fuel to electricity and determine some crucial parameters by MATLAB simulation.

2. Small Military Vehicle

For our paper we consider to replacing the combustion engines of small military vehicles [4] used by the armed forces of many states including the Armed forces of the Slovak republic. Concretely Polaris MRZR-D4 (Fig. 1), is a turbo diesel powered, all wheel drive, high mobility vehicle. The capacity of the vehicle is four fully equipped soldiers. Some of the vehicle parameters are shown in Table 1.

Fig. 1 MRZR-D4 Polaris

Considering actual options in the field of electric vehicles and the advantages and disadvantages of electric vehicles, mostly the time to recharge the batteries, small electric vehicles should be used on very special stealth operations. Conventional combustion engines will be primarily used for standard operations. As mentioned before, the original vehicle is driven by a diesel turbo diesel engine and has on demand all wheel drive. Our aim is to transfer the whole drive mechanism from the combustion engine to the electric drive.

Table 1

Vehicle parameters

Parameter	Value
Length	3,55 m
Width	1,51 m
Heigh	1,87 m
Wheelbase	2,71 m
Engine type	4-Stroke SOHC Three Cylinder Turbo Diesel
Cylinders displacement	993 cm^3
Transmission	Automatic
Fuel capacity	35,9 l
Range	250 km
Curb weight	952 kg
Payload capacity	680 kg

There are three options to arrange the driving [5] mechanism:

– single electric engine

The first way to remake the driving mechanism is to use the single electric engine with a reduction gearbox, connected to a differential gear, which drive the rear axle. This option should be the least expensive and the simplest, but the vehicle lost the ability of all wheel drive and there is a need of using a more powerful electric engine.

– two electric engines

Another way is to use two electric engines with reduction gearboxes, connected to differential gears, which drives both axles. As the vehicle again gains the ability of all wheel drive, the mechanism is more complicated and thus economically less effective. Potentially gain in driving parameters in comparison with a single electric engine could be affected by increasing vehicle mass. Even if used less powerful engines, the combined weight of the whole driving mechanism will be increased due to the second differential

– four electric engines

A more complex way is to use a special electric engine for every wheel. As we could use less powerful engines and from the driving mechanism we withdraw differential gears, driving parameters will be better.

As civil vehicles have limitations in weight and dimensions due to legislation, military vehicles are limited by specific types of transport. Small reconnaissance vehicles should be transported by military aircraft, so dimensions and weight are limited. An electric vehicle with a single electric engine gives the possibility to use the largest battery, thus the longest range while preserving payload capacity. Using multiple electric engines will be more demanding on battery capacity. Every further expansion of vehicle range is possible at the expense of payload capacity or even of reducing passenger capacity.

3. Simulated Vehicle

Within the simulation, we deal with an electric vehicles with nearly similar physical parameters as the military buggy MRZR-D4. As electric drive [6] we choose a single 50 kW DC electric engine which transfers its power through descending gearbox to the rear axle, where the power is divided on the rear wheels by differential. The battery used for simulation was a 50 V Li-Ion battery with a capacity of 115 Ah. This arrangement provides satisfactory driving performance [7] with a fair vehicle range. The simulated vehicle is shown in Fig. 2.

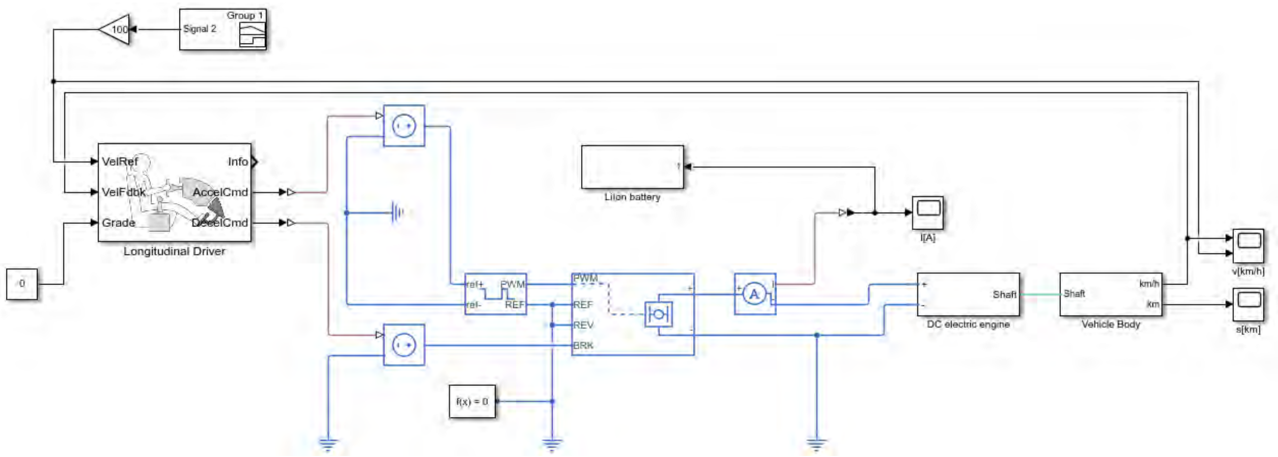


Fig. 2 Simulated vehicle

Individually subsystems are shown on Figs. 3-5

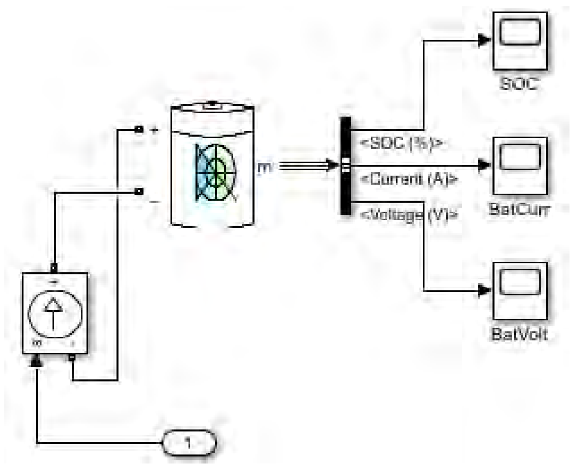
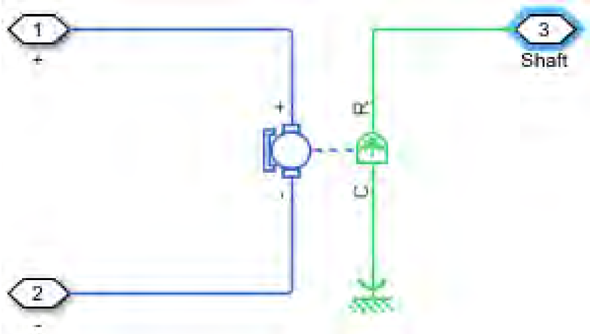


Fig. 3 LiIon battery



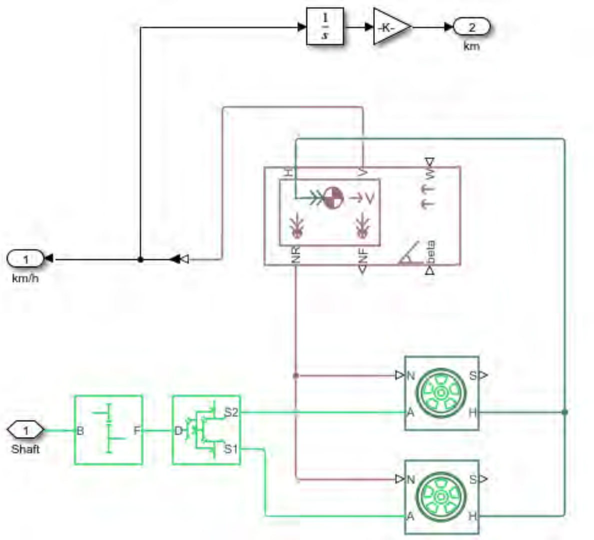
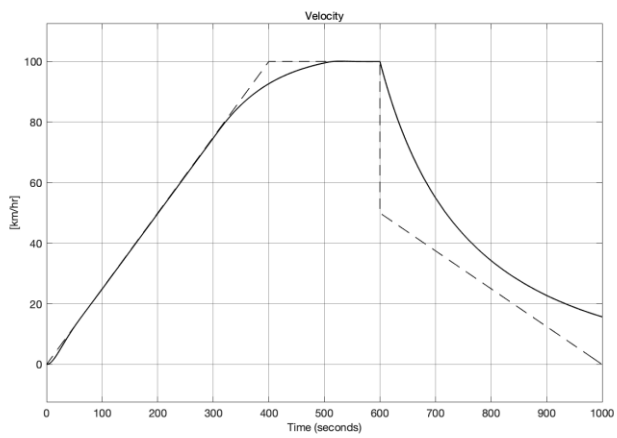


Fig. 4 DC electric engine

Fig. 5 Vehicle body

4. Simulation Results

The conditions which we determined for simulation was straight road without any slopes or wind. The demanded speed was determined for shown of vehicle dynamics and is shown as dotted line on Fig. 6. Real vehicle speed is shown on same figure as solid line.



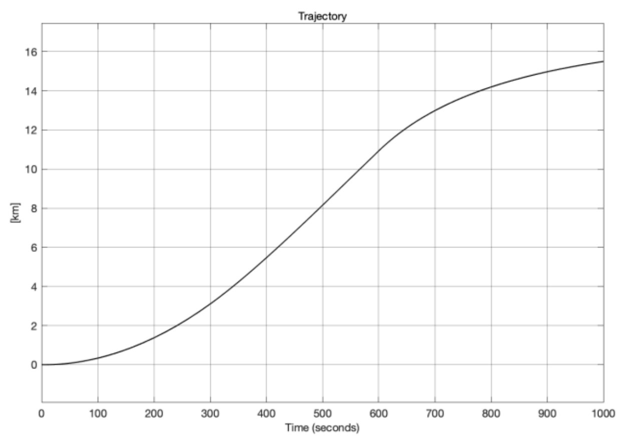


Fig. 6 Vehicle velocity (dotted line – desired speed, solid line – simulated speed)

Fig. 7 Vehicle trajectory

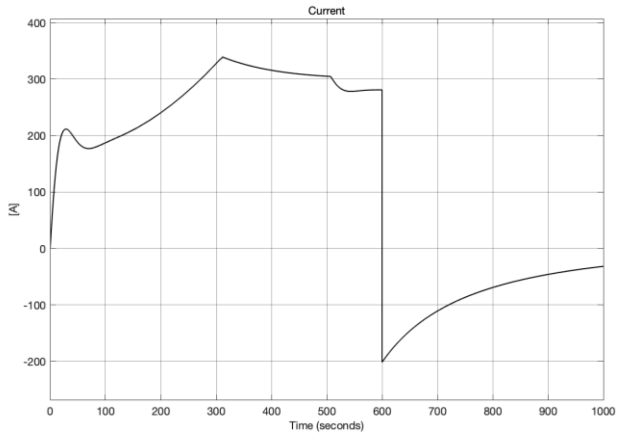


Fig. 8 Electromotor current consumption

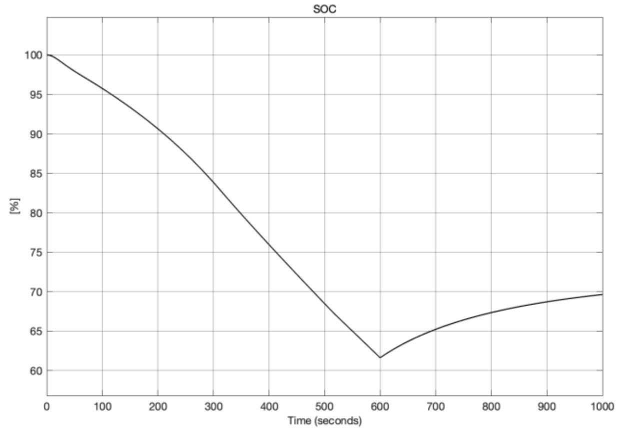


Fig. 9 Battery state of charge

As shown in figures above (Figs. 7-9), the presented model of the vehicle is able to reach a speed 100 km/h. The regulator can copy the demanded speed. After 1 000 seconds vehicle passed more than 15 (Fig. 7) km with the battery discharged at approximately 70%. Coming out of these results we consider a range of approximately 40 km. The question is what is the real range of such a vehicle? We consider driving on a flat surface with a constant speed of 50 km/h (Fig. 10).

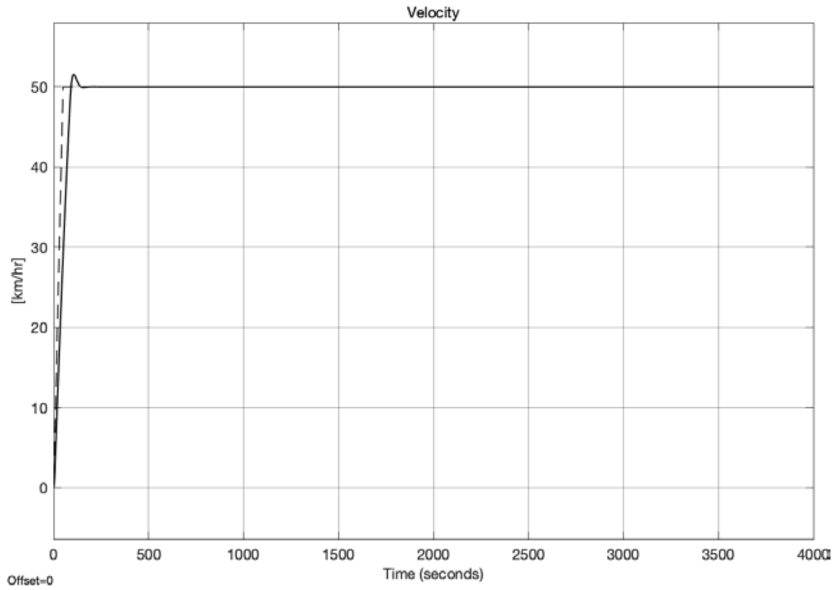


Fig. 10 Velocity

If we assume the initial charge of the battery to 95% (Fig. 11), it is obvious from the discharge curve that the minimum discharge level of 20% is reached after approx. 4000 seconds (1,1 hour) of continuously driving, which represents a range of approx. 55 km (Fig. 12).

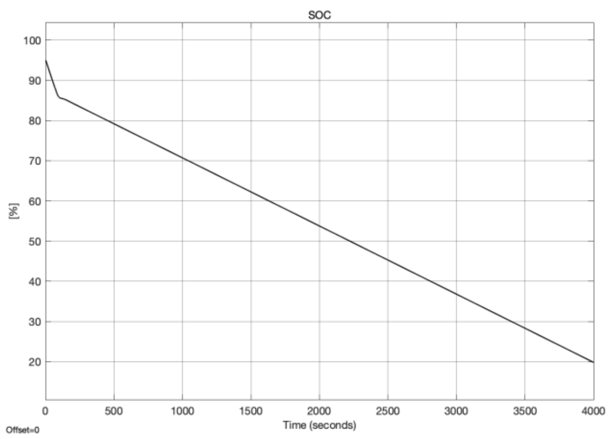


Fig. 11 Battery state of charge

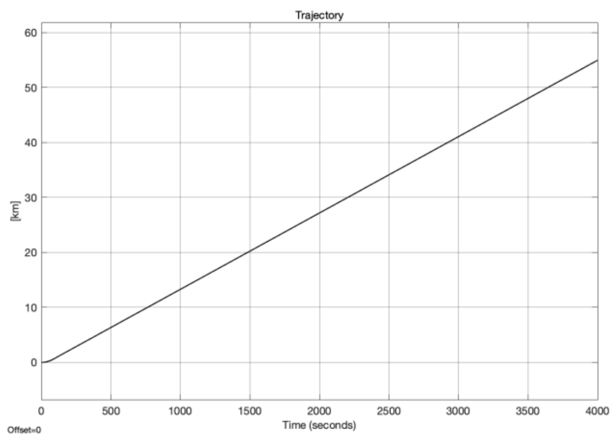


Fig. 12 Trajectory

5. Conclusions

Simulation has proven that electric vehicle with our specific parameters is operational. As a main disadvantage of our configuration became vehicle range. Assuming that the standard travel speed on unpaved roads will be approximately 50 km/h, our vehicle will be operational for more than an hour with a range of 55 km until the battery is drained to 20%. Another vehicle range can be added by using a battery with a bigger capacity or using multiple batteries.

Acknowledgements

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Interaction Assessment of the Component Parts of the Rolling Stock with the Infrastructure by Determining the Dynamic Characteristics of the Movement of Converted Hopper Wagons after Long-Term Operation

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Abstract

Ensuring traffic safety is one of the most important requirements for the operation of railways. Among the accidents and disasters in railway transport, derailment is the most dangerous, as it can lead to serious consequences. The reasons for derailment are related to rolling stock malfunctions, deviations from track maintenance standards, unsatisfactory train dynamics, as well as their operating conditions. Empty platform wagons and modernized hopper wagons with the roof removed were among the wagons that most often derailed. In the work, theoretical and experimental studies (running dynamic tests, computer simulation) of the indicators of the quality of movement of converted hopper cars were performed.
KEY WORDS*:* *testing, dynamics, hopper car, modeling, technical condition, reduced packaging, derailment, traffic safety.*

1. Introduction

The main disadvantage of the railway transport of Ukraine is the reduced speed of trains with freight wagons in which the tare is reduced from the nominal one in an empty state, which are equipped with model 18-100 bogies.

The reasons for the derailment of freight cars are: malfunctions of the undercarriage of the cars, damage to the sides and suspension beams, damage to the wheel pairs, malfunctions of the axle unit, wear of vibration dampers, excessive wear of the bogie elements. Also, during the research, it was established that the significant reason is the reduction of the wagon's tare by more than 12% from the nominal one.

It is necessary to establish the necessity of carrying out these running dynamic tests. In the work, theoretical and practical research was carried out with the determination and evaluation of indicators of dynamic and running qualities of converted hopper cars, determination of the coefficient of stability of the wheel from derailment, computer modeling of the dynamics of the movement of empty converted hopper cars depending on the technical condition of the track, technical condition of wagons and with different masses of containers. The conducted studies allow determining the safe speed of movement of wagons in an empty state.

2. Materials and Methods

At present, a number of works are devoted to the issue of research on the quality of freight cars, which explains their relevance [7-9, 15]. The paper [1] describes the results of studies of the strength of the freight car. But the purpose of these studies was to assess the structural reserves, rather than indicators of the quality of movement of freight cars. The material [2] describes the prospects for improving the design of cars by increasing the service life. But it is proposed to increase the service life of the freight car by improving their design properties. In the material [3] modern methods of the wagon dynamics and the theory of vibrations are used to build a mathematical model for determining the accelerations in the supporting structure of the wagon body. Work [4] describes the improvement of the wagon body frame to ensure a secure attachment to the deck of the railway ferry. The creation and use of a dynamic model that will take into account the quality of the movement of wagons is not described. Estimation of the dynamics of a wagon with an open platform is described in [5]. The calculation is performed in MSC Adams. The work [6] describes the capacity of the railways intended for the transportation of raw materials and finished products of the metallurgical industry. Material [10] describes the influence of the rolling profile of the wheels of the bogie on the overall dynamics of the rolling stock. In this case, no attention was paid to the simulation of the corresponding wear and tear and the study of dynamic qualities. In [11], the dynamic load on the load-bearing structure of the wagons transported by ferries was studied using mathematical and computer simulations and certain accelerations on the wagon body. The work [12] is devoted to the description of the results of improving the dynamic qualities of the rolling stock during the passage of curved sections of the track by improving the relevant structural elements. Articles [14, 13] describe the development of the load-bearing structure of a covered freight car, the feature of which is that the body elements are made of round pipes, but the paper does not describe how to determine the dynamics of the wagon and equipped with new generation couplings. In [16] the peculiarities of design and manufacture of open freight cars of the new generation with their load-bearing system of round pipes that reduces costs are described. Work [17] describes the study of the dynamic load of the container in the combined train during transportation by train ferry.

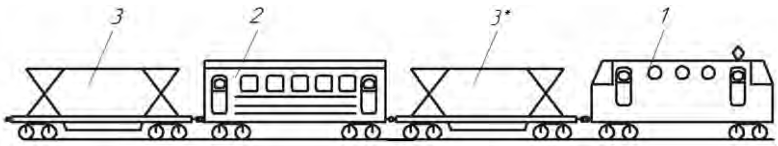
2.1. Practical Research

The objects of research are wagons for bulk cargo of model 19-923-01, built in 1988 (Fig. 1) and hopper wagon model 11-715-01, built in 1988 (Fig. 2) in an empty state.

Fig. 1 Hopper wagon model 19-923-01

Fig. 2 Hopper wagon model 11-715-01

Tests to determine the quality indicators of the movement of hopper wagons were performed by specialists of the NDKTI branch of Ukrzaliznytsia JSC in an empty state as part of an experimental coupling. The test coupling was formed of: locomotive, experimental hopper wagon model 19-923-01, laboratory wagon, hopper wagon model 11-715-01 (Fig. 3), on the section "Darnytsia-Myronivka-Darnytsia" South-West railway. The section of the track on which the tests were performed on the composition of straight and curved sections, met the requirements for the track for running dynamic tests.



1 – locomotive, 2– laboratory wagon, 3, 3* – research wagons for transportation of bulk cargo

Fig. 3 The scheme of the experimental coupling

An example of a bogie of research wagons on which measuring equipment is installed (Fig. 4) for recording data which will be used in the future to assess the performance of research wagons.

Fig. 4 Bogie with installed equipment

During the study of the dynamic indicators of the hopper car, a dynamic model was developed in the licensed software complex "UM 6.0" taking into account the design features of converted hopper cars on model 18-100 trolleys (body, wagon base, centers of mass) with the possibility of variations in the condition of the track, the technical condition of the wagons and the mass of the container.

The subsystem approach is used to develop a computer model of freight car dynamics. The subsystem approach allows to form subsystems of the same type once and use them in the model as many times as necessary. Visualization of the current dynamic model is shown in Fig. 5.

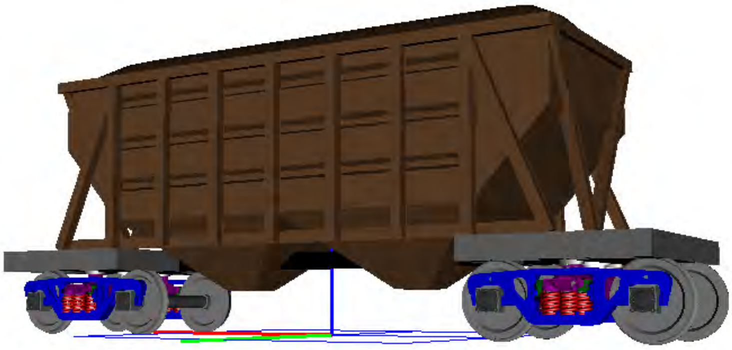


Fig. 5 Visualization of the dynamic model of the hopper wagon of the re-equipped model 11-715-01

2.2. Results and Discussion

During preparation for running dynamic tests calibration of vertical and horizontal forces is carried out.

The coefficient of margin of stability from the derailment is determined by the formula:

$$K_{wa}=\frac{tg\beta-\mu}{1+\mu tg\beta}\cdot\frac{Q_h\left(\frac{2(\mathrm{b}-a_2)}{l}+K_D^N\frac{2\mathrm{b}-a_2}{l}+K_D^{NR}\frac{\mathrm{b}-a_2}{l}\right)+q\frac{\mathrm{b}-a_2}{l}+\frac{r}{l}H_{hl}}{\mu Q_h\left(\frac{2(\mathrm{b}-a_1)}{l}+K_D^N\frac{a_1}{l}-K_D^{NR}\frac{2\mathrm{b}-a_2}{l}\right)+\mu q\frac{\mathrm{b}-a_1}{l}+\left(1\frac{r}{l}\mu\right)H_{hl}}, \qquad (1)$$

where β – the angle of inclination of the wheel flange generatrix to the horizontal plane; μ – the coefficient of friction of surfaces of wheels and rails; Q_h – the force of the weight of the suspended parts of a car, acting on the neck of the axle of the wheel pair; qwp – the weight of nonsuspended parts that falls on the wheel pair; K_D^N – the estimated value of the coefficient of vertical dynamics of a car; K_D^{NR} – the estimated value of the coefficient of lateral wobbling dynamics; H_{hl}- – the calculated mean value of the frame force; b – half distance between the middle parts of the axle necks; l – an average distance between contact points of wheels with rails; $a_{1,2}$ – the calculated distance from the contact points to the middle of the necks of the wheel pair axle; r – the radius of the wheel.

The results of running dynamic tests of wagons in the empty state are shown in Table 1.

Table 1

Test results of wagons in empty condition

Speed, km/h	The indicator of the coefficient of the margin of the wagon wheel stability is not less than 1,3	
	Model 19-923-01	Model 11-715-01
40±5	1,58	1,56
50±5	1,53	1,51
60±5	1,42	1,41
70±5	1,39	1,38
80	1,38	1,37

Modeling of the experimental wagon in the technically sound condition of the wagon and track. The average track profile was used for modeling. General simulation results are shown in Table 2.

Table 2

General results of modeling at technically serviceable condition of the wagon and track

Speed range, km\h	The coefficient of vertical dynamics of the sprung mass of the bogie, K_D	The coefficient of vertical dynamics of the unsprung frame of the bogie, K_{DN}	The coefficient of stability of the wheel from derailment on straight and curved sections of the track
40-50	0,30–0,40	0,39–0,49	1,50–2,00
50-60	0,31–0,41	0,40-0,52	1,46–1,70
60-70	0,33–0,45	0,50–0,56	1,42–1,75
70-80	0,38–0,51	0,51–0,60	1,38–1,42
80-90	0,39–0,50	0,52–0,60	1,38–1,41

The wagon, when simulating the movement in the technically serviceable condition of the wagon and the track, has a sufficient level of dynamics to ensure safe operation.

Modeling of a experimental wagon in a technically serviceable condition of the track while reducing the weight of the tare. The average track profile was used for modeling. The general results of modeling are given in Table 3 and Table 4 with two steps to reduce the weight of the tare: up to 18.5 tons and up to 17.0 tons for the wagon model 11-715-01; up to 20 tons and up to 19 tons for the wagon model 19-923-01.

Table 3

General results of modeling at technically serviceable condition of a track and the reduced tare of the wagon of model 11-715-01

Speed range, km\h	The coefficient of vertical dynamics of the sprung mass of the bogie, K_D		The coefficient of vertical dynamics of the unsprung frame of the bogie, K_{DN}		The coefficient of stability of the wheel from derailment on straight and curved sections of the track	
	Tare weight - 18,5 t	Tare weight - 17,0 t	Tare weight- 18,5 t	Tare weight - 17,0 t	Tare weight - 18,5 t	Tare weight - 17,0 t
40-50	0,29–0,40	0,26–0,35	0,39–0,48	0,38–0,52	1,49–2,00	1,42–2,00
50-60	0,31–0,40	0,30–0,39	0,40-0,51	0,39–0,54	1,45–1,65	1,42–1,62
60-70	0,32–0,46	0,29–0,45	0,49–0,55	0,48–0,56	1,42–1,73	1,39–1,58
70-80	0,37–0,50	0,35–0,50	0,50–0,59	0,51–0,61	1,37–1,44	1,34–1,42
80-90	0,38–0,51	0,35–0,52	0,50–0,60	0,53–0,55	1,35–1,42	1,32–1,39

Table 4

General results of modeling at technically serviceable condition of a track and the reduced tare of the wagon of model 19-923-01

Speed range, km\h	The coefficient of vertical dynamics of the sprung mass of the bogie, K_D		The coefficient of vertical dynamics of the unsprung frame of the bogie, K_{DN}		The coefficient of stability of the wheel from derailment on straight and curved sections of the track	
	Tare weight - 20,0 t	Tare weight - 19,0 t	Tare weight - 20,0 t	Tare weight - 19,0 t	Tare weight - 20,0 t	Tare weight - 19,0 t
40-50	0,29–0,39	0,29–0,38	0,40–0,48	0,39–0,51	1,55–1,90	1,53–1,88
50-60	0,31–0,39	0,31–0,38	0,41-0,52	0,39–0,53	1,50–1,68	1,48–1,64
60-70	0,32–0,45	0,31–0,44	0,48–0,56	0,48–0,56	1,43–1,70	1,40–1,60
70-80	0,38–0,49	0,38–0,50	0,51–0,60	0,52–0,62	1,39–1,50	1,39–1,46
80-90	0,39–0,52	0,39–0,51	0,51–0,60	0,52–0,61	1,39–1,49	1,38–1,44

Wagons, when modeling the movement in a technically sound condition of the track and reduced body mass of the body have a sufficient level of dynamics to ensure safe operation. There is a tendency to decrease the coefficient of stability of the wheel from derailment, but the values are at an acceptable level.

Modeling of the experimental wagon in a technically serviceable condition in the presence of track deviations (Table 5). The average track profile with additional coefficients of track irregularities - 1.5 and 2.0 was used for modeling. From the experience of modeling the dynamics of wagons found that the coefficient of track irregularities in the range of 1.0… 1.5 corresponds to the actual technical condition of the track JSC "Ukrzaliznytsia", the value of 1.5 roughly corresponds to the maximum permissible level of deviations, the coefficient of track irregularities at level 2, 0 corresponds to exceeding the permissible values of deviations.

Table 5

General results of wagon modeling in technically serviceable condition in the presence of track deviations

Speed range, km\h	The coefficient of vertical dynamics of the sprung mass of the bogie, K_D		The coefficient of vertical dynamics of the unsprung frame of the bogie, K_{DN}		The coefficient of stability of the wheel from derailment on straight and curved sections of the track	
	Track irregularities coefficient – 1,5	Track irregularities coefficient – 2,0	Track irregularities coefficient – 1,5	Track irregularities coefficient – 2,0	Track irregularities coefficient – 1,5	Track irregularities coefficient – 2,0
40-50	0,38–0,48	0,40–0,49	0,44–0,50	0,48–0,56	1,51–1,81	1,50–1,81
50-60	0,39–0,52	0,41–0,48	0,45-0,58	0,49-0,66	1,44–1,55	1,43–1,56
60-70	0,40–0,52	0,45–0,59	0,51–0,65	0,53–0,71	1,38–1,42	1,32–1,40
70-80	0,41–0,51	0,51–0,68	0,55–0,71	0,57–0,75	1,32–1,37	1,29–1,37
80-90	0,41–0,53	0,55–0,71	0,59–0,74	0,60–0,80	1,32–1,37	1,28–1,36

The wagon, when modeling the movement in a technically serviceable condition in the presence of track deviations tends to reduce the levels of dynamics. With a significant increase in track irregularities, it is possible to reduce the coefficient of the stability of the wheel from the derailment to an unacceptable level. The speed at which the reduction of the level of stability begins - 70 ± 5 km / h. Modeling of an experimental wagon with deviations in the technical condition. The average track profile, a bogie with a deviation of the technical condition in the form of maximum wear friction wedges), a bogie with a deviation of the technical condition in the form of maximum wear increased by 15% were used for modeling. General simulation results are shown in Table 6.

Table 6

General results of car modeling with deviations in technical condition

Speed range, km\h	The coefficient of vertical dynamics of the sprung mass of the bogie, K_D		The coefficient of vertical dynamics of the unsprung frame of the bogie, K_{DN}		The coefficient of stability of the wheel from derailment on straight and curved sections of the track	
	Maximum wear	Maximum wear +15%	Maximum wear	Maximum wear +15%	Maximum wear	Maximum wear +15%
40-50	0,30–0,41	0,32–0,42	0,40–0,49	0,42–0,49	1,50–1,91	1,50–1,91
50-60	0,31–0,41	0,33–0,44	0,41-0,52	0,43-0,55	1,45–1,57	1,43–1,53
60-70	0,33–0,45	0,37–0,39	0,51–0,56	0,53–0,58	1,37–1,48	1,28–1,37
70-80	0,38–0,50	0,38–0,50	0,53–0,61	0,56–0,62	1,31–1,40	1,28–1,39
80-90	0,39–0,50	0,39–0,50	0,54–0,62	0,56–0,66	1,33–1,37	1,29–1,40

The wagon, when modeling the movement with deviations in the technical condition tends to reduce the levels of dynamics. With increasing deviations (wear) of the elements of the bogie, there is a decrease in the coefficient of stability of the derailment to an unacceptable level.

3. Conclusions

Summarizing the results of running dynamic tests and computer modeling of the dynamics of the movement of hopper cars in the empty state, it was determined:

- the results of the running dynamic tests of experimental wagons can be concluded that the dynamics indicators are within the permissible limits up to and including 80 km/h.

According to the results of computer simulation, it was established that:

- the technical condition of the track and wagons is satisfactory. The dynamic indicators do not exceed the permissible values;
- deviation of the technical condition of the wagons and the track, there is a decrease in the indicators of the dynamics of the wagons to a critical level;
- the speed at which the stability reserve level decreases to a minimum in the presence of deviations is set to 70±5 km/h;
- simultaneous deviations of the track and the technical condition of the wagons reduce the dynamics of the wagon, which in turn lowers the safe speed of movement.

Simulation of individual track irregularities in the form of waves with a given height of 6 mm, given lengths, displacements of left and right rail irregularities, given parameters of horizontal wave irregularities suggests that the impact of real track irregularities (vertical and horizontal) on wagon dynamics is much greater than the above wave inequalities. The actual dependence of the stability of the wagon on the irregularities of the track should be considered systematically, taking into account the values of the largest deviations, and the values of all other vertical and horizontal deviations in the experimental section of the track.

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Selected Risk Analysis Tools

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Abstract

The article deals with the issue of analytical activities in the study of risks with a focus on the period of operational use of products. This period of the life cycle is the longest phase of the product, the manufacturer usually achieves maximum profits, sales volume stagnates, there is a strong influence of competition and the manufacturer often offers benefits. Users have mastered the product and the phase of full use begins, the failure rate decreases and the period of application of optimal maintenance begins, eg with the use of the RCM (Reliability Centered Maintenance) program. The specific application presented is focused on the issue of risk analysis in the period of standard use of special mobile devices.
KEY WORDS: *mobile resources, reliability, wear, failure rate, risk analysis methods, RCM*

1. Introduction

The current requirement in all branches of industry, production technologies, services, but also in the use of products, in our case special mobile technology, etc., is to increase quality, maintain inherent reliability and safety. The analysis of possible risks is becoming very important in these areas. In general, there are a relatively large number of risk analysis tools. These are, for example, FMEA methods (Failure Mode and Effect Analysis), resp. FMECA (Failure Modes and Effect and Criticality Analysis), FTA (Failure Tree Analysis), hazard study HAZOP (Hazard Analysis and Operability Study), preliminary hazard analysis PHA (Preliminary Hazard Analysis), structured technique SWIFT (Structured What If Technique), root cause analysis RCA (Root Cause Analysis), event tree analysis ETA (Event Tree Analysis), cost benefit analysis CBA (Cost Benefit Analysis), multicriteria decision analysis MCDA (Multi Criteria Decision Analysis) and many others. FMEA / FMECA methods are among the massively used tools of risk analysis, they are part of many legislative documents, manuals such as for automotive, aviation, chemistry, transport, pharmacy, oil industry services, etc. Historically, the beginnings of these methods date back to 1949, when the US military issued a directive for suppliers of military products [1]. FMEA / FMECA methods are typically team analytical inductive methods using two approaches, namely top-down, for the early design phase before deciding on the entire system structure, and a bottom-up approach, when the concept is already decided. Furthermore, the Criticality Analysis (CA) is performed using a quantitative or qualitative approach depending on data availability, component configuration and failure rate. A quantitative approach is used when relevant data on system components is used, and a qualitative approach is used when this data is unavailable. Fig. 1 [2] schematically shows the procedures of activities using FMEA / FMECA methods and a possible graphical representation of the FMEA method is shown in Fig. 2 [2].

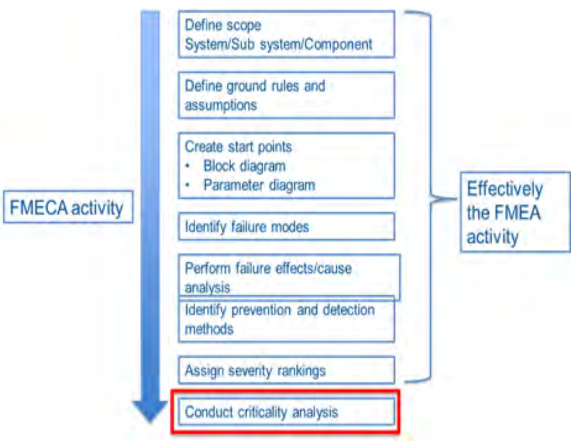


Fig. 1 The procedures of activities using FMEA / FMECA methods

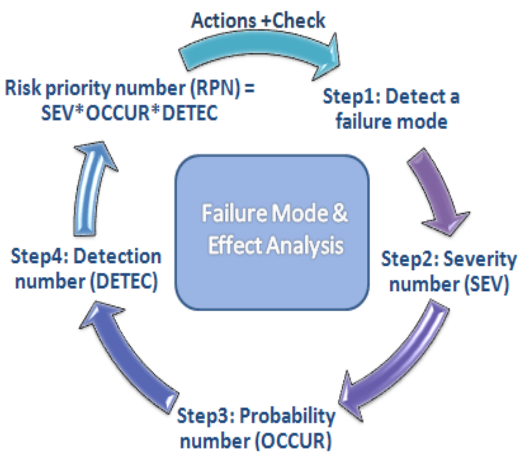


Fig. 2 Possible graphical representation of the FMEA method

2. FMEA / FMECA Risk Analysis Methods

FMEA analysis [2] is a technique used to identify those ways in which components, systems or processes may fail to meet their design intent.

The FMEA analysis identifies:

- all possible modes and consequences of failures of different parts of the system (the mode of failure is what is observed to have a failure, what has failed or what is malfunctioning);
- the consequences that these disorders may have on the system;
- fault mechanisms, a way to prevent faults and / or mitigate the consequences of faults on the system.

The FMECA analysis extends the FMEA so that each identified mode of failure is classified according to importance or criticality [3]. This criticality analysis is usually quantitative or semi-quantitative, but can be quantified with knowledge of the actual disturbance intensities. There are several FMEA analysis applications, from product design for components, products or entire products, to manufacturing and assembly processes, services and software, etc. Applications cover the entire product life cycle. The main advantage in terms of reliability is the ability to implement the results of analyzes at the design stage. FMEA / FMECA analysis can be used for the following activities:

- to choose design alternatives with high (pre-designed) reliability;
- to take into account all types of system and process failures and their consequences for operational use (maintenance);
- to identify the ways and consequences of human error;
- to plan tests and maintenance of physical systems;
- to improve the design of procedures and processes;
- to provide qualitative or quantitative information for analysis techniques, eg fault tree analyzes, etc.

FMEA / FMECA analyzes provide input to other analysis techniques, such as bebo event tree analysis, both qualitatively and quantitatively. Analyzes may include:

- drawings or flowcharts of the analyzed system and its components, or stages of the process;
- understanding the function of each stage of the process or component of the system;
- environmental details and other parameters that may affect the operation;
- understanding the causes and consequences of failures;
- historical fault information, including fault intensity data, if available.

The FMEA / FMECA implementation process is as follows [4]:

- setting the scope and objectives of the study, building a team, detailed understanding of the system or process;
- decomposition of the system into components or steps and determination of their function, for each component, function or stage listed:
  - In what conceivable way can a component fail?
  - What mechanisms could trigger these modes of failure?
  - What could be the consequences if these failures occur?
  - Is each of these errors harmless or harmful?
  - how is this fault detected?
- ensure the implementation of inherent measures to eliminate the failure.

For analysis, the team classifies each identified failure mode according to criticality. There are several ways to do this, standard proven methods include:

- criticality criticality index;
- level of risk;
- risk priority number.

Criticality is an indicator of the probability that the method considered will lead to a failure of the system as a whole; is specified as the product of the probability of a failure, the intensity of the failure mode and the operating time of the system. An example of the criticality matrix is given in Table 1 [4-5].

One of the most commonly used criticality matrices uses the following scale:

- criticality number 1 (E), unlikely occurrence, probability of occurrence: $0 \le P_i < 0.001$;
- criticality number 2 (D), very low incidence, probability of occurrence: $0.001 \le P_i < 0.01$;
- criticality number 3 (C), occasional occurrence, probability of occurrence: $0.01 \le P_i < 0.1$;
- criticality number 4 (B), probable occurrence, probability of occurrence: $0.1 \le P_i < 0.2$;
- criticality number 5 (A), frequent occurrence, probability of occurrence: $P_i \ge 0.2$.

Table 1

Example of cfritica ty matrix

Probabilit y of occurrence	5 (A)				High risk
	4 (B)		Mode of failure 1		
	3 (C)				
	2 (D)			Mode of failure 2	
	1 (E)	Low risk			
		I	II	III	IV

Severity of consequence of the failure

The level of risk includes the combination of the consequences of the occurrence of the mode of failure with the probability of failure. It is used when the consequences of different failure modes differ. The level of risk can be expressed qualitatively, semi-quantitatively or quantitatively. The risk priority number (RPN) is a semi-quantitative criticality indicator obtained by multiplying numbers from a classification scale (usually 1 to 10) for the consequences of a failure, the probability of failure and the ability to detect the failure. If the fault is difficult to detect, the fault is assigned a higher priority. The method is often used in quality assurance applications. Once failure modes and mechanisms are identified, corrective actions can be identified and implemented on more severe failure modes. The basic output of FMEA analysis is a list of failure modes, failure mechanisms and consequences for each component, system or process. Information on the causes of the failure and the consequences for the system as a whole is also provided. The output of the FMEA analysis includes a classification based on the likely possibility that the system will have a failure, the level of risk resulting from that type of failure, or a combination of the level of risk and the detectability of the type of failure. FMEA analysis can provide quantitative output if relevant data on failure intensities and failure consequences are available. An example of a list of fault modes, their consequences and probability of occurrence for a motor vehicle starter circuit is given in Table 2 [4], [7-10] in various types of industry.

Table 2

Example of failure modes, their consequences and probability of occurrence

S. n.	Mode of failure	Consequence of failures	Probability of occurrence of the consequence
1	Fault during operation	The starter motor does not work	$8 \cdot 10^{-3}$
2	Start-up failure within the prescribed time	The trigger speed is slower than specified	$6 \cdot 10^{-4}$
3	Shutdown failure within the prescribed time	The pinion did not fit into the ring gear	$1.1 \cdot 10^{-5}$
4	Prescribed operation	The starter motor runs prematurely	$3.6 \cdot 10^{-7}$

Potential failure modes can be identified in buildings. Data on typical modes of malfunction can be found in the following areas:

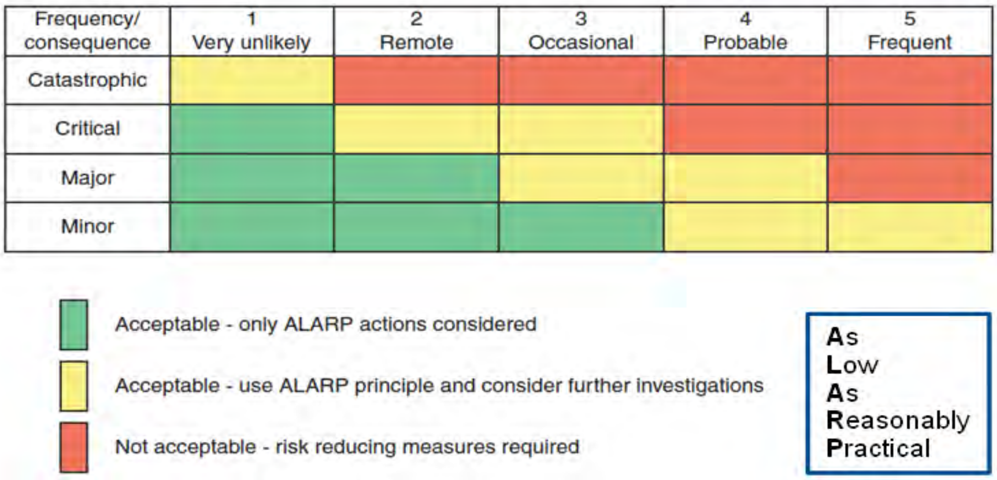
- for new objects, it is possible to refer to other objects with a similar function and structure, to the result of tests at appropriate stress levels;
- for records that are in operation, operational records and fault data can be used;
- possible failure modes can be derived from functional and physical parameters typical of the operation of the objects.

The analysis requires the identification and description of the most likely causes of each possible mode of failure. The causes can be determined on the basis of an analysis of operating faults or faults during testing, resp. from expert opinions. The consequence of the fault as a consequence of the type of fault for operation must be determined, evaluated and recorded.

Fault detection can be standardly implemented using the built-in EOBD test (European On Board Diagnostic) during operation, the introduction of a special inspection procedure before operation, diagnostics during maintenance, repairs, etc. Measures to compensate for failures identified in the FMEA analysis include: backup, alternative modes of operation, monitoring or alarm equipment, other means of efficient operation or damage mitigation. The purpose of assessing the consequence or criticality of a failure mode is to determine the frequency or probability of each failure mode occurring. To determine the probability of failure, it is important to consider, in addition to information on the intensity of failures, the specifics of operation (environment, mechanical and / or electrical, etc. stress) of each component that contributes to the probability of failure. The intensity of component failures and the consequent intensity of failures of the considered failure mode increases in most cases with power dependence or exponentially with increasing stress. In Table 3 [2] is a possible example of a qualitative classification of the severity (criticality) of the final consequences of failures for a product, product or system.

Table 3

An example of a qualitative classification of the severity (criticality) of the consequences of disorders



The probability of occurrence of system failure modes can be estimated from tests of reliability and service life of components, from the historical database of failure intensity, from current data on failures, from data on failures of similar objects or components of a given class, etc. If the probability of a failure mode is estimated, the FMEA must focus on the time period for which the estimates are made. This is usually the warranty period or predetermined periods of standard use, which, for example, fully applies to special mobile devices, etc.

3. Specifics of Failure Analysis, Consequences and Criticality Analysis (FMECA)

Determining the criticality of failures consists in adding a quantitative indicator of the magnitude of the consequences of the type of failures. The purpose of criticality analysis is to quantify the relative magnitude of each failure consequence as a decision aid so that a combination of severity and frequency can prioritize measures to mitigate, minimize, or completely eliminate the consequences of certain failures. The method consists of two basic parts:

1. Failure probability analysis - the probability of occurrence of each failure is determined quantitatively using analytical estimates. Estimating the probability of a given failure for specific operating conditions requires a statistically significant amount of relevant data. Probability classification, resp. frequencies of individual disorders into groups, creates probability categories, eg: very low (1), low (2), medium (3), high (4).
2. Failure consequence analysis - helps to decide on follow-up measures, as well as their significance. Each consequence considered is classified according to its severity with respect to the overall functionality of the product or system and takes into account the criteria chosen.

One of the methods for quantifying criticality is the Risk Number (*R*) and the Risk Priority Number (*RPN*). *R* risk is assessed here by a subjective indicator of the severity of the consequence and by estimating the expected probability of its occurrence in a predetermined time period expected for the analysis. Rapport apply:

$$R = S \cdot P\,, \tag{1}$$

where S – severity: a reating of the severity or seriousness of each potential failure effect; P – probability of occurrence; and

$$RPN = S \cdot O \cdot D\,, \tag{2}$$

where O – occurrence: a rating of the likelihood of occurrence of each potential failure cause; D – detection: a rating of likelihood of detecting of failure cause.

RPN is used to prioritize failure mitigation. In addition to RPNs, the severity of these disorders also has a severity in mitigating the effect of the methods, ie if there are failure modes with similar or identical *RPNs*, attention is focused on those failure modes that have higher severity numbers. Relevant rapport can be numerically evaluated on either a continuous or discrete scale (finite number of specified values). The fault modes are then sorted according to their *RPN* numbers and the high *RPN* is assigned a high priority. In different types of FMECA analysis, different scales are assigned to the *S*, *O*, and *D* values. Criticality can be presented, eg using the criticality matrix, Table 4. If the required product of the analysis is a criticality matrix, it can be evaluated on the basis of assigned levels of severity and frequency of events. Risk acceptability is determined subjectively or governed by professional and financial decisions and varies across industries.

Table 4

Failure criticality matrix

Frequency of appearance	**Level insignificant**	**Level marginal**	**Level critical**	**Level catastrophic**
5: Numerous occurrence	Undesirable	Inadmissible	Inadmissible	Inadmissible
4: Probable occurrence	Permissible	Undesirable	Inadmissible	Inadmissible
3: Occasional occurrence	Permissible	Undesirable	Undesirable	Inadmissible
2: Very low incidence	Negligible	Permissible	Undesirable	Undesirable
1: Unlikely to occur	Negligible	Negligible	Permissible	Permissible

In Table 5 [5] shows an example of a severity classification used in the automotive industry. The severity class is divided according to the failure consequence of each type of failure based on the severity of the consequences for the overall technical parameters (performance) and safety of the system in terms of requirements, objectives and constraints on the system with respect to the object (vehicle, etc.) as a system. Determination of severity according to tab. 5 for severity numbers 6 and higher is considered objective; determining severity for numbers 3 through 5 may be subjective.

Table 5

Severity of the mode of failure

Severity	**Criteria**	**Classification**
None	No detectable result.	1
very little significant	Noisy and creaking object; does not comply with the requirements for correct storage, processing, etc. The defect will be discovered by demanding customers (< 25%).	2
Insignificant	The noisy and creaking object does not comply with the requirements for proper storage and processing. About 50% of customers find the defect.	3
very low	The noisy and creaking object does not comply with the requirements for correct storage, processing, etc. The defect is discovered by most customers (> 75%).	4
Low	The object is operational, but the equipment providing comfort has reduced technical parameters. The customer is somewhat dissatisfied.	5
Medium	The object is operational, but the comfort equipment is not operational.	6
High	The object is operational, but with a reduced level of technical parameters. The customer is very dissatisfied. The customer is not satisfied.	7
very high	The object is not operational (loss of basic function).	8
dangerous with warning	Very high level of severity, the type of failure draws attention to itself by warning, affects the safe operation of the object and / or means non-compliance with legislation.	9
dangerous without warning	Very high level of severity, the type of failure does not draw attention to itself by warning, affects the safe operation of the object and / or means non-compliance with applicable legislation.	10

Table 6 [5] provides examples of qualitative indicators of failure mode occurrence that can be used in conjunction with the use of an *RPN* number. E.g. in tab. 6, the term "frequency" is used as the average occurrence of failure modes during use, mission or a specified lifetime, which is comparable to the "proportion of objects with a failure" or probability of occurrence. E.g. the failure mode, which is rated 9, could cause the critical system to fail over a predetermined period of time. In this case, the determination of the probability of occurrence must relate to the time period of interest. The optimal procedure is when the probability of occurrence is calculated for components and failure modes based on their specific failure intensities when applying the expected stress (environmental and operational influences). If this information is not available, an estimate may be used, but if the estimate is used, the significance of the number of occurrences must be clear - this is the number of occurrences per thousand objects at a predetermined time used for analysis (warranty period, object life, etc. It should be noted that, unlike the severity scale, the incidence scale is neither linear nor logarithmic. It should be noted that, unlike the severity scale, the incidence scale is neither linear nor logarithmic. It follows that the resulting *RPN* must be used with special care.

Table 6

Occurrence of the type of failure in relation to the frequency and probability of occurrence

Occurrence of the failure mode	**Severity classification**	**frequency**	**Probability**
Very weak: failure is unlikely	1	$\leq 0{,}010$ per thousand objects	$\leq 1 \cdot 10^{-5}$
Low: relatively few faults	2 / 3	0,1 / 0,5 per thousand objects	$1 \cdot 10^{-4} / 5 \cdot 10^{-4}$
Medium: intermittent disorders	4 / 5 / 6	1 / 2 / 5 per thousand objects	$1 \cdot 10^{-3} - 2 \cdot 10^{-3} - 5 \cdot 10^{-3}$
High: recurrent disorders	7 / 8	10 / 30 per thousand objects	$1 \cdot 10^{-2} - 2 \cdot 10^{-2}$
Very high: failure is almost inevitable	9 / 10	50 / ≥ 100 per thousand objects	$\geq 5 \cdot 10^{-2} - 1 \cdot 10^{-1}$

Failure detection probability classification

When using the RPN number, it is necessary to estimate the probability that a fault will be detected, ie the probability that potential faults will be detected in time based on parameters, properties, procedures, methods, means, etc. to prevent a fault at the system-wide level. For process-oriented applications, this includes the likelihood that the controls of an ongoing process will be able to detect and isolate the fault before it is transmitted to subsequent processes or to the final output of the product. For general-purpose products that can be used in several diverse systems or applications, it can be difficult to estimate the probability of detection.

Risk assessment

The rather intuitive approach described above must be followed by a prioritization of measures to ensure the best level of security. E.g. a fault mode with high severity (eg 10), low intensity (eg 3) and high detection (eg 2) may have a much lower *RPN* (eg 60) than a fault mode that has all parameters average (eg 5) which in this case leads to the value of the *RPN* (125). Additional procedures are often provided to ensure that failure modes with a high severity class (eg 9 to 10) are given high priority and mentioned first. In this case, the decision should be based on the size of the severity rather than the *RPN* number itself. For an optimal decision-making process, it is good practice to assess the severity class of the failure modes together with the *RPN* number. *RPN* risks are also determined in other FMEA methods, especially those that are primarily qualitative in nature. Using these tables, *RPNs* are calculated and often used as a guide to mitigate failure modes. In addition to the benefits, there are also some shortcomings of the *RPN*:

- gaps in ranges: 88% of range values are empty, only 120 out of 1000 numbers are generated;
- identical numbers: *RPNs* for some combinations different factors lead to the same *RPNs*;
- different sensitivity to small changes: a small change of one factor has a much greater effect when other factors are larger than when they are small (eg 9 x 9 x 3 = 243 and 9 x 9 x 4 = 324, in contrast 3 x 4 x 3 = 36 and 3 x 4 x 4 = 48);
- inappropriate unit conversion: ratios in tab. 6 the occurrence of the mode of failure is not proportional or linear (eg there may be a ratio of 2.5 or 2 between successive classes);
- inadequate *RPN* scale: differences between *RPN* numbers should appear to be negligible, while in reality they are very significant eg values $S = 6$, $O = 4$, $D = 2$ give number *RPN* = 48, while values $S = 6$, $O = 5$, $D = 2$ gives the number *RPN* = 60. This second number *RPN* is not twice the first number, while in fact $O = 5$ is twice the number of the class of occurrence of the fault mode with the number $O = 4$. Therefore, *RPN* numbers cannot be compared linearly;
- possible misleading conclusions from the comparison of *RPN* numbers, as their scales are serial and not proportional.

4. Continuity of Analyzes by FMEA / FMECA10pt Methods

The combination of FMEA and FMECA analyzes may advantageously use a different approach to both methods. FMEA / FMECA use "Bottom-Up" approaches, resp. "Top-Down" and the Criticality Analysis and can examine the failure modes of system elements and monitor the possible consequences of the failure of individual elements on the entire system, this is a typical cause-and-effect model. The combination of these methods increases the robustness of the system and the likelihood of detecting causes that disrupt the functionality of the product under assessment [9]. The procedure itself usually includes, for example, the definition of analysis limits, relevant functions and peak events, with the possibility of creating a tree of fault conditions using some standardly available software tool, Fig. 3 [6]. Software tools allow the entire process to be recorded, automatically analyzed, checked and, if necessary, modified. An example of writing data to the FMEA module using software eg [7] is in Table 7.

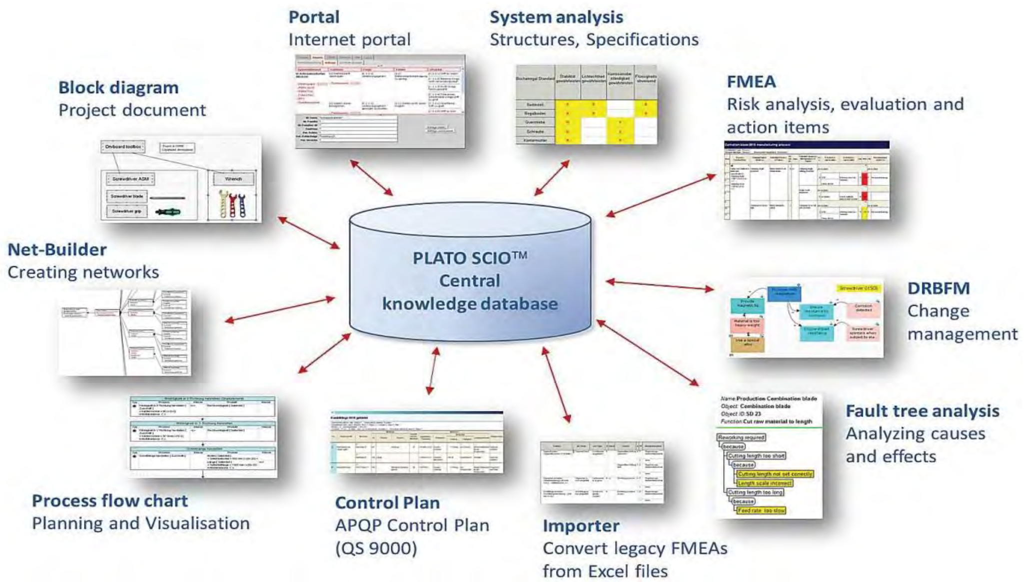
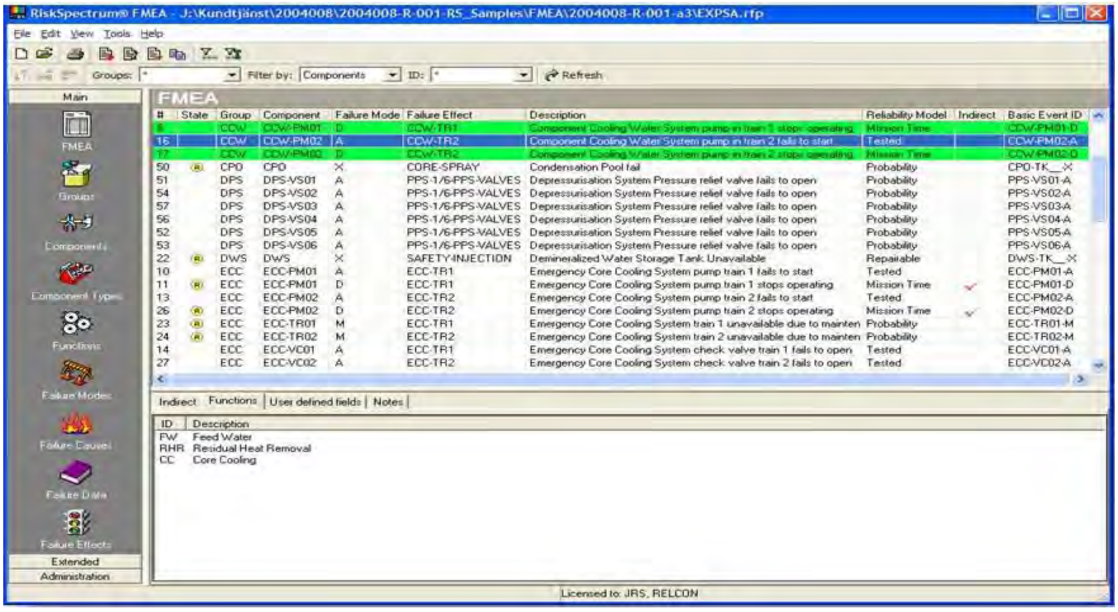


Fig. 3 PLATO SCIO^{TM} software system information modules

Table 7

Possible data entry into the FMEA module using the RiskSpectrum software



After creating a tree of fault conditions, it is advisable to write these conditions in the FMEA / FMECA worksheet and analyze them, eg using available historical data on the occurrence and detection of the causes of faults. This is followed by the determination of the minimum critical sections and the calculation of the probability of occurrence of individual events. The final part of the analysis is the completion of FMEA / FMECA for the most critical causes.

5. Discussion - Conclusions

The aim of the article was a general analysis of selected tools for risk analysis, focusing on FMEA and FMECA methods and their continuity. It can be stated that the strengths of the FMEA / FMECA analyzes:

- are widely applicable to modes of failure (failure) of human activity, to modes of failure of equipment, systems, hardware, software, etc.;
- identify component failure modes, their causes and consequences for the system and present themselves in an easy-to-read format;
- avoid the need for costly modifications to equipment put into operation by early identification of problems at the design stage, identify single-point failure modes and requirements for back-up or security systems;
- provide inputs to technical condition monitoring programs by emphasizing key features to be monitored, etc.

Conversely, there are some limitations of FMEA / FMECA analyzes:

- analyzes can only be used to identify individual failure modes, not to combine failure modes;
- Studies tend to be time-consuming and relatively costly if they are not adequately managed and not adequately addressed by senior management;
- for complex multilayer systems, they can be difficult and time consuming.

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Logistic Planning Tool for Perishable Goods in Accordance with Green Distribution Logistics and Green Reverse Logistics

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Abstract

Distribution and reverse logistics processes are becoming extremely important for companies today. The aim is to reduce continuously the delivery time of goods to buyers or customers while maintaining a set level of customer service. Perishable goods are a special category of goods with a very limited shelf life. This type of goods is very sensitive to temperature fluctuations and any problems in the distribution logistics of perishable goods can lead to their un-saleability in extreme cases. Distribution and reverse logistics processes have an important link to the pillars of sustainability. From the perspective of the social pillar, these logistic activities ensure supply and reverse transport that is important for the functioning of modern human society. From an economic perspective, these logistic processes generate significant costs for companies. From an environmental perspective, distribution and reverse logistics processes generate negative environmental impacts (emissions, noise, and vibration). The aim of the manuscript is to present a vehicle routing problem with pickup and delivery with time windows algorithm-based tool to support logistic planning in the context of distribution and reverse logistics processes and to illustrate its use in a real case study. The use of this tool has led to a reduction in greenhouse gas emissions and cost savings in distribution and reverse logistics for a particular perishable's distribution company.

KEY WORDS: *green logistic, distribution logistics, city logistics, vehicle routing problem with pickup and delivery with time windows, sustainability*

1. Introduction

The logistics of perishable food goods is a major challenge for all chains in the relevant logistics chain, not only in terms of logistics activities. The characteristics of perishable goods affect most logistics activities such as demand forecasting, purchasing, supply, packaging, storage, transport, logistics communication, customer service etc. All logistics activities add value to the customer and are essential. On the other hand, logistics activities also generate negative environmental and social impacts. Companies' efforts towards sustainable logistics activities are also reflected in green practices in distribution and reverse logistics, which is indispensable in the perishable logistics chain. Green distribution logistics and green reverse logistics is therefore a current topic in the perishable's logistics chain.

2. Theoretical Background

The perishable food industry contributes significantly to the economy and society of many developing and developed countries of the world [1]. The perishable food products are characterized by a shorter shelf life and complex and lengthy supply chains [2]. Greening perishable food logistics activities has become an issue of interest to limit the production of greenhouse gas emissions [3]. Perishable goods are goods that are easily rotting, decomposing, and damaged during the distribution logistics processes [4]. The distribution logistics of perishable goods is clearly more complex than that of traditional goods because of uncertainty in all aspects of demand and distribution [5]. This fact is also confirmed for the case of reverse logistics of perishable food [6].

The authors divide the vehicle routing problems into static, dynamic, and eco-friendly [7]. Static vehicle routing problems (hereinafter VRP) include: capacitated VRP, heterogenous VRP, stochastic VRP, multi-depot VRP, pickup and delivery VRP, VRP with time windows, split-delivery VRP, VRP with loading constraints, and multi-echelon VRP; dynamic VRP include: capacitated dynamic VRP, dynamic VRP with time windows, stochastic dynamic VRP, pickup and delivery dynamic VRP, and heterogenous dynamic VRP; eco-friendly VRP include: VRP with reverse logistics, and pollution routing problem [7]. It is evident that the issue of VRP is still very topical. This is evidenced by the large number of research articles in this area, for example [8-10].

The aim of the manuscript is to present a vehicle routing problem with pickup and delivery with time windows algorithm-based tool to support logistic planning in the context of distribution and reverse logistics processes and to illustrate its use in a real case study.

3. Methods and Data

The processing procedure was as follows. In the first step, the existing delivery and collection routes were obtained from the T-Cars software and were analysed. Subsequently, a random standard day was selected; customer´s (store´s) requirements for distribution logistics (delivery), customer´s (store´s) requirements for reverse logistics (collection), exact locations, and time windows of customers were analysed. This data was imported into the VRP Spreadsheet Solver. Subsequently, new distribution and reverse logistics routes were modelled for a randomly selected standard day. Finally, the results of the new routes were compared with the original routes and savings in individual parameters were analysed. The Microsoft Excel workbook "VRP Spreadsheet Solver" is an open-source unified platform for solving and visualizing the results of Vehicle Routing Problems and this platform uses public Geographical Information Systems (Bing Maps) and metaheuristics [11]. There are many studies focusing on the issue of vehicle routing problems addressed by the author of the workbook "VRP Spreadsheet Solver" [12-25]. VRP Spreadsheet Solver uses an algorithm of heuristic method for Vehicle routing problem with pickup and delivery with time windows according to [26] and presented in formulas 1-15. It uses these types of variables: binary flow variables x_{ijk}, time variables T_{ik} (specifying when vehicle k starts the service at node $i \in V_k$) and variables L_{ik} giving the load of vehicle k after the service at node $i \in V_k$ has been completed [26].

$$min \sum_{k \in K} \sum_{(i,j) \in A_k} c_{ijk} x_{ijk} \tag{1}$$

subject to

$$\sum_{k \in K} \sum_{j \in N_k \cup \{d(k)\}} x_{ijk} = 1 \,;\ \forall i \in P \,; \tag{2}$$

$$\sum_{j \in N_k} x_{ijk} - \sum_{j \in N_k} x_{j,n+i,k} = 0 \,;\ \forall k \in K \,, i \in P_k \,; \tag{3}$$

$$\sum_{j \in P_k \cup \{d(k)\}} x_{o(k),j,k} = 1 \,; \forall k \in K \,; \tag{4}$$

$$\sum_{j \in N_k \cup \{o(k)\}} x_{ijk} - \sum_{j \in N_k \cup \{d(k)\}} x_{ijk} = 0 \,;\ \forall k \in K \,,\ j \in N_k \,; \tag{5}$$

$$\sum_{i \in D_k \cup \{o(k)\}} x_{i,d(k),k} = 1 \,;\ \forall k \in K \,; \tag{6}$$

$$x_{ijk} \left(T_{ik} + s_i + t_{ijk} - T_{jk} \right) \le 0 \,; \forall k \in K \,, (i,j) \in A_k \,; \tag{7}$$

$$a_i \le T_{ik} \le b_i \,;\ \forall k \in K \,, i \in V_k \,; \tag{8}$$

$$T_{ik} + t_{i,n+i,k} \le T_{n+i,k} \,;\ \forall k \in K \,, i \in P_k \tag{9}$$

$$x_{ijk} \left(L_{ik} + l_j - L_{jk} \right) = 0 \,; \forall k \in K \,, (i,j) \in A_k \,; \tag{10}$$

$$l_i \le L_{ik} \le C_k \,;\ \forall k \in K \,, i \in P_k \,; \tag{11}$$

$$0 \le L_{n+i,k} \le C_k - l_i \,;\ \forall k \in K \,, n+1 \in D_k \,; \tag{12}$$

$$L_{o(k),k} = 0 \,; \forall k \in K \,; \tag{13}$$

$$x_{ijk} \ge 0 \,; \forall k \in K \,, (i,j) \in A_k \,; \tag{14}$$

$$x_{ijk} binary \,; \forall k \in K \,, (i,j) \in A_k \,. \tag{15}$$

In terms of scientific methods, analysis, comparative analysis, and interpretive case study were used in this manuscript. The method of comparative analysis is a data analysis technique for determining which logical conclusions a data set supports [27]. This method was used to compare the original and newly proposed distribution and reverse logistics routes in terms of basic indicators. The interpretative case study is very suitable for exploratory research [28]. The interpretative case study approach minimizes the distance between the explorer and the key decision-maker [29]. The fundamental decisions within the interpretive case studies lie in previous theories, the unit(s) of analysis, the number and selection of cases, the techniques of data collection, and the method(s) by which the collected data will be analysed [30]. The interpretive case study method was used throughout the manuscript when the application of the "VRP Spreadsheet Solver" workbook to the distribution and reverse logistics routes of a specific company focused on perishable food products is illustrated.

4. Results

The company deals with the delivery of perishable food goods to stores and the removal of reverse logistics objects (especially pallets, shipping boxes, etc.) from stores. Distribution logistics is limited by the time windows of individual customers (stores). This is therefore a typical vehicle routing problem with pickup and delivery with time windows task. The company is based in Hodonín (South Moravia). Geographically, the company covers these four regions: Slovakia, North Moravia, East Moravia, and West Moravia. Each region is generally served by two or three vehicles and routes. Table 1 presents original routes by average number of customers, service time, and transport distance within a randomly selected standard day. This data was obtained from the T-Cars software.

Table 1

Original routes by average number of customers, service time, and transport distance [authors, T-Cars software]

Region	Route	Average number of customers [-]	Average service time [hours]	Average transport distance [km]
Slovakia	A	32	7:15	256
	B	33	7:20	235
North Moravia	C	24	7:10	236
	D	26	5:45	136
	E	25	6:30	119
East Moravia	F	30	8:00	192
	G	32	6:15	111
	H	09	4:35	166
West Moravia	I	26	7:50	270
	J	27	8:10	291
	Total	264	68:50	2012

The region of Slovakia and the region of West Moravia was served by two routes (A, B, I, J), while the region of North and East Moravia was served by three routes (C, D, E, F, G, H). Thus, a total of 10 distribution and reverse logistics routes were implemented, and 264 customers (stores) in total were served. The average service time on the route’s ranges from 4 hours and 35 minutes (route H) to 8 hours and 10 minutes (route J). The total service time for all routes is 68 hours and 50 minutes. In terms of transport distance, the shortest route is route G (111 km), and the longest route is route J (291 km). The total transport distance of all routes was 2 012 km, and they are always round trips that start and end in Hodonín.

Subsequently, customer´s (store´s) specific requirements for distribution logistics (delivery), customer´s (store´s) specific requirements for reverse logistics (collection), exact locations, and time windows of customers were imported into the VRP Spreadsheet Solver. Furthermore, new distribution and reverse logistics routes were modelled for all original routes. An example of the original route F (obtained from the T-Cars software) and the newly designed route F (exported from the VRP Spreadsheet Solver) is shown in Figs. 1 and 2. Fig. 2 visualises the routes only as the crow flies, but the transport distance is calculated using roads.

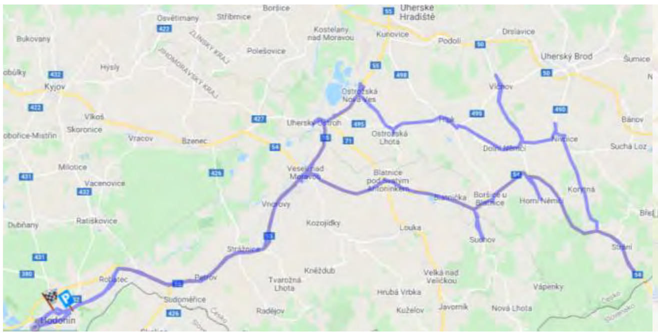

Fig. 1 Route F – original version (T-Cars software)

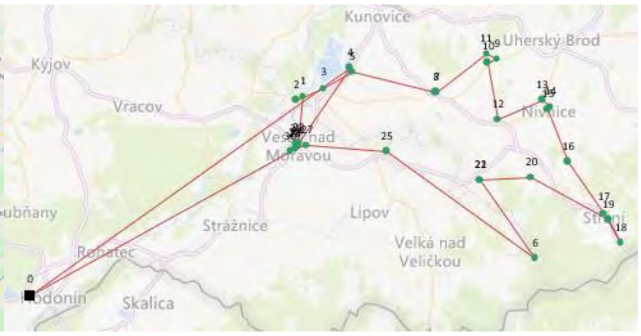

Fig. 2 Route F – proposed version (VRP Spreadsheet Solver)

The specific plan for the proposed version of Route F is shown in Table 2. Table 2 shows the exact order of customers (C 1 – C 30) on the route. The starting point of the route and the destination of the route is the depot in Hodonín. For each customer (store), the exact geographical coordinates (latitude x, y) are presented, which have been imported into a VRP Spreadsheet Solver using Bing maps.

Finally, all routes modelled and proposed by the VRP Spreadsheet Solver using the comparative analysis method were compared with the original routes. The result of the comparison between the original and proposed routes is shown in Table 3.

Table 2

Plan of the proposed version of route F according to individual customers [authors, VRP Spreadsheet Solver]

Loc.	Latitude [y]	Latitude [x]	Distance [km]	Loc.	Latitude [y]	Latitude [x]	Distance [km]	Loc.	Latitude [y]	Latitude [x]	Distance [km]
Dep.	48,8493900	17,1041600	00.00	C 70	48,9876500	17,5281800	66.32	C 19	48,9007800	17,7074300	101.96
C 40	49,0047500	17,4382600	36.86	C 11	49,0141000	17,5796800	72.10	C 20	48,9296265	17,6272373	112.89
C 23	48,9535600	17,3841900	44.69	C 90	49,0084610	17,5821590	73.29	C 22	48,9283295	17,5738907	120.30
C 26	48,9529500	17,3815100	44.92	C 10	49,0109100	17,5913400	74.19	C 21	48,9283295	17,5738907	120.30
C 28	48,9491500	17,3801100	45.66	C 12	48,9692500	17,5922900	80.23	C 60	48,8749100	17,6310600	132.95
C 24	48,9508000	17,3828700	46.17	C 13	48,9827200	17,6383400	84.68	C 25	48,9471700	17,4762500	149.86
C 10	48,9848500	17,3888600	51.79	C 14	48,9779800	17,6469500	85.72	C 27	48,9517000	17,3931100	157.31
C 20	48,9825800	17,3821100	52.39	C 15	48,9763031	17,6443329	86.07	C 29	48,9501000	17,3802400	158.82
C 30	48,9909100	17,4103900	55.13	C 16	48,9406900	17,6653700	90.55	C 30	48,9471500	17,3755000	159.61
C 50	49,0016500	17,4401300	58.36	C 17	48,9058100	17,7026900	97.08	Dep.	48,8493900	17,1041600	188.00
C 80	48,9878300	17,5276300	66.21	C 18	48,8854800	17,7202900	99.84				
Notes: Loc. = Location, Dep. = Depot, C = Customer (store)											

Table 3

Comparison of original and proposed routes [authors]

Region	Route	Service time			Transport distance			Fuel
		Current [hours]	Proposed [hours]	Savings [hours]	Current [km]	Proposed [km]	Savings [km]	Savings [l]
Slovakia	A	7:15	4:30	-2:45	256	206	-50	-10.1
	B	7:20	5:12	-2:08	235	213	-22	-4.8
North Moravia	C	7:10	5:27	-1:43	236	219	-17	-1.5
	D	5:45	5:30	-0:15	136	126	-10	-1.0
	E	6:30	5:27	-1:03	119	118	-1	-0.0
East Moravia	F	8:00	5:25	-2:35	192	188	-4	-0.1
	G	6:15	4:01	-2:14	111	99	-12	-0.4
	H	4:35	3:59	-0:36	166	159	-7	-0.2
West Moravia	I	7:50	6:55	-0:55	270	246	-24	-5.0
	J	8:10	7:05	-1:05	291	268	-23	-4.9
	Total	68:50	53:31	-15:19	2012	1842	-170	-28.0

Three main parameters were compared, namely service time (hours), transport distance (kilometres) and fuel consumption (litres). On each analysed route (A – J), savings were always generated in all monitored parameters. The indicators are partially interlinked with each other. In terms of service time, the greatest savings were recorded on route A (savings of 2:45 hours). The original service time on all routes was 68:50 hours. The newly proposed service time on all routes is 53:31 hours, it is a time saving of 15:19 hours per day. Of course, this time saving is also linked to an economic saving, as there may be a reduction in personal costs for the vehicle drivers.

In terms of transport distance, the greatest savings were also recorded on route A (50 km savings). The original total transport distance on all routes was 2 012 km. The new proposed total distance on all routes is 1 842 km, it is a saving of 170 km per day. This saving is of course linked to economic savings, as fuel costs will be reduced; environmental savings, as lower greenhouse gas emissions will be produced, and the depreciation of the company's fleet will be reduced.

Table 4 presents calculation of fuel cost savings per day, week, and year. Table 4 shows that the daily fuel saving on all routes is 28 litres. On a weekly basis, the fuel saving is approximately 140 litres (assuming a week of 5 working days when the routes are implemented). Over a year, the fuel saving is about 7 280 litres (we assume that a year has 52 weeks when the routes are implemented).

Table 4

Calculation of fuel cost savings per day, week, and year [authors]

Region	Route	Fuel savings			Cost savings		
		Per day [l]	Per week [l]	Per year [l]	Per day [€]	Per week [€]	Per year [€]
Slovakia	A	-10.1	-50.500	-2 626.00	-19.392	-96.960	-5 041.92
	B	-4.8	-24.000	-1 248.00	-9.216	-46.080	-2 396.16
North Moravia	C	-1.5	-7.500	-390.00	-2.880	-14.400	-748.80
	D	-1.0	-5.000	-260.00	-1.920	-9.600	-499.20
	E	-0.0	-0.005	-0.26	-0.001	-0.009	-0.49
East Moravia	F	-0.1	-0.500	-26.00	-0.192	-0.960	-49.92
	G	-0.4	-2.000	-104.00	-0.768	-3.840	-199.68
	H	-0.2	-1.000	-52.00	-0.384	-1.920	-99.84
West Moravia	I	-5.0	-25.000	-1 300.00	-9.600	-48.000	-2 496.00
	J	-4.9	-24.500	-1 274.00	-9.408	-47.040	-2 446.08
	Total	-28.0	-140.005	-7 280.26	-53.761	-268.809	-13 978.09
Notes: week = assumption of 5 working days, year = assumption of 52 weeks, price of fuel (diesel) = 1.92 € / l							

The economic evaluation focuses only on fuel savings although other savings are generated in this area. We assume a diesel price of 1.92 € / litre of fuel. The daily fuel saving is approx. 53 €, the weekly saving is approx. 268 € and the annual fuel saving on all routes is 13 978 €, which is not negligible. As already mentioned, the proposed solution may also generate further savings in the economic area (reduction of wage costs for drivers) and environmental benefits (reduction of greenhouse gas emissions, noise, and vibration).

5. Conclusion

The issue of logistics planning in the context of distribution and reverse logistics is a very complex matter and a challenge for many companies. In the food industry, especially for perishable goods, it is a challenging task that can have an impact on the entire supply chain.

The aim of the manuscript was to present a vehicle routing problem with pickup and delivery with time windows algorithm-based tool to support logistic planning in the context of distribution and reverse logistics processes and to illustrate its use in a real case study. The use of logistics planning tools in distribution and reverse logistics is an absolute necessity in today's dynamic and turbulent times, as it helps companies to streamline processes, reduce costs and increase competitiveness. One of the logistics planning tools for distribution and reverse logistics processes is VRP Spreadsheet Solver. This tool allows to solve vehicle routing problem with pickup and delivery with time windows. Using the scientific method of comparative analysis and an interpretive case study, this manuscript illustrated the use of this tool for logistics planning with the comparison of standard routes that the analysed company usually uses. The conclusions of the study are that the use of this tool to support logistics planning can bring economic, personnel, as well as social and environmental benefits to the company. A limitation of this manuscript is that only one company's routes were analysed, but this is standard practice for an interpretive case study. At the same time, it can be assumed that savings would be generated for other routes and companies using this tool. Another limitation is the fact that the tool does not consider the current traffic situation and does not allow dynamic real-time replanning. However, these facts may be the subject of further research.

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Analysis of Port Efficiency Assessment Methods, Development of a New Multidimensional Complex Model

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Abstract

The transport sectors are developing dynamically. The volume of conveyances is increasing not only in the interior of certain countries, but also in the international traffic. The global transport system encompasses all types of long-distance transport and international conveyances form the basis for the functioning of the global market. The increase in the turnover of international goods leads to relevant increase in freight traffic. The efficiency of port performance is an important requirement to survive in the fiercely competitive freight sector, where every port struggles to attract and handle as much freights as possible. The aim of this study is to improve the methodology for assessing the efficiency of port performance by identifying the positive aspects and weaknesses in the port performance efficiency assessment model, as well as to develop suggestions for improving the port performance efficiency assessment model. The following tasks are set to achieve the goal: based on selected literature, to explore port performance efficiency assessment models and calculation methods, as well as the latest scientific conclusions on the researched problem; to study the role of ports in the economic growth of the transport sector; to identify key performance indicators of the efficiency of ports that could be used to analyse the efficiency of ports; to develop options for improving the port performance efficiency model.
KEY WORDS: *Ports Efficiency, Stochastic Frontier Analysis, Data Envelopment Analysis*

1. Introduction

Assessment of the efficiency of port performance is particularly important in countries and regions, where the ports are the driving force of the economy, providing taxes to the state budget, inflow of investments, creation of new jobs, development of infrastructure, etc. All ports in the world are unique in their nature and the task of measuring and analysing their performance after a single standard is not a simple one. The difficulty of establishing common standards is created by the fact that there is no common approach to summarising all the key aspects of the efficiency of port performance. Assessment of performance results is a fundamental concept for any business. Does the company assess the achieved results in terms of the set goals, tasks or either by considering the competitors? The development of ports is directly influenced by the globalization processes in the world: the global economic crisis – the real estate and banking crisis, economic sanctions, fluctuations of energy prices worldwide, the development of the Eurasian Silk Road.

2. Materials and Methods

The theoretical and methodological basis of the study. When developing the study, research by S. Esmer, K. Bichou, W. C. Huang, J. Tongzon, P. Langen, M. were used. Also the results of the research carried out independently by the Author were used in the study, as well as information available on the Internet and in the international scientific databases. In order to successfully achieve the goal of the study and to meet the set goals, the Author uses Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) in the study.

3. Results and Discussion

Currently, there is no unified approach to assessing the performance results of ports in the world. In practice the performance of container terminals is analysed the most using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). In some studies and publications on the assessment of port performance efficiency, individual terminals are analysed, but this analysis does not demonstrate the overall efficiency of the port. Such studies are emerging increasingly due to the fact that the terminals in their essence are the basis for port performance and development.

Soner Esmer points out multiple reasons why ports and terminals must assess their efficiency:

1. Ports and terminals must know how efficiently they operate, in terms of the amounts of cargo and passengers processed etc.
2. It is important to know the amounts of resources available (workforce, equipment, land), in order to enable complex port activities.
3. Ports and terminals must compare their current output with past operation results, in order to determine whether their results have improved or deteriorated.
4. All businesses need goals, which is why it is necessary to compare the goals set with the operating results, and ascertain whether the goals set have been achieved within the period specified for them.

5. Comparison of business results with those of competitors.
6. Taking into account the current efficiency assessment, it is necessary to set new goals in order to boost efficiency in the future.
7. Continuous monitoring of customer satisfaction with the services and facilities offered.

In view of the above, it is important that the port management assess their operating results, set goals for assessing operating results and regularly evaluate their results relative to the goals set.

Analysing the efficiency of container terminals through DEA (Soner Esmer, 2008) points out that the biggest problem preventing the creation of a uniform methodology for assessing the operation of any port is the lack of agreement between different ports, international organisations, experts in relation to what indicators must be chosen, and how they should be defined and assessed [9].

Traditionally, ports have been assessing their operating results by using a simple approach, i.e. comparing their actual and optimal throughput, measuring them in tonnes or containers processed [14]. If the actual long-term throughput of the port is close to its optimal throughput, one can conclude that the performance of the port within the specific time period has improved, or otherwise [13].

At the time, no globally-accepted uniform approach for assessing the operating results of ports has been developed. DEA and SFA are the world's most common models for analysing container terminal operating results. When considering the assessment of port operating efficiency, various studies and articles analyse individual terminals, without including the overall efficiency of their corresponding ports. Such studies are becoming more and more frequent, taking into account the fact that terminals, in essence, act as the basis for port operations and development. Kevin Cullinane highlights that ports and terminals must not be considered as separate units, and their performance must be assessed as a whole [5].

Sensitivity analysis is used to know how sensitive the solution values and efficiency scores of the DMUs are to the numerical observations. In order to know the robustness of the efficiency scores, we propose a new model for sensitivity analysis in the new slack model (NSM) of DEA (Agarwal S, 2011) by changing the reference set of the inefficient DMUs [1].

Data envelopment analysis (DEA) is a well-established methodology for the assessment of performance of a homogeneous set of decision making units (DMUs), e.g. economies, bank branches, schools or hospitals, which are described by their input and output quantities. DEA shows a high potential regarding the aggregation problem mentioned before, as DEA does not require explicit weights. The main problem when using DEA in the ecological context is the fundamental assumption that for a DMU, to achieve efficiency, ceteris paribus larger quantities of outputs and smaller quantities of inputs are preferable [7].

Having reviewed various academic sources [12], the author has concluded that, in practice, three data processing methods are largely used to assess port and terminal operation results and efficiency:

1. using DEA;
2. using SFA;
3. using port capacity indicators.

In view of the fact that the DEA and SFA methods are largely used to assess terminal operating results, the author has emphasised the essence of these methods in her study.

DEA, which does not include the functional forms of production, is one of the main efficiency analysis methods. In essence, it encompasses the use of linear programming methods for establishing parameters. DEA is the main linear programming model for efficiency analysis. Meanwhile, SFA is an econometric method, which is most frequently used between parametric methods.

SFA is a production margin function, which can be described as an 'extension of a known regression model, based on the microeconomic assumption that the production function is an ideal value, maximum output that can be achieved taking into account the entirety of raw materials available.' In recent studies, the difference between the estimated production margin and the observed one is calculated to determine the level of efficiency of a company/organisation. Before this analysis, the researchers developed various approaches to measure efficiency in an econometric way. On a fundamental level, SFA determines the minimum costs at a certain output level, and the costs of raw materials based on the current production technology. This method can be successfully integrated in assessing the efficiency of ports, assessing investments into the development and maintenance of port infrastructure, relative to the amounts and types of cargo processed. This method makes it possible to determine the level of efficiency of a specific entity, in relation to the inefficient use of raw materials, within a certain cost function.

This is why the efficiency of a decision-making unit (DMU) (Fig. 1), which can belong not only to a bank, hospital or university, but also to a port, is calculated relative to the 'best-practising' market participant. Furthermore, in order to determine statistical error and to separate it from the concept of efficiency, introduced two-way deviations, and an additional 'possibility-limited' efficiency analysis was integrated in DEA models [8]. Ultimately, this efficiency assessment method is used in a large number of different fields, including management, operational research and economics.

In order to demonstrate the basic DEA model mathematically, we will assume that every decision-making unit uses m inputs to get n outputs at a certain level of technology. This mathematical representation can be explained by finding appropriate values m and n, which increase the level of efficiency of the unit, which all efficiency indicators are related to.

The popularity of the DEA method in assessing the efficiency of ports is growing, and it is increasingly used to assess the capacity of individual terminals. The author proposes that the non-parametric, deterministic DEA method be combined with the parametric SFA method, which is used more as a method for assessing technical efficiency. In the opinion of the author, combining these two methods in assessing port operations can yield more complete port efficiency assessment data. It should be highlighted that DEA models have been only recently adapted to consider the network of internal production processes taking place within a DMU [3, 17]. Chien-Ming (2009) argued that if these dynamic effects are not accounted for, then the measure of efficiency obtained would be biased and provide misleading information to the decision-makers [3].

DEA and SFA non-parametric and parametric statistical methods are used by port researchers mostly to assess container terminal operating results, evaluating the performance of decision-making units to create a basis for such an assessment [4]. Multiple similar input data converted in multiple similar output data are taken as the basis. Although, DEA is the most popular non-parametric method to assess port efficiency, it is not exempt from criticism [11]. Container terminal production may be best modelled as a network of interrelated sub-processes [2] or with multiple outputs [15].

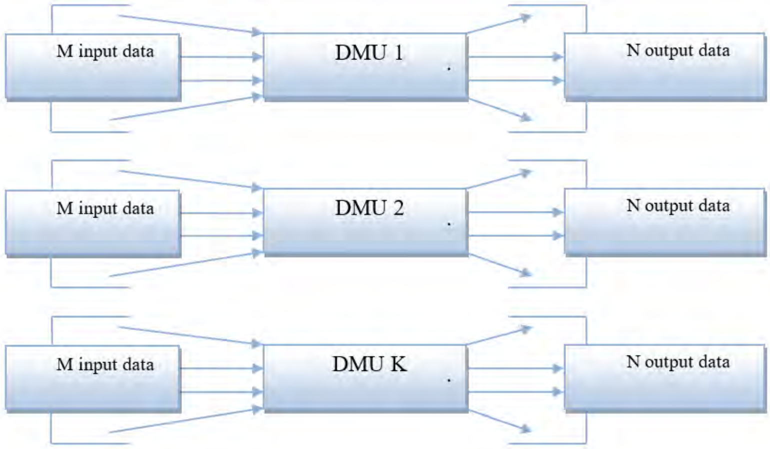

Fig. 1 DMU and homogeneous units [16]

The author of the study has developed a table that includes the most common input data, which, if processed using DEA and SFA, produce their corresponding output data (see Table).

The number of input and output data values does not have to be the same, e.g. two input data values may generate 3, 4, 5...n output data values. The author has observed that in most cases, these methods do not involve more than 9−10 data values per position.

Table

Common input and output data used with DEA and SFA [author's construction]

DEA		**SFA**	
Input data	Output data	Input data	Output data
• berth capacity • cargo handling capacity	• tonnes of cargo transhipped • number of vessels • revenue • customer satisfaction	• length of berth • terminal area • number of gantry cranes • number of employees	transhipped TEUs
• berth dimensions • area of terminals • number of cranes	transhipped TEUs	• labor force • capital	turnover
• number of employees • value of assets	• number of vessels • tonnes of cargo transhipped • transhipped TEUs	total cost	• labor force • capital • intermediate costs
• labor costs • depreciation costs • other expenses	• tonnes of cargo transhipped • port fee revenue	• labor force • capital	turnover

Following an exposition of the DEA methodology, the many previous applications of the technique to the port industry are reviewed and assessed. The DEA technique is illustrated through a detailed example application using sample data relating to the world's leading container ports. The different DEA models give significantly different absolute results when based on cross-sectional data. However, efficiency rankings are rather similar. The efficiency estimated by alternative approaches, therefore, exhibits the same pattern of efficiency distribution, albeit with significantly different means. An analysis of panel data reveals that container port efficiency fluctuates over time, suggesting that the results obtained from an analysis of cross-sectional data may be misleading. Overall, the results reveal that substantial waste exists in container port production. It is also found that the sample ports exhibit a mix of decreasing, increasing and constant returns to scale. The chapter concludes that the optimum efficiency levels indicated by DEA results might not be achievable in reality, because each individual port has its own specific and unique context. Consequently, more singular aspects of individual ports should be investigated to determine the reasons that explain estimated efficiency levels [5].

The basic information derived from the above three DEA models, i.e. the DEA-CCR model, the DEA-BCC model and the Additive model, is whether or not a firm can improve its performance relative to the set of firms to which it is being compared. A different set of firms is likely to provide different efficiency results because of the possible movement of the production frontier [6].

The economic impact of a port is largely measured using result indicators and resources related to them: cargo turnover, employment. (Talley, 2006) Believes that one of the options for achieving set economic goals is increasing the turnover of cargo at the port. Ports are classified based on the amount of cargo they process, and these data are published on the websites of port administrations, in statistical databases etc. It is commonly thought that increasing the turnover of cargo suggests that the efficiency of the port is improving, although one should keep two limitations of this indicator in mind. The author agrees with the opinion of (Langen, 2007) [10] in that increases in turnover are largely contingent on the flow of international trade, and not on the rising efficiency of the port in question. The aforementioned researchers also note that the amount of cargo processed does not say anything about its economic effect on the port.

Even though academic sources often praise the flexibility of DEA, its structure can be troublesome if the weights assigned to the input/output sets have unrealistic properties. Because of this, researchers can create more realistic models, to improve model discrimination, using limitations on the weight of input and/or output bundles. The upper and lower limits are set for the weight of the input and output sets, after which they are included in the linear programming system (output limitations), (input limitations). The main problem of WR models is the possibility of reaching an unacceptable limit, which only depends on the judgement of the researcher.

4. Conclusions

A comparison of SFA and DEA based on selected data shows that for simple basic technologies, the performance of stochastic frontier models (relative to DEA) depends on the choice of functional forms. Furthermore, with SFA, incorrect input data can lead to a certain level of inefficiency correlation, making DEA more attractive. All of the above arguments make it patently clear that choosing one of the two methods can yield different results, and even if the input and output data are similar, they are not equal, and there will always be certain cost alternatives. It is impossible to recommend one method or the other, because they both have their advantages and disadvantages; in this context, the best approach is to combine them to reduce the efficiency error. The main difference between stochastic and deterministic models is that stochastic analysis includes the concept of error, which enables it to separate the effect of inefficiency from statistical deviation. Should both of these methods be implemented in port economics, one will be able to obtain reliable efficiency assessment results by choosing appropriate input and output indicators that can be expressed numerically and can be calculated.

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The Procedure for Security Checking of Vehicles at the Entrance

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Abstract

The article focuses on the area of vehicle inspections carried out by guards. The authors pass from general information about private security and physical protection through the rights of security guards to the key topic - vehicle inspection. The final part of the article focuses on an assessment of the applicability of the means used by security guards to control cars and trucks. In the development of this part of the article, knowledge from practice has been used. Specifically, the opinions of security managers of large companies. The article is processed as an output of the project Cultural and Educational Grant Agency Ministry of Education, Science, Research and Sport of the Slovak Republic KEGA 036ŽU-4/2022
KEY WORDS: *private security, guarding, physical protection, private security means, checking of the vehicle.*

1. Introduction

Physical protection or guarding service is part of the protection system, together with mechanical barriers, technical means and regime measures, which can be used to ensure the protection of assets [1-3]. Physical protection can be defined in different ways. In general, physical protection can be defined as the protection of persons, premises, objects or processes by a person. Physical protection is also a targeted activity aimed at ensuring the security of a protected asset by means of human force and available legal means (communication equipment, transport means, weapons etc.). Physical protection can also be defined through the general activities that it covers, namely patrolling and guarding the protected area and operating an alarm system, as well as management and control of these activities [4, 5].

Physical protection can be carried out by state or private security forces [1, 3, 6]. The common feature of these units is their objective. The objective is always to protect an asset, to take action or to act preventively. The asset to be protected may be a person (life and health), material or nonmaterial property, or the environment [7]. The difference in the provision of physical protection by state or non-state security forces lies on 3 levels.

The difference in the provision of physical protection by state or non-state security forces lies in 3 levels.

1. The stimulus to action. In private security services, the stimulus comes from the client. The client directs to the private security service a request to perform physical protection. The private security service takes action only if the assets under threat are in danger. State-owned forces act on the impulse of the law and citizens. The jurisdiction of the state security forces is not established by contract, but by law (Prison guard protects the objects of the court and the objects of the Ministry of Justice, Military police protect the objects of the Ministry of Defence, etc.). The cooperation of state security forces with each other or with a third party is also regulated by law [8]. There are situations in which the state security force is also bound by a contract. An example is the protection of objects carried out by the police force.
2. The idea of creation and the aim of the company. Private security service is a profit-oriented company. State-owned forces do not make a profit but protect all citizens indiscriminately.
3. Result of work. The result of private security services is the protection of property, ensuring the operability or reduction of losses of the client. The result of the work of a private security service is more preventive. State security forces are more repressive and the result of their activity is often the arrest of the offender and prosecution. The use of repression is a typical feature of police-security forces. Preventive action is typical of private security forces.

In terms of the need for protection, the collection and processing of information are of particular importance. For the state security forces, this activity can be referred to as operational-search activity. However, operational-search activities may be used only by selected state security services, in cases listed exhaustively by law and under the conditions laid down. In the case of private security services, we are talking about private detective research. The difference between operational and private detective activities lies in the extent of interference with the privacy of the persons concerned, as allowed by law [9]. The common feature of monitoring, investigation, intelligence, search and operational-search activities is that it is an activity, the content of which is the prevention, detection and documentation of events and conditions of interest, or the identification of persons responsible for an event or condition of interest. The act or condition of interest may be a criminal or other unlawful activity, facts related to that activity, etc. The aim is to ensure the protection of persons and property or clarify circumstances or trace persons and things. The difference between a private security service search and a state security force search lies in the means, which are legal and legitimate.

2. Object Protection and Vehicle Control

Entrances and exits to/from the protected area often represent a vulnerable point in the protection system. They are particularly vulnerable when the flow of people, vehicles and cargo is not sufficiently controlled or monitored. The following are used to protect entrances/exits:

- Technical means - barriers, ramps, camera systems, alarm systems, etc.
- Regime measures - rules for entry and movement in the protected area, instructions for control of people and vehicles, luggage, goods, cargo and materials.
- Physical protection/Guarding - supervision of compliance with regime measures, an inspection of vehicles, luggage, goods and material, intervention activities, response to emergencies, etc.

Physical protection at the entrance/exit has the task, among other things, to ensure that persons at the entrance/entry do not pose a danger to the assets. The mandate of the guards can be divided into the following categories [9]:

- authority to deny entry,
- authorisation to evidence or electronically record by technical means,
- authorisation to check (to ascertain by eyesight, by touch, by technical means),
- the power to remove objects resulting from an unlawful activity related to an asset or objects which could be used to commit an unlawful activity,
- the authorisation to require proof of identity,
- the authorisation to restrict personal freedom,
- the power to bring a person to a guard post.

The procedures and means used in guarding assets are determined:

- the type of asset and its vulnerability or identified threats. The procedures and means used, for example, to protect manufacturing companies, where the priority of guards may be to protect against theft by their own employees, are different from those used to protect soft targets, where there is a higher risk of a terrorist attack;
- the area of assets - the procedures and means used to protect large companies are different from those applied to small and medium-sized ones;
- Asset value - as the value of assets increases, the level of security risks increases and therefore the requirements for the actions of entry/exit guards increase;
- the financial requirements of security or the company's budget - providing security is a cost for the company, which acts primarily as a preventive measure. Not every company wants or can afford to protect assets at the recommended level.

3. Technical Means and Procedures for Security Checking of Vehicles

The procedure for checking a vehicle at the entry and exit points differs primarily in terms of what the purpose of the check is. Of course, there is also a difference in whether the subject of the check is a passenger car or a truck and the frequency with which vehicles enter/exit.

The guards aim to ensure that unauthorised persons do not enter the protected area. Guards are responsible for ensuring that persons and vehicles are registered and monitored and that items that are prohibited or may be dangerous (weapons, storage media, chemicals, or even the wrong goods or goods of the wrong quality) are not brought into the protected area. On exit, the goal of the guards is to ensure that persons and vehicles leaving the protected area are properly accounted for and that no unauthorized materials or goods are removed from the protected area or persons leave the protected area without authorization or a record of their departure. Despite the different objectives of the control and therefore the different procedures, certain points are common to these procedures. The technical means used for checking entry and exit are also common.

Control at the entrance

1. Check the entry authorisation and vehicle registration.
2. Registration of the driver and crew of the vehicle. Check the authorisation for the vehicle crew to enter the protected area.
3. Vehicle check.
   a) Inspection of the cargo or luggage compartment - usually weighing the vehicle, checking the seal, quality, etc., comparing the cargo with the documentation;
   b) A security check, in particular a check for prohibited or dangerous substances and materials.
4. Instructing the driver and crew of the vehicle on the regime, security and safety in the protected area.

Control at the exit

1. Check the exit authorisation and vehicle registration
2. Checking the identity of the driver and crew.
3. Vehicle check.
   a. Cargo inspection - usually weighing, checking the cargo for tamper evident seals, quality, etc., comparing the cargo with the documentation;
   b. A security check, particularly a check aimed at detecting theft.

The technical means used to check the vehicle are [10-11]:

1. Optical equipments - inspection mirrors, endoscopes (boroscopes, fibroscopes and videoscopes) are used to inspect hard-to-reach places, chassis, luggage compartment. Optical instruments are the basic technical equipment of the guard at the entrance to the protected area.
2. Metal detectors in the form of frame detectors or hand-held detectors are used for checking persons (drivers, vehicle crew). The aim of its use is to detect whether a person is carrying or wearing prohibited objects.
3. Scanners for the control of transport means based on the principle of fast pulsed neutron analysis. The scanners allow automatic detection of items of interest, which is a great advantage in objects with a high frequency of entries. The possibility of human failure caused by inattention, due to the monotony of the work, is eliminated.
4. X-ray equipment represents a more advanced group of devices that are used for vehicle inspection. Whole vehicles or only selected cargo may be subjected to X-ray inspection. They are often used in the inspection of consignments, i.e. not at the entrance to the protected area but only in the follow-up inspection.
5. Trace part detectors - frame or hand-held detectors focusing on prohibited substances and their precursors.
6. Dog, not a technical means, but it is one of the means used by the officers in the control of the entrance. The dog may be used to locate a specific prohibited substance, or it may be a means that protects both the officer and the asset.
7. Security means used in the intervention. Devices to stop the vehicle (stop belts, retractable barriers), restrain the offender (handcuffs), or protect the officer and the protected area (batons, stun guns, defensive sprays), and a weapon.
8. Special means, e.g. pyrotechnic robots during vehicle checks aimed at detecting an explosive ordnance disposal system [12].

The table (Table) lists the types of equipment used by officers and a numerical indication of the appropriateness of the use of the equipment according to the type of vehicle and the frequency of vehicle movements. Table 1 was compiled in a brainstorming session attended by 15 security managers from large enterprises of various backgrounds. In assessing suitability, the acquisition and operating costs of the asset, the benefits of its use, space and staffing requirements were taken into account.

Table

Evaluation of the appropriateness of the use of equipment

Equipment	Truck		Passenger vehicle	
	Low frequency of vehicle movements	High frequency of vehicle movements	Low frequency of vehicle movements	High frequency of vehicle movements
Optical equipments	2	0	2	1
Hand-held metal detectors	2	1	2	1
Frame scanners	1	2	0	2
X-ray (mobile)	0	0	1	1
X-ray (stacionar)	1	1	0	0
Hand-held trace part detectors	1	1	1	1
Dog	2	0	2	0
Security means used in the intervention	2	2	2	2
Special means	1	1	1	1

Rating scale: 0 – unsuitable for use; 1 - suitable for use in specific cases only; 2 – suitable for use

According to the assessment of the appropriateness of the use of types of equipment:

- Optical equipment is suitable for the control of passenger cars and trucks at a low frequency of movement.
- Hand-held metal detectors are suitable for the inspection of trucks and passenger vehicles at a low frequency of movement.
- Frame scanners are suitable for inspecting vehicles at a high frequency of movement.
- X-ray static is suitable when inspecting trucks, but depending on the security situation. Mobile x-ray units are indicated as suitable for passenger vehicles. Again, however, depending on the security situation.
- Hand-held trace detectors are appropriate depending on the security situation, regardless of vehicle type or frequency of vehicle movement.
- A dog is suitable for checking vehicles at low frequencies of movement, or for random checks.
- The security devices used in the intervention are essential equipment for the officer.
- Other special means are such a specific category that their use depends on the security situation. It is therefore not possible to make a definitive statement on the appropriateness of their use.

The applicability of the means used by guards is largely influenced by the specific security situation [13] and whether every vehicle is checked or only selected vehicles are checked

4. Conclusions

Guards carry out several different inspection and registration tasks at the entry and exit of vehicles. Some of these are aimed at security. These operations aim to ensure that only authorised and registered persons are in the protected area, so the checking of persons at entry and exit is also part of the vehicle check. Another goal is to ensure that prohibited materials and objects are not brought into the protected area and that nothing is stolen from the protected area. Other actions of the guards are focused on the cargo, its inspection and weighing, or checking the documents and instructing the driver and crew of the vehicle.

The guards use a variety of equipment in the listed activities. In the registration of access, the use of surveillance cameras is common, barriers are used to regulate the entrance. Guards also supervise compliance with regime measures and are responsible for instructing persons entering the protected area. In addition, there is a group of means that are used by officers in providing security. These are optical devices metal detectors scanners based on the principle of fast pulsed neutron analysis, X-ray equipment, trace detectors, and security means used in the intervention. Devices to stop the vehicle (stop belts, retractable barriers), restrain the offender (handcuffs) or protect the officer and the protected area (batons, stun guns, defensive sprays), and weapons and special means, e.g. pyrotechnic robots, when checking a vehicle to detect a booby-trapped explosive system.

When evaluating the usability of the above-mentioned means, the security means used during the intervention were mentioned as a necessity in the equipment of the guards. This is because the intervention is an indispensable function of security guards. Yet it is not possible to carry out an intervention without guards taking part in it.

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Activities Affecting the Safety of Transport Companies by Changing the Process and Awareness of Employees, and the Implementation of Innovative Technical Infrastructure

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Abstract

The article refers to the safety of transport companies through the use of appropriate risk management models and the implemented technical infrastructure. The aim is to demonstrate potential, desired and effective changes in various spheres of the enterprise, including processes and awareness of human capital. The study, in the form of an in-depth interview, is conducted on representatives of the transport industry - transport companies. The conclusions are to lead to the correctness of applying corrections, securing companies against negative accidents, while maintaining the continuity of the process, giving the possibility of development and construction and increasing the competitive advantage. The subject of the research is to indicate potential paths of action.
KEY WORDS: *transport, safety, risk, prevention, process*

1. Introduction

Today's entrepreneurs meet the challenges posed by contractors, the market - the industry in which they operate, as well as those provided by more or less trained employees - the human factor (capital). The strategy implementing the growth and scaling of the enterprise is supported by the right foundation in the spheres of safety and prevention. Securing the organization for success requires the implementation of dedicated and specialized models of conduct, response processes as well as cost-effective implementation of newer and newer certifications. Transport and forwarding companies, thinking about scaling their business, choose to use innovative and modern programs that shorten the response time, as well as increase the effectiveness of undertaken and implemented assumptions. It is the facilitations by platforms and applications that solve problems by responding to the needs of the market and the industry that accelerate the race for gaining a competitive advantage, as well as the development of new business niches. Conscious companies implement preventive procedures, while those who are just entering the industry implement demanding security tasks, often only after a critical event has been noted. The aim of the article is to demonstrate the problem and the need to generate appropriate and appropriate security measures for a given organization, in correlation with the existing as well as new emerging threats to the continuity of the company's operation. The detailed goal is to indicate specific practices used by model organizations, as well as to show the recommended applications and software for optimization, having a direct impact on the increase in security, by reducing the possibility of errors or the importance of emerging difficulties. Integration of human awareness and its potential, along with modern technology based on algorithms and artificial intelligence, using the company's technical infrastructure - is a monolith to the foundation, in order to achieve strategies and specific goals as a result of operations in the TSL industry.

2. Transport Companies and Possible Risks in the Transport Industry

Companies in the transport, forwarding and logistics sectors must be characterized by greater flexibility to changes and a higher ability to correct in the event of failures as a result of the tasks performed. There are many situations that may lead to a company's stoppage or instability, as well as termination of activity. Starting from extended payment terms from 30 through 60, ending with 90 days, including the risk of not receiving any remuneration for the completed freight, in the event of fraud, which results in a temporary or total inability to finance the costs. Fixed costs can be significant, taking into account the model chosen by the owner of the company and his economic and management abilities. Both fuel as one of the largest costs of a logistics company, as well as employee remuneration and the financing of the rolling stock, i.e. the carrier's fleet, or its leasing, are clear and characteristic items on the cost side of the enterprise. Traps related to companies - the so-called frauds or poles, become known with a delay, when we can no longer react appropriately. An example may be numerous frauds of valuable cargo or obtaining remuneration from customers and not passing it on to the actual carriers performing the transport - impersonating the contractual carrier, i.e. the freight forwarder in the common understanding of the operational function. However, this is only the beginning of the risks that can lead to bankruptcy of the company. The most spectacular catastrophes relate to traffic accidents, cargo theft, as well as the release of a significant amount of substances into the environment. However, other spheres of carrier activity should also be looked at, for the sake of business growth. Inefficient payment monitoring, improper organization of deliveries, as well as an excessive number of empty runs affect the profitability of the company. Too high fuel costs, in comparison with too low rates, as well as a shortage of drivers determine the significant problems of business owners. Recovery plans, visualization of scenarios and generation of preventive procedures thus become the basis for the work of managers managing transport and forwarding companies [3].

The risk can be reduced only through proper and systematic action, and the pattern can be a properly configured manager's checklist, based on awareness and setting of values:

– profit-oriented institutions as well as charities should be effectively managed;
– managerial education never ends;
– interweaving acquired knowledge - education, with professional experience combining knowledge (logic) with art (intuition and instinct).

In terms of management efficiency, it is also worth emphasizing the importance of the concept of praxeology, referring to the construction and justification of standards related to operational efficiency. Experience and practice should be derived from the failures and successes of other companies operating in our sector - the TSL industry. In particular, failed attempts should be taken into consideration, verifying the causes of failures in order to build up one's own processes more effectively. The observation of gaining an advantage and developing a niche by others, mastering the tasks performed to perfection, also results in new, inexperienced industry participants with new - key skills [4].

3. Challenges Facing Modern Dynamic Supply Chains

The TSL industry bases its values on specific principles that can be defined on the basis of three words: time, quality, efficiency. The basis is to transport a specific good from place A to point B. However, in practice it is a highly complex dependency, which affects the need to create innovative patterns, try to develop a niche, implement intuitive software and dedicated applications that affect ergonomics, as well as model emergency scenarios, helping to overcome crisis situations. To start from scratch, an attempt should be made to articulate the problems and challenges faced by entrepreneurs whose goal is to build an organization, survive on the market, and obtain a BEP - Break Even Point, based on profitability, and finally recording and scaling profit. Visualizing the perception of the supply chain through the prism of its multi-level and multi-dimensional nature boils down to a definition that emphasizes the dynamics of supply chains. It applies to any combination of functions and processes, as well as the relationships and paths of the enterprise, and the interaction between entrepreneurs, in both directions. We are talking about cooperation on the product, service and information lines, as well as in financial transactions. All movements are considered together and individually. Starting from the producer, through the consumer, end user, with the commitment of each employee of the company - each contributes their individual value, which is often underestimated or even unnoticeable [2].

Selected challenges defined by representatives of Sawa Logistics Sp. z o.o., and Botam Transport Sp. z o.o.:

– competitive struggle for dominance on the market, or taking over as many clients as possible for own service;
– a battle for the company's survival, with the real specter of collapse / liquidation;
– time-consuming and cost-effective efforts to develop a niche - being a pioneer;
– effort to deliver value that solves customer problems / needs - industry innovation (improvement);
– breaking down everyday barriers with the support of process optimization applications;
– efficient response to emergencies (emergency shipping);
– minimizing losses through planned steps to be taken after the event;
– reconstruction of the enterprise after the crisis;
– prevention in preventing threats - a structured plan and an authorized methodology of proceeding;
– avoiding threats by predicting conflicts, ambushes (companies, pillars, frauds, debtors, bankruptcies);
– methods and models of solving international / ethnic / social tensions (between contractors in the supply chain).

The above variables relate to the real feelings and experiences from the life of dynamically developing organizations with a transport and forwarding profile, which have been carrying out logistic tasks in the TSL industry for many years. The owners of companies - Mr. Robert Sadowski and Mr. Marcin Bobik, are aware of the effort, the necessity to incur costs, the risk of not avoiding hazards in a specific, quality and time-oriented industry. Managers managing the fleet and forwarding operations are exposed to constant stress caused by the seriousness of the orders being carried out, as well as the value and quantity of cargo transported in a given period, entrusted from key customers whose contracts are the basis for the operation of transport companies. Dependence on ordering parties makes it necessary to build situational models as well as specialized paths to follow after an incident.

The internal diagram (Fig. 1) in the analyzed organization relates to the process of dealing with complaints about the service. It is worth paying attention to the place where the manager of the company or a representative of the board is involved, which clearly indicates the intention to solve problematic issues at lower levels, without involving key people for the company, in order to maintain their efficiency and effectiveness in the global management of the organization.

Acquiring a client, on the other hand, is often associated with the certification requirement. The company thus confirms its professionalism, through, inter alia, obtained ISO (ISO 28000 - supply chain security management system), AEO (obtaining the status of an authorized entrepreneur in the field of safety and security), or GDP certificate (related to good drug distribution practice). However, they do not constitute the basis for starting, maintaining or scaling cooperation. The key values relate to trust as well as common understanding in specific actions in crisis situations. The added value is not only having an idea and vision of action in such situations, but above all, a real plan that can be implemented immediately.

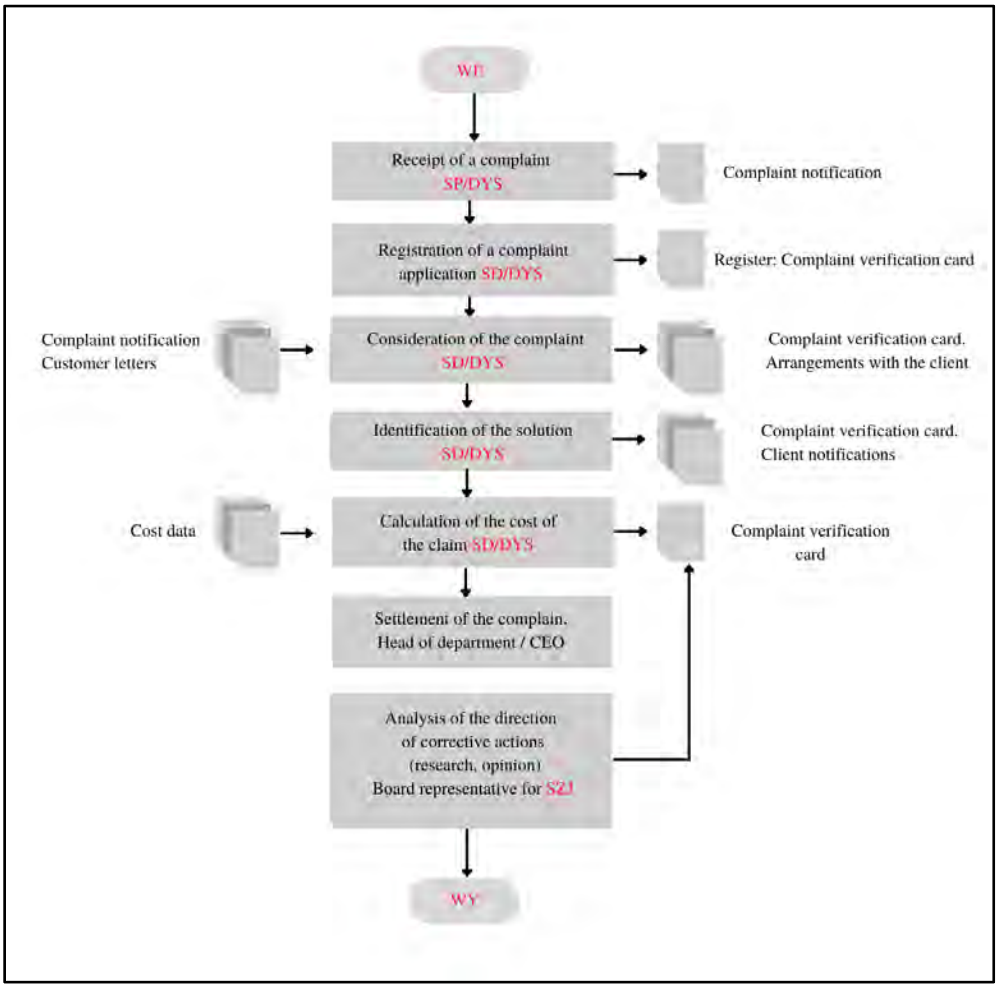

Fig. 1 A dedicated model of managing a complaint notification for internal needs at Sawa Logistics Sp. z o.o. Source: internal material of Sawa Logistics Sp. z o.o.

It is important to draw the right conclusions in building the company's size, including the following - that well / optimally secured enterprises that build success and consciously set goals, setting plans and making decisions alone are not enough to achieve the highest goals - partners and advisers are necessary , mentors. It is also worth emphasizing the dependence and importance of our motivation, skills, and willingness to fulfill the defined duties. It is the appropriate diagnosis of problems and estimation of activities that causes the selection of optimal tools in subsequent stages, in order to provide an effective and timely response. We will choose different tools to prevent empty runs, others to reduce the frequency of damage to loads and vehicles. It will also be useful to analyze the characteristics of entrepreneurs in order to define the positions / departments of the company and assign specific people to them - specializing in given fields, with predispositions to do so [1].

4. Recommendations of Preventive Actions with the Use of Modern Software and Innovations and Their Impact on Improving the Safety and Profitability of Transport Companies

It is not possible to formulate identical rules and guidelines determining the efficient operation of companies in a detailed manner. The reason for this state of affairs is the differentiation of companies in terms of both the employment structure, existing clients and contracts, as well as the chosen management model. These enterprises operate in different internal and external conditions.

Therefore, the recommendations may effectively refer to the use of tools ensuring economic security - influencing the analytics of investment profitability, with the use of modern software, equipped with innovative algorithms. An example is the SNARTO company, i.e. an integrated logistics platform that uses the achievements of artificial intelligence to optimize transport time and costs, both on the part of the carrier and the client. Another platform whose project managers have focused on visibility and clarity in the supply chain is the solution provided by CO3 (real-time cargo monitoring) and Project44 (provides visibility during the full life cycle of the shipment, and enables workflow automation). Accurate and structured data analytics enable supply chain risk reduction and real-time informed decision making with dynamic ETA times, arrival geolocation and proactive alerts.

The need for transparency and global identification of operations with geolocation and created transport corridors was signaled by the leader and President of the Management Board of one of the largest companies in Europe - Girteka

Logistics, having its formal roots in Lithuania, currently owning and managing over 10,000 tractor units.

Better data visibility and transparency through the use of telematics, IoT (Internet of Things), RFID, NFC and other information and autonomous technologies directly improves the TSL industry, and the data is collected through organizations connected by a supply chain. The use of blockchain technology additionally ensures:

- access to the same data by all parties;
- real-time information acquisition;
- permanent data storage;
- information secured against manipulation;
- tracking modifications to stored data.

By reducing the information gaps, each participant in the logistics chain has the knowledge that builds peace of mind about the data where the shipment is currently located, which makes it possible to predict the time of its arrival and thus reduce unnecessary costs. It is the dedicated platforms that create solutions related to the transparency of the transported property. Examples are software provided by companies CO3 and Project44, respectively.

Other selected and recommended platforms optimizing the process, thus solving the problems and needs of entrepreneurs:

- Goodloading (optimal cargo space planning);
- FireTMS (transport and shipping management program);
- InterLAN (communicating participants of the TSL industry with their environment);
- CapePack (solutions for palletizing and containerization of loads).

These software are also the backbone of the safety laboratory of the International University of Logistics and Transport in Wrocław, designed by Grzegorz Wiśniewski, together with other experts in the field of safety, transport and forwarding.

Fig. 2 illustrates the survey conducted with carriers, asking managing managers for their opinion on modern technologies and their suitability for the industry.

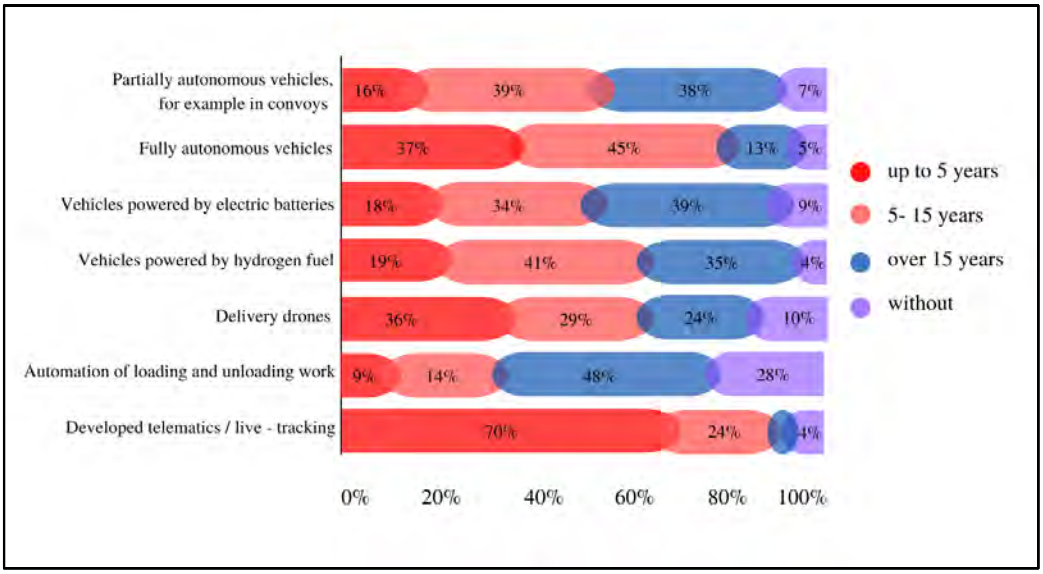

Fig. 2 In what period will the above-mentioned technologies be widely used on the market? [6]

The research conducted by TLP and SpotData shows that industry representatives see a faster possibility of implementing and using hydrogen-powered vehicles on a larger scale than electric batteries. So what could be the reason for this? The answer is simple - electric ones will not work well on long distances, but only on shorter distances. In addition, the weight of the battery reduces the weight of the transported load, which may eventually mean the need to put even more cars on the road to carry the same weight. The costs of disposing of batteries after several years of use are not yet known. The technology that, according to the respondents, will find widespread market application in the next five years is advanced telematics and live-tracking. As many as 70 percent of the TSL industry representatives think so [6].

Another noteworthy study by PWC shows the impact of autonomous motorization on road transport.

Process autonomy, as shown in Fig. 3, reduces costs in terms of automation and autonomy - process automation. This is a reduced global cost compared to 2016, which gives significant investment opportunities, taking into account the statement of the company's turnover to the cost matrix. Even greater possibilities are perceived in partial autonomy, which gives as much as 15% savings. Remote supervision - which means the lack of a driver in the cabin, eliminates the problem of the shortage of employees in the TSL industry and thus eliminates one of the greater labor costs in the transport of goods.

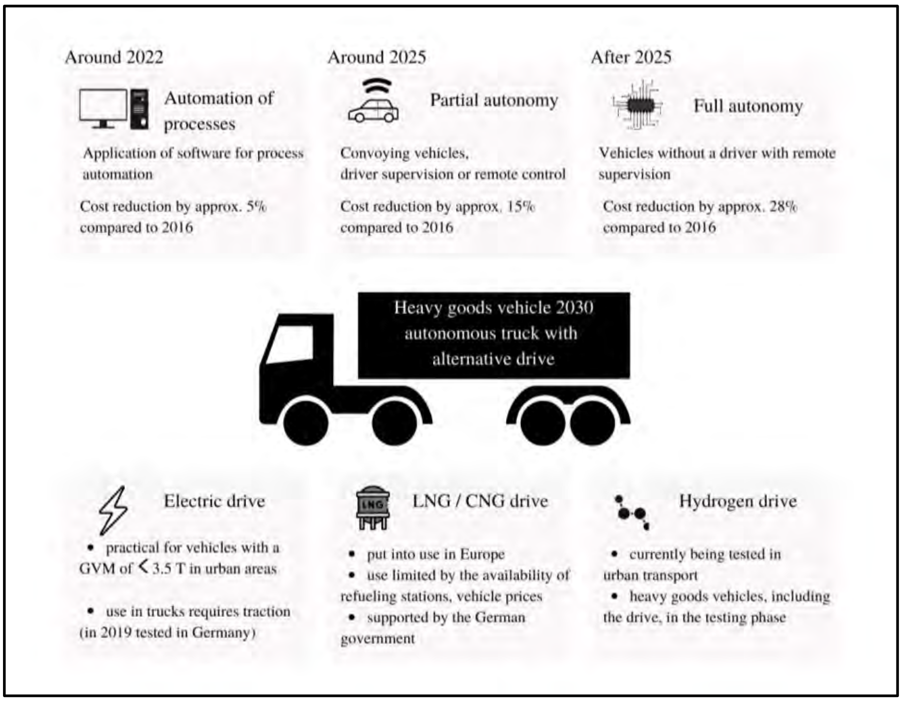

Fig. 3 Expected impact of autonomous motorization and alternative drives on road transport [7]

Almost 30% of savings resulting from this can completely transform the model of organization of processes and the cross-section of the nature of the activity chosen by persons managing forwarding. The above-mentioned elements indicate the huge potential, as well as the multiplying questions about possible barriers and problems in the implementation of automation and partial autonomy, as a result of unforeseen events and taking responsibility for e.g. disasters in land traffic. This is a serious topic for the necessary discussions, exchange of experience and interpretation of industry experts, employers' associations and representatives of the public sector, as well as private / commercial and social sectors. A joint dialogue can lead companies to simplified solutions or find answers to the most difficult questions that pose the challenges of modern logistics and a dynamic supply chain [7].

5. Summary

Specific questions should be asked to illustrate the effect of deliberations and understand the overtones of the values of scenario analysis, in-depth interview and content analysis related to prevention, security, industry recommendations for proceedings in the TSL industry. So how should experience be optimally collected? Which variables and acquired values should be implemented in a mandatory process in the company? Will the software be effective in avoiding errors? How will innovation and post-audit recommendations affect the competitive advantage of companies in the TSL industry? The aim of the article was achieved by demonstrating the practices used by representatives of the TSL industry - transport and forwarding companies, which concern increasing the efficiency of business, reducing errors, by, inter alia, introducing clarity and visibility of all supply chain processes through the implemented advanced IT tools based on tailored algorithms and artificial intelligence. The analysis of the content and source materials showed the problems and difficulties noted by the industry, while in-depth interviews and direct conversations with fleet managers made it possible to obtain an industry perspective, outlining conclusions, preventive and corrective actions, in connotation with a check-list of the organized process. Employees' awareness of threats and various types of risks affecting the continuity of the company's operations is the key, and appropriate implementations ensure that the strategies and profits are secured against bankruptcy, as part of the resulting situations. Chronological procedures after the incident - based on precision, knowledge, composure, based on the designed response paths, provide an opportunity to reduce the negative effects of damage and potential losses.

6. Conclusions

Individual adjustment of dedicated IT tools to transport and forwarding companies focused on development and competition is inevitable. It is it that allows you to collect data, analyze it, properly process and draw conclusions in order to implement corrections in the company, its processes and management style.

People - managers responsible for supervising processes in the company, as well as for introducing norms and standards of conduct based on the detection of errors and bottlenecks are of great value. We are as strong as our weakest link and as prepared for market expansion as the smallest bottleneck in the process.

Innovative programs and applications, based on digitization of the process and digitization in combination with artificial intelligence and big data, mark out previously unknown forms of activity, while providing a different quality.

Thus, the sooner they are adapted in the company and appropriately matched to the business profile, the sooner the know-how will be built and a competitive advantage will be built.

Problems on the market create niches for development. The sooner the efficient eye of the owner of the company or the interpretations of the shareholders' intention go into active operation - the sooner the company will gain a new market or the ability to scale to other countries. The challenge is the shortage of drivers, unfavorable legal changes, high fuel prices, international conflicts, covid-19, as well as ecological and ergonomic aspects, in line with sustainable development. Problems are challenges, and they are opportunities.

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Load on Free-Falling Lifeboat Passengers

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Abstract

The article deals with the movement of a free-falling lifeboat in a vertical plane after contact with the water surface. The maximum accelerations of both the center of mass of the boat and the passengers sitting at the ends of the boat at a simplified boat geometry have been calculated. The water resistance forces in the longitudinal direction of the boat are definitely observing the friction of the water along the hull of the boat, but in the direction perpendicular to the longitudinal axis of the boat - as jet pressure forces on the plane. It has been found that even at relatively low fall heights, passenger accelerations and, consequently, passenger loads can reach life-threatening levels.
KEY WORDS: *free-falling lifeboats, water resistance forces, the load on passengers.*

1. Introduction

Today, ships with a small number of crews, as well as stationary offshore platforms, are increasingly equipped with free-falling lifeboats secured on sloping guides. Such boats have a number of advantages over classic lifeboats launched by boat cranes - mainly shortening the evacuation time of people. However, free-falling boats (Fig. 1) have much higher loads on the people in them. Today, manufacturers of such boats comprehensively test their products, testing the strength of boat hulls and their coatings at different heights of fall - up to 25 m. The load on the passengers during the immersion of the boat is also measured. However, such experimental studies are quite labor-intensive and expensive, and it is difficult to analyze the effect of various falling parameters on the magnitude of the load. Therefore, it would be desirable to analytically calculate the expected maximum values of this load already at the design stage.

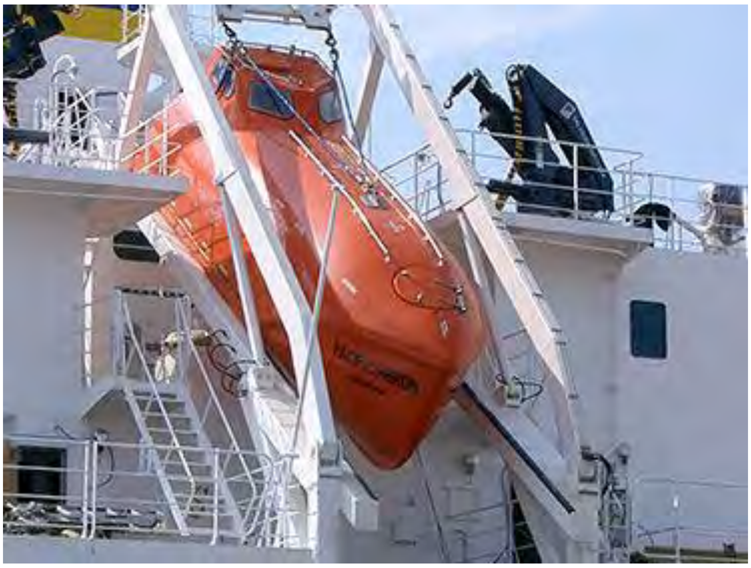

Fig. 1 Free-falling lifeboat (informative image)

2. Calculation Scheme

The rules of boat motion, starting with sliding on guides, are found in [1], where the shape of the boat is replaced by a rectangular parallelepiped and the water resistance force for movement in all directions is calculated as the reduced jet pressure force on the plane. However, such a scheme does not allow for differences in resistance forces in the longitudinal and transverse directions of the boat. We will reduce the geometry of the boat to the shape shown in Fig. 2. Consider the movement of a free-falling boat in a vertical plane after contact with water. The water resistance forces in the longitudinal direction of the boat will be determined by considering the friction of water along the hull of the boat, but in the direction perpendicular to the axis of the boat - as the jet pressure forces on the plane. The forces acting on the boat are shown in the calculation scheme (Fig. 3).

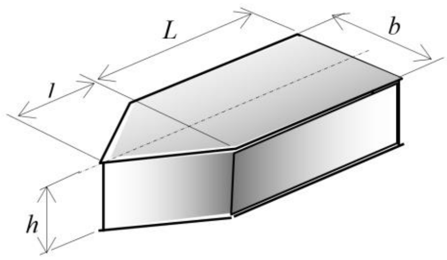

Fig. 2 Simplified boat shape

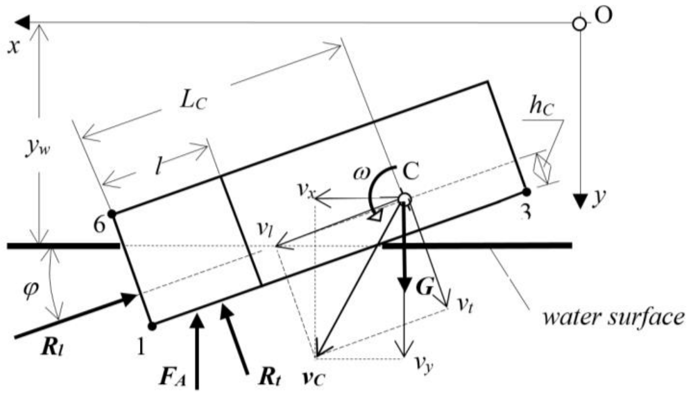

Fig. 3 Scheme of forces acting on a boat

where G − the force of gravity of the boat applied to the boat's center of gravity C, total water lifting force F_A, water resistance force in the direction of the boat's longitudinal axis R_l, water resistance force in the direction perpendicular to the boat's longitudinal axis R_t. The directions of the resistance forces are marked when the velocity of the center of gravity in the longitudinal direction v_l is directed towards the edge 1 - 6, but in the longitudinal axis perpendicular to the edge v_t - towards the edge 1 - 3. The starting point O of the coordinates is selected in the position of center of gravity C at the moment when the boat's point 1 touches the water surface. The angle of inclination of the longitudinal axis of the boat to the horizont φ, the projections of the center of gravity speed v_x, v_y and the angular velocity ω at this time are denoted by φ_0, v_{x0}, v_{y0} and ω_0 respectively.

Water resistance forces are calculated using the relations [2]:

$$R_l = 0.5 \cdot C_F \cdot \rho \cdot \Omega \cdot v_l^2 , \tag{1}$$

where $C_F = 0.455 \cdot \left(lg\, Re\right)^{-2.58} + C_A$; $v_l = v_x \cdot cos\,\varphi + v_y \cdot sin\,\varphi$, here Ω − wetted surface area; ρ − water density; Re − Reynolds number; C_A − coefficient that takes into account the roughness of the wetted surface.

$$R_t = \int \rho \cdot \left(v_t + \omega \cdot z\right)^2 \cdot b_z \cdot dz ; \quad F_A = \gamma \cdot V ; \quad v_t = v_y \cdot cos\,\varphi - v_x \cdot sin\,\varphi , \tag{2}$$

b_z − width of the boat at a distance z from the center of gravity C (Fig. 3); V − volume of the submerged part of the boat; γ − specific weight of water.

$$\left.\begin{aligned} & M_C\left(F_A\right) = \int_{z_1}^{L_C} z \cdot cos\,\varphi \cdot dF_A ; \\ & M_C\left(R_t\right) = \int_{z_1}^{L_C} z \cdot dR_t ; \\ & dR_l = \rho \cdot \left(v_t + \omega \cdot z\right)^2 \cdot b_z \cdot dz ; \\ & dF_A = \gamma \cdot dV . \end{aligned}\right\} \tag{3}$$

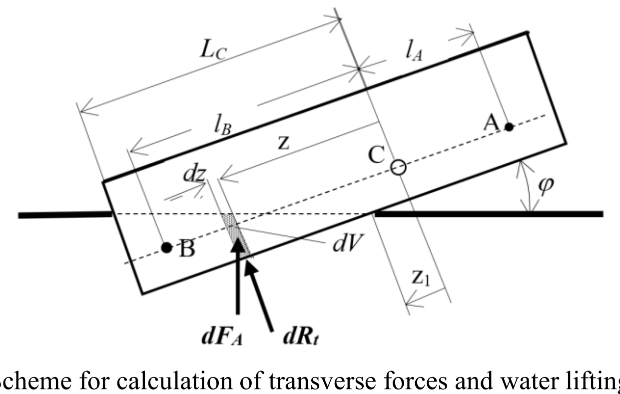

Fig. 4 Scheme for calculation of transverse forces and water lifting forces

Here, the resistance force in the transverse direction dR_t can only have a positive value. If dR_t meets negative for certain values of v_t and ω, then 0 should be inserted instead.

$$b_z = \begin{cases} b & \text{if } z \le L_C - l \\ \dfrac{b \cdot (L_C - z)}{l} & \text{if } z > L_C - l \end{cases}$$

The coordinates of points 1, 3 and 6 (Fig. 3 and Fig. 4) are:

$$y_1 = y_C + L_C \cdot sin\varphi + h_C \cdot cos\varphi\,;\; z_1 = z_6 = L_C - \frac{y_1 - y_w}{sin\varphi}\,;\; y_3 = y_1 - (L+l)\cdot sin\varphi\,;\; z_3 = -(L+l-L_C)\,;\; y_6 = y_1 - h\cdot cos\varphi$$

The calculation of V, dV, Ω, z_1 and b_z, depending on the position of the boat in relation to the water surface, is done purely geometrically in 8 cases (Fig. 5).

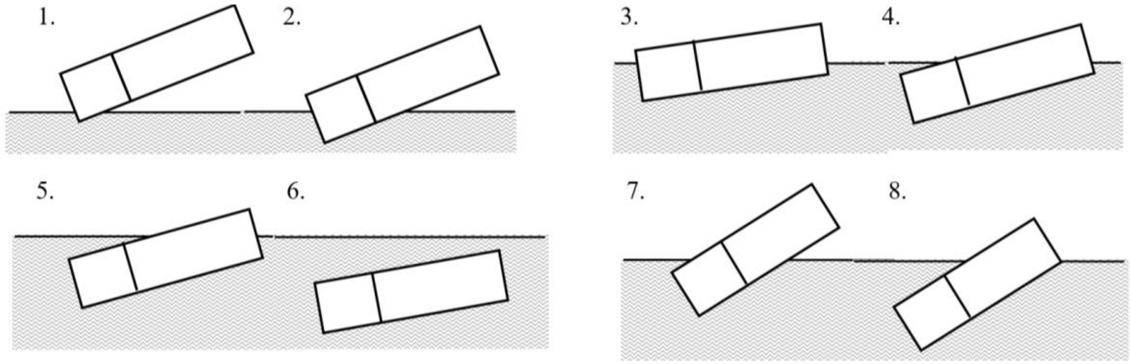

Fig. 5 Positions of the boat in relation to the water surface

<u>In position 1</u>

$$dV = b_z(z - z_1)tan\varphi \cdot dz\,;\; V = \frac{b(L_C - z_1)^3 tan\varphi}{6\cdot l}\,;\; tan\alpha = \frac{b}{2\cdot l}\,;\; \Omega = \frac{2(L_C - z_1)^2}{sin2\varphi\cdot cos\alpha} + \left(\frac{L_C - z_1}{sin\varphi}\right)^2 tan\alpha\,.$$

<u>In position 2</u>

$$dV = b_z(z - z_1)tan\varphi\cdot dz\,;\; V = \frac{b}{2}\left[(L_C - l - z_1)^2 tan\varphi + \frac{l(y_1 - y_w)}{cos\varphi} - \frac{2\cdot l\cdot tan\varphi}{3}\right];$$

$$\Omega = \frac{b\cdot l}{2} + (L_C - l - z_1)^2 tan\varphi + \frac{l}{cos\alpha}\left[\frac{2(y_1 - y_w)}{cos\varphi} - l\cdot tan\varphi\right].$$

<u>In position 3</u>

$$dV = b_z\left[(L + l - L_C + z)tan\varphi + y_1\right]\cdot dz\,;\; V = \frac{b}{2}\left[(L_C - l)^2 tan\varphi + \frac{l(y_1 - y_w)}{cos\varphi} - \frac{2\cdot l\cdot tan\varphi}{3}\right];$$

$$\Omega = \frac{b\cdot l}{2} + \frac{2L(y_3 - y_w)}{cos\varphi} + L^2 tan\varphi + \frac{l}{cos\alpha}\left[\frac{2(y_1 - y_w)}{cos\varphi} - l\cdot tan\varphi\right].$$

<u>In position 4</u>

$$\text{if } z \le L_C - l \text{ then } dV = b_z\left[(L + l - L_C + z)tan\varphi + y_1\right]\cdot dz\,;$$

$$\text{if } z > L_C - l \text{ then } dV \approx b_z\cdot h\cdot dz\,;$$

$$V = \frac{b}{2}\left[L\cdot\left(\frac{y_3 - y_w}{cos\varphi} + h\right) + l\cdot h\right];\quad \Omega = \frac{b\cdot l}{2} + L\left(\frac{y_3 - y_w}{cos\varphi} + \frac{l\cdot tan\varphi}{2}\right) + \frac{2\cdot l\cdot h}{cos\alpha}\,.$$

In position 5

$$\text{if } z \le L_C - l \text{ then } dV = b_z\left[\left(L + l - L_C + z\right)tan\,\varphi + y_1\right]\cdot dz\,;$$

$$\text{if } z > L_C - l \text{ then } dV \approx b_z \cdot h \cdot dz\,;$$

$$V = \frac{b}{2}\left[h\left(2L + l\right) - \left(h - \frac{y_3 - y_w}{cos\,\varphi}\right)\cdot\left(\frac{h}{tan\,\varphi} - \frac{y_3 - y_w}{sin\,\varphi}\right)\right];$$

$$\Omega = b\cdot l + 2\cdot h\cdot L - \left(h - \frac{y_3 - y_w}{cos\,\varphi}\right)\cdot\left(\frac{h}{tan\,\varphi} - \frac{y_3 - y_w}{sin\,\varphi}\right) + \frac{2\cdot l\cdot h}{cos\,\alpha}.$$

In position 6

$$dV = b_z \cdot h \cdot dz\,;\quad V = b\ \cdot h\cdot\left(\frac{l}{2} + L\right)dz\,;\quad \Omega = b\cdot l + 2\cdot h\cdot L + \frac{2\cdot l\cdot h}{cos\,\alpha}.$$

In position 7

$$dV = \min\,;\begin{bmatrix} b_z\cdot\left(z - z_1\right)\cdot tan\,\varphi\cdot dz; \\ b_z\cdot h\cdot dz; \end{bmatrix}\quad V \approx h\cdot b\cdot\left(\frac{y_1 - y_w}{sin\,\varphi} - \frac{3\cdot l}{4}\right);$$

$$\Omega \approx \frac{2\cdot l\cdot h}{cos\,\alpha} + 2\cdot b\cdot\left(\frac{y_1 - y_w}{sin\,\varphi} - \frac{3\cdot l}{4}\right) + \left(\frac{y_6 - y_w}{sin\,\varphi}\right)^2\cdot tan\,\alpha\,.$$

In position 8

$$dV = \min\,;\begin{bmatrix} b_z\cdot\left(z - z_1\right)\cdot tan\,\varphi\cdot dz; \\ b_z\cdot h\cdot dz; \end{bmatrix}\quad V \approx \frac{h\cdot b}{2}\cdot\left(l + \frac{y_1 + y_6 - 2y_w}{sin\,\varphi}\right);$$

$$\Omega \approx \frac{2\cdot l\cdot h}{cos\,\alpha} + l\cdot b + b\cdot\left(\frac{y_1 + y_6 - 2y_w}{sin\,\varphi} - 2\cdot l\right) + h\cdot\left(\frac{y_1 + y_6 - 2y_w}{sin\,\varphi} - l\right).$$

3. Calculation of Accelerations

Differential equations describe the motion of a boat during immersion:

$$m\cdot a_{Cx} = R_t\cdot sin\,\varphi - R_l\cdot cos\,\varphi\,;\quad m\cdot a_{Cy} = G - F_A - R_t\cdot cos\,\varphi - R_l\cdot sin\,\varphi\,;\quad J_C\cdot\varepsilon = -M_C\left(F_A\right) - M_C\left(R_t\right),$$

here m is the mass of the boat; J_C – moment of inertia of the boat mass against the center of gravity C; a_{Cx}, a_{Cy} – acceleration projections of the center of mass; ε – angular acceleration of the boat.

Numerical integration of the differential equations of motion is not complicated. The full accelerations of the center of mass of the boat C and points A and B can be found by the formulas:

$$a_{Ax} = a_{Cx} + \varepsilon\cdot l_A\cdot sin\,\varphi + \omega^2\cdot l_A\cdot cos\,\varphi\,;\quad a_{Ay} = a_{Cy} - \varepsilon\cdot l_A\cdot cos\,\varphi + \omega^2\cdot l_A\cdot sin\,\varphi\,;$$

$$a_{Bx} = a_{Cx} - \varepsilon\cdot l_B\cdot sin\,\varphi - \omega^2\cdot l_B\cdot cos\,\varphi\,;\quad a_{By} = a_{Cy} + \varepsilon\cdot l_B\cdot cos\,\varphi - \omega^2\cdot l_B\cdot sin\,\varphi\,;$$

$$a_C = \sqrt{a_{Cx}^2 + a_{Cy}^2}\,;\quad a_A = \sqrt{a_{Ax}^2 + a_{Ay}^2}\,;\quad a_B = \sqrt{a_{Bx}^2 + a_{By}^2}\,.$$

4. Example of Calculations

As an example, calculations have been made for the free-falling lifeboat LBF490C at different starting conditions.

The main dimensions of the boat: L = 3.40 m, l = 1.50 m, b = 2.40 m, h = 3.10 m, L_C = 3 m, l_A = 1 m, l_B = 2 m. Boat with crew mass: 4200 kg. The total center of gravity is located at a height of 0.2 m above the bottom of the boat, moment of inertia against the axis through the center of mass J_C = 8400 kgm^2, C_F = 0.01.

In Fig. 6, the values of accelerations depending on the angle of inclination of the boat φ_0 at the moment of contact with water at two different speeds in the vertical direction and v_{x0} = 5 m/s, ω_0 = 0 are shown in the form of graphs. Fig. 6 show the graphs of the acceleration of the boat points A, B and C at v_{y0} = 15 m/s, ω_0 = 0 and φ_0 = 0.4 rad.

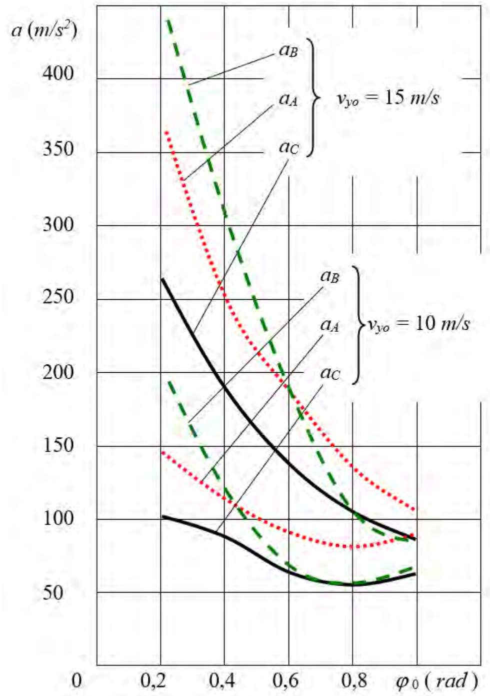

Fig. 6 Acceleration schedules

Table 1 summarizes the results of some calculations with time step Δt = 0.01 s at different initial conditions. All calculations are made at v_{x0} = 5 m / s. Fig. 7 shows accelerations as a function of time.

Table 1

Maximum accelerations of points A, B and C

v_{y0} m/s	ω_0 s^{-1}	φ_0 rad	maxa_A m/s^2	maxa_B m/s^2	maxa_C m/s^2
5	0	0,6	49	36	37
		0,8	51	42	37
		1,0	83	48	45
5	0,2	0,6	43	37	36
		0,8	46	43	40
		1,0	51	47	40
10	0	0,2	139	194	103
		0,4	110	119	85
		0,6	90	71	72
		0,8	79	60	60
		1,0	91	72	73
15	0	0,2	369	441	263
		0,4	246	300	184
		0,6	187	185	142
		0,8	137	104	107
		1,0	106	83	88

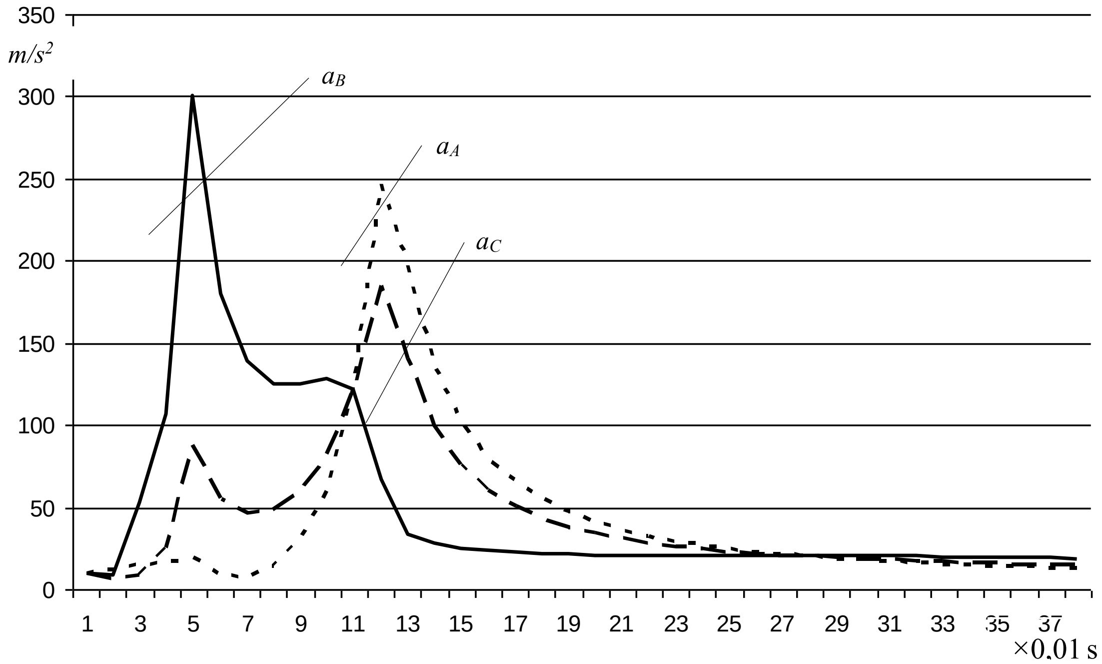

Fig. 7 Acceleration as a function of time

5. Conclusions

The calculation results for the boat LBF490C at different starting conditions allow to draw the following conclusions:

- the angular speed of the boat at the time of contact with water has practically no effect on the load on passengers;
- the acceleration of the boat's center of gravity does not fully characterize the load on passengers;
- As the angle of inclination of the boat decreases at the time of contact with the water, the load on the passengers increases. However, at too great an angle, the boat will "roll over" with the bottom up, and taking a normal position may also take longer;
- at an unfavorable heeling angle, the load on the passengers, especially at the ends of the boat, can reach a lethal level; therefore it is recommended to use this type of boat only in stationary structures;
- On floating vessels, the boat should start to move along the guides when the longitudinal oscillation or roll of the vessel increases the angle of inclination of the guides.

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On the Development of Electric Vehicles for the Tourism Industry

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Abstract

The article discusses issues related to the use of electric drive on cars with a buggy body, the development of a working prototype within the framework of student research and development work. The prototype has passed sea trials and is being finalized. The layout schemes and types of electric motors for this type of car are considered. At this stage of work, an electric motor and traction batteries have been selected by calculation and experimentally. The main objectives of the work carried out: to investigate the possibility of creating a special tactical vehicle with an electric drive of the driving axle, to establish an optimal law for controlling power flows in a wheel drive, to investigate transients in individual drive that occur when the type of drive and the quality of the bearing surface under the driving wheels change in rectilinear and curved motion.
KEY WORDS: *bugs, electric motor, power, battery, charge*

1. Introduction

In recent years, the domestic automotive industry has shown increasing interest in cars with hybrid or electric powerplant. One of the most prominent representatives of hybrid cars of domestic development can be noted the family of concept cars of the brand "E", which are a sequential hybrid car with an electric transmission with combined power from a generator, a rotating gas-gasoline engine and a capacitive energy storage [1]. Work on the creation of hybrid cars is also underway in universities. At the Faculty of Engineering of the Toraigyrov University, within the framework of experimental design development, work is being carried out jointly with students on the topic "Development of an electric car with a buggy body for the tourism industry of the Pavlodar region».

The use of an electric drive makes it easy to implement the modular design principle, optimally distribute the weight of the machine over the driving wheels and use the same power transmission units for various modifications within the same, but extensive family. With all of the above advantages, the electric drive also has an important advantage over all mechanical transmissions, namely the relative simplicity of providing an individual drive for each drive axle or even wheel through the use of electric motors by the number of axles or driving wheels. This makes it possible to increase the mobility, cross-country ability and efficiency of vehicles, due to individual regulation of the power supplied to the driving wheels, depending on the requirements of road conditions. However, the absence to date of a unified approach in the selection of criteria and laws for regulating the distribution of power on a wheel drive with a manual transmission is fully visible in the case of the use of an electric drive. The incompleteness of scientific justifications leads to suboptimal power distribution and, as a consequence, to incomplete realization of the potential properties of wheeled vehicles, which in turn can lead to fractures and other breakdowns of the running gears of machines and not only [2].

2. Main Part

We have developed a prototype of a car with a buggy-type body with an electric drive on the rear axle. From a standard car, the complex uses: a running system (wheel drive, suspension); a braking system and a steering system.

Having considered the analogues of electric vehicles of this class, the most optimal layout was chosen. Options are considered: with one and several electric motors located near the wheels.

Layout with two or four electric motors. With proper calculation and proper selection of components, the car has good dynamic characteristics, excellent handling, The disadvantages of such an arrangement is the high complexity of manufacturing hub elements, also, in order to realize all the possibilities of such an arrangement, it is necessary to develop and implement a complex electric motor control system, the cost of manufacturing such an electric vehicle will be high.

Layout with one electric motor: simple design, simple control algorithm. The peculiarity of this layout is that it will require the use of a differential to distribute power between the driving wheels, this leads to an increase in the mass of the transmission elements, possible wheel slippage during cornering - which will not allow the full potential of the electric vehicle to be realized. We used a differential from a German-made production car.

Significant factors influencing the choice of traction motors for electric vehicles are [3]:

– weight of the electric motor;
– high efficiency;
– compliance of the mechanical characteristic, i.e. the dependence of the torque on the speed of rotation, with the conditions of electric traction (decrease in torque as the speed increases);
– minimal maintenance in operation;
– high overload capacity of the electric motor to obtain high starting accelerations;
– cost.

The following types of electric drives have received practical application in electric vehicles: valve electric motors, asynchronous frequency-controlled, DC electric motors with independent excitation and DC electric motors with sequential excitation [4, 5].

Taking into account the specifics of the electric vehicle, we will choose suitable, electric motors for comparison. The considered variants of electric motors and their characteristics are summarized in Table.

Table

Comparative characteristics of electric motors

Title	Electric motor Agni 95 RDCMotor	Electric motor HPM-10KW-Fan- Cooling	Electric motor Perm-Motor PMG-132
Maximum power, kW.	16	20	14,5
Maximum torque, N/m	53	60	38,5
Rotation speed, rpm	4000	6000	3480
Supply voltage, V.	12-72	48-120	12-72
Efficiency, %	92%	91%	90%
Weight, kg	11	17	11

The Perm-MotorPMG-132 electric motor is supplied by the manufacturer in large batches to order. The engine has a good power/weight ratio, has a high overload capacity, and a low cost, however, it is not found on sale piece by piece.

HPM-10KW - brushless DC electric motor (BLDC) 10KW (Fig. 1) with water cooling is used on electric cars, electric motorcycles, electric boats, etc. It has high characteristics, but has a significantly larger mass than other options.

The ADC 203-06-4001A electric motor is used on electric loaders, as well as in other technology. It is also used on the railroad on hump yards [6-8]. It has good performance characteristics, but it has a very large mass, so it does not suit us.

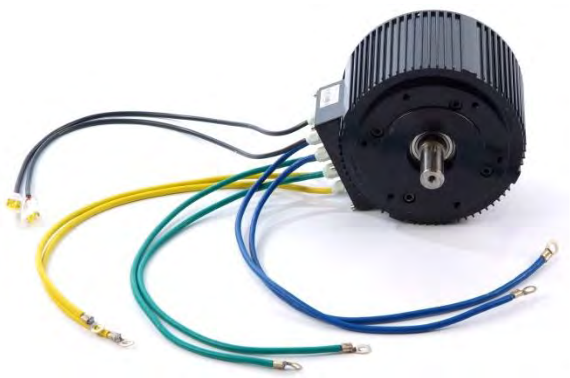

Fig. 1 HPM-10KW Electric Motor

At the stadium of Toraighyrov University, the prototype was tested in the form of time-laps.

To determine the amount of energy needed to pass endurance races, we use the data of the instruments when passing one lap of the endurance race.

According to the simulation results, the lap time is 67.8 seconds, the energy consumption was 0.306 kW/h. The length of the circle is 400 meters, the entire distance will require 0.306 · 100 = 30.6 kW/h. If you reduce the maximum torque by 20%, then the lap time will be 70.1 seconds, the energy consumption will be 0.265 kW/h per lap, 26.5 kW/h will be required for 100 laps. The prototype uses an HPM-10KW electric motor, the weight of the car is 280 kg. The required amount of energy to complete the endurance race is 26.5 kW / h, however, we will not allow the batteries to be completely discharged, as this can lead to a rapid battery failure. Let's take the minimum charge level to which the battery will be discharged equal to 20%. To do this, we will increase the battery power reserve by 20%, respectively, and it will amount to 6.4 kW/h (Fig. 2).

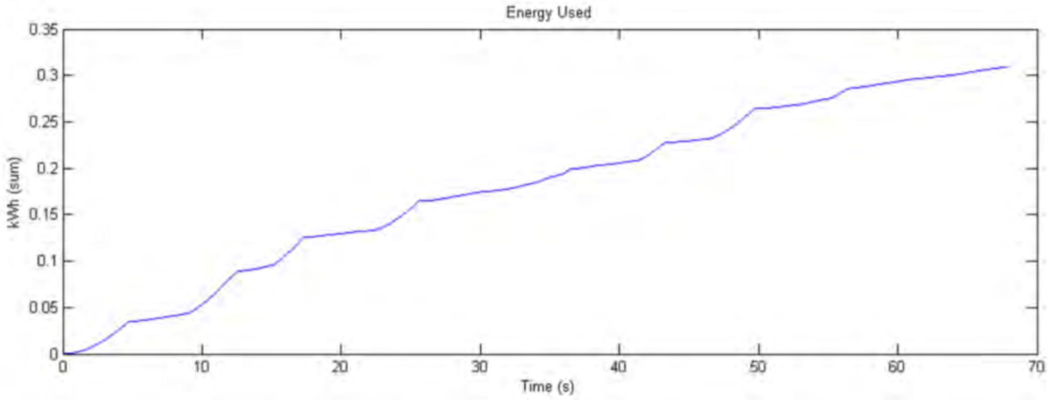

Fig. 2 Simulation of energy consumption per lap of an endurance race

Traction and Dynamic Calculation of an Electric Vehicle

Determination of the traction and speed properties of the car is necessary when designing new models, as well as when choosing types of cars in accordance with different operating conditions [9]. This problem is solved by the methods of the theory of the automobile - the science of operational properties, which characterize the possibility of effective use of the car in certain conditions and allow us to assess to what extent its design meets these conditions.

When starting the calculation, you should first study the relevant sections of the theory of the car, master the methods of analyzing such characteristics of the car as power and power balances, dynamic characteristics, etc.

Initial Data

Car type - rear-wheel drive passenger car of the Buggy class

Wheel formula - 4x2

Number of people - $n = 1$ (people)

Length = 2420 mm.

Width = 1500 mm.

Height = 1200 mm.

Curb weight $m_0 = 260$ kg.

Tire dimension : 175/65R 13

Air resistance coefficient $C_x = 0.3$

Rolling resistance coefficient $f_0 = 0.013$ Coefficient depending on the slope of the road $\alpha_{max} = 0.25$

Maximum speed - $V_{max} = 40$ km/h

The maximum speed of the motor shaft $\omega_e^{max} = 418$ s^{-1} (4000 rpm)

Transmission efficiency $\eta_{tr} = 0.85$

Determination of the Power and Torque of the Electric Motor

Determination of the total mass of the car:

$$M_a = M_0 + \left(M_{man} \cdot n\right) + M_b ; \qquad (1)$$

$$M_a = 260 + \left(75 \cdot 1\right) + 10 = 345 \text{ kg},$$

where M_0 – curb weight of the vehicle; M_{man} – weight of a person (75 kg.); M_b – weight of cargo per person; n – number of people in an electric car.

Determination of the static radius of the wheel:

$$r_{st} = 0.5 \cdot d + \lambda \cdot H , \qquad (2)$$

where $d = 13$ – is the landing diameter, inches ($d = 0.256$ m); $\lambda = 0.92$ – is the coefficient of vertical deformation of tires, depending on the specifics of the tires used $H/B = 65$ – is the height of the tire profile relative to its width, %; $B = 65 \cdot 0.175 = 0.114$ – is the height of the tire profile, m.

$$r_{st} = 0.5 \cdot 0.256 + 0.8 \cdot 0.114 = 0.256 \text{ m}$$

Determination of the coefficient of streamlining:

$$k = \frac{C_x \cdot \rho}{2} ; \qquad (3)$$

$$k = \frac{0.3 \cdot 1.293}{2} = 0.19,$$

where C_x – is the air resistance coefficient; ρ = 1.293 – air density under standard conditions.

Calculation of the frontal area of the car:

$$F = 0.8 \cdot B_r \cdot H_r; \tag{4}$$

$$F = 0.8 \cdot 1.25 = 1 \text{ m}^2$$

Calculation of rolling resistance coefficient:

$$f = f_0 \cdot \left(1 + \frac{V^2}{2000}\right); \tag{5}$$

$$f = 0.013 \cdot \left(1 + \frac{25^2}{2000}\right) = 0.017$$

First, the power of the electric motor is determined at the highest speed of the electric vehicle, taking into account the efficiency of the transmission according to the power balance formula:

$$N_V = \frac{1}{\eta_{tr}} \left(G_a \cdot \psi V \cdot V_{max} + \frac{C_x}{2} \cdot \rho \cdot F \cdot V_{max}^3 \right), \tag{6}$$

where ψV – is the coefficient of road resistance at the maximum speed of the car.

For light cars, the road resistance coefficient is assumed to be equal to the rolling coefficient at maximum speed.

$$\psi V = f = 0.017.$$

Where $G_a = mg$ – is the total weight of the car; ρ = 1,293 – is the air density under normal conditions.

$$N_V = \frac{1}{0.85}\left(345 \cdot 9.81 \cdot 0.017 \cdot 25 + 0.15 \cdot 1.293 \cdot 25^3\right).$$

According to the calculations obtained, an electric motor can be selected. We have selected an electric motor HPM-10KW (Fig. 1) with liquid cooling. The motor is controlled by a VEC500 sine controller for a 10 kW BLDC motor. This model is designed to control the operation of a BLDC motor, or a 10 kW brushless electric motor. It is equipped with reliable protection against moisture, overload and overheating. It is installed on almost any type of electric transport: bicycles, motorcycles, cars, boats, golf carts and even tricycles. VEC500 vector controller allows you to monitor and adjust all parameters of the electric motor:

– selection and switching of the operating mode;
– receiving and processing data from sensors and sensors;
– output of all necessary data to the display;
– assessment of the battery charge level.

The characteristics of this electric motor are shown in Table 1.

We use AGM batteries as power sources. AGM batteries cope better with increased loads. The main problem when using conventional batteries is a reduction in their service life due to high electrical loads, because in modern machines there are much more consumers of electric energy than before (on–board computer, preheater, etc.), because of this additional requirements are imposed on the battery. In addition, AGMs can be discharged without damage, up to 40% and up to 30% – without a serious reduction in service life. For comparison: batteries of traditional design will be seriously damaged with multiple discharges below 50% – their capacity will drop to 15...20% of the original value. Since the plates and gaskets in AGM batteries are much more tightly pressed against each other, and the housings are sealed, these batteries are more resistant to vibration and shock loads, from which the batteries of trunk trucks and road construction vehicles suffer on domestic roads and off-road. Thanks to all the qualities listed above, the service life of AGM batteries is much longer than conventional batteries [10, 11].

AGM batteries are less sensitive to temperature fluctuations and are able to operate at lower temperatures – from -40 to +70°C, since they do not contain free water that could freeze and expand, respectively, their service life at low temperatures is much longer than conventional batteries.

AGM batteries are completely maintenance-free, the battery case is completely sealed, and opening cans, checking or refilling distilled water, and especially the electrolyte is not required during the entire service life. They pay off faster, despite the high cost. Due to the extended service life, the cost of using AGM batteries will be less than traditional ones.

Fig. 3. Prototype of an electric buggy

3. Conclusions

The developed prototype (Fig. 3) is currently already being used as a research tool. The main objectives of the work carried out: to investigate the possibility of creating a special tactical vehicle with an electric drive of the driving axle, to study the joint operation of several electric motors as part of a wheel mover, to establish an optimal law for controlling power flows in a wheel mover, to investigate transients in individual drive that occur when changing the type of drive and the quality of the bearing surface under the driving wheels with rectilinear and curved movement. The solution of the tasks set will make it possible to clarify the structure and formulate technical requirements for the development of new models of electric vehicles to ensure maximum operational properties, mobility and efficiency.

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Assessment of the Use of Alternative Energy Sources with Emphasis on Electromobility in the Slovak Republic

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Abstract

As the prices of basic fuels and limited resources increase, the importance of alternative fuels is constantly growing. Alternative fuels most often include biofuels, electricity, hydrogen, LPG and natural gas. For individual countries, this offers potential and attractive prospects for the future, as well as a reduction in dependence on limited resources. One of the main benefits of using alternative fuels is their lower negative impact on the environment. They have a lower carbon footprint than basic fuels. However, the realization of their potential is hampered by lower consumer demand, which is mainly due to higher prices for cars and a lack of charging and filling stations. These shortcomings discourage consumers from using these fuel sources. The European Union has been working to improve this problem for a long time, with an emphasis on building the necessary charging and pumping infrastructure in its Member States. In this article, we focus on the analysis of the current state of this infrastructure in the individual states of the European Union. With the help of comparison, the charging and pumping infrastructure in individual states with an emphasis on alternative fuels is examined. In order to obtain correct conclusions, we also analysed the Gross domestic product per capita in Purchasing Power Standards in individual countries. Using the scientific method of comparison, we will show whether the economic situation in a given state has an impact on building the necessary infrastructure with regard to alternative fuels in the country. Comparison of Slovakia within the member states will make it possible to point out the suitability of using these alternative sources.
KEY WORDS: a*lternative fuels, electromobility, European Union, GDP, environment*

1. Introduction

Currently, there is a growing number of cars in road transport. The development of vehicles and motor propulsion is also determined according to ecological aspects. This shown by the stricter standards for exhaust gases. With the declining number of fossil fuels, more focus needed on the use of alternative fuels in transport. There are several requirements for motor fuels. These include, for example, guaranteed security of supply, overall economic viability, including environmental and situation protection requirements. Another important benefit to take advantage of the use of alternative fuels depends on some countries. Current events in the light point to the importance of looking for ways to use different sources of fuel and thus not depend on the conditions of a state. Also with the development of alternative fuels, it is necessary to provide for other things around it. People need to be interested in buying cars on alternative drives. The interest in such countries is trying to achieve various subsidies or cars through taxes. For the user, however, the only criterion for buying a car with alternative fuel is not its price. Additional infrastructure or refuelling stations are available among the criteria that include the purchase of this car. Therefore, their availability in the given states is important. It is also important that charging infrastructure or refuelling stations are available in other countries. That is why the European Union is trying to support cars with alternative propulsion, but also to build the necessary infrastructure and construction throughout the territory. Such construction requires a certain amount of money.

2. The Economic Situation in the State and Its Impact on the Construction of Transport Infrastructure

Gross Domestic Product GDP is a macroeconomic indicator by which we measure the economic performance of the national economy. Gross domestic product represents the market output of all goods and services produced in one year by the factors of production in the territory of a given country [1]. When focusing on GDP in countries, it is important to focus on their economic cycles as well. The economic cycle is the alternation of upward and downward phases of economic development around a long-term development trend. In the economic literature, it also referred to as the economic or industrial cycle. The economic cycle is the fluctuation of overall economic performance over time. Economic cycles and their rotation are very irregular and have different depths, lengths and intensities. ”In the economic cycle, there are phases of recession, bottom, expansion and peak. The recession comes when a decline in gross domestic product recorded for two consecutive quarters. This situation will continue until gross domestic product reaches its minimum, and then we are at a stage where a recession must distinguished from a depression, where a recession indicates a slight reduction in the performance of the economy, which does not last long. On the contrary, we denote a significant decline in depression, which can be more than 15 %, when serious problems in the economy can see and the duration is much longer than in a recession. The bottom is the stage between recession and expansion, marking the lowest level of gross domestic product in the economic cycle, when the economy gathers its strengths in the future in order to start growing. We can say that this is a phase of cleaning up the surplus of employees or goods. In expansion, there is a resumption of growth, ie recovery, of gross domestic product, production increases average values, unemployment decreases, it depends, but on the situation in the economy. The peak is the phase called the upper turning point, at this stage the maximum values occur. Subsequently, the economy goes back to recession [2].

At a time when a country's economy is doing well, funding should be set aside for various projects that would improve the quality of life in that country in the future. These investments should include the construction or subsidization of charging infrastructure or service stations with regard to alternative fuels. States should also strive to be more energy independent and invest in development and new technologies [3, 4]. Also, the subsidies that companies could receive would also allow companies to better invest in the development of transport infrastructure. This would also reduce the risk that large investments would jeopardize the company's operations [5]. The ability to charge an electric car or refuel with alternative fuel should be part of the smart city concept. This would make it possible to improve the quality of life in municipalities while reducing the carbon footprint [6].

“The Green Deal adopted by the new European Commission sets a clear objective: by 2050, transport emissions will have to be reduced by 90 percent, compared to 1990 levels. Alternative fuels, including the infrastructure to recharge and refuel them, are developing in Europe at an accelerating pace. Private vehicle users, market actors and policy makers all alike depend on comprehensive, reliable, targeted and timely data and information on alternative fuels vehicles and infrastructure developments in the EU. Information of this kind is underpinning important decision-making, be it concerning the purchase of such a vehicle, the investment into infrastructure projects or the set-up of public support or market regulation. In view of the functioning of the internal market for transport, it is also indispensable that this information is provided for the EU as a whole in a coherent and reliable manner. The Commission has therefore installed the European Alternative Fuels Observatory – EAFO. Having started in 2015, it has developed over the years into a key reference point for information about alternative fuels in Europe, where all interested parties find data on vehicles and infrastructure, and information on public incentives and legislation. EAFO is a key information support tool for the European Commission in the implementation process of Directive 2014/94/EU. Under the reporting obligations of the Directive, the Commission is tasked with assessing the overall relevance and effectiveness of National Policy Frameworks and their coherence at Union level. The assessment of the deployment of infrastructure along the TEN-T network is of particular relevance. In particular, the Directive requires Member States to adopt National Policy Frameworks (NPFs). The Commission is using data and information from EAFO to underpin its assessment of the overall NPFs and their impact in Member States. Moreover, the Directive contains a number of deployment targets for those fuels with distinct infrastructure requirements than conventional fuels, or for which the network was considered insufficient to support their take-up back in 2014, when the Directive was adopted.

- For electricity, the Directive foresees that an appropriate number of publicly accessible points are established in urban and sub-urban areas and other densely populated areas by end 2020 and that electricity recharging at shore-side is established at all ports of the TEN-T core networks and other ports by end 2025.
- For CNG (Compressed Natural Gas), it foresees that an appropriate number of points are established in urban and sub-urban areas and other densely populated areas by end 2020 and along the TEN-T core network by end 2025.
- For LNG (Liquified Natural Gas), it foresees that points are established at all maritime ports of the TEN-T core network by end 2025, at all inland ports of the TEN-T core network by end 2030 and that an appropriate number of points are established along the TEN-T core network for heavy-duty vehicles by end 2025.
- For hydrogen, it foresees that, in the Member States who choose to develop this fuel, an appropriate number of publically refuelling points are established by end 2025” [7].

3. Results and Discussion

In order to find out the current state of charging stations and filling stations with regard to alternative fuels, it was necessary to carry out an analysis of the individual member states of the European Union. Table 1 shows the input data that will be used further. The column showing People per alternative fuels recharging and refuelling points is important. The lower the number of people in it, the better the infrastructure of charging stations and filling stations with regard to alternative fuels.

We also took important data in a clear Fig. 1. In this figure, the member states of the European Union ranked according to GDP per capita in PPS. It is also to the individual curve shown, which represents the people behind the places of recharging and refueling of alternative fuels. for the most part, countries with higher per capita GDP in PPS had more accessible places for recharging and refueling alternative fuels for the population. The graph also shows two extremes, namely Cyprus and Romania.

Table 1

Member States of the European Union with infrastructure for charging stations and filling stations for alternative fuels [8-10]

State	GDP per capita in PPS	The total number of normal and high-power public recharging points	Total number of LPG refuelling points	The total number of CNG/LNG refuelling stations	Total number of hydrogen refuelling points	The total number of alternative fuels recharging and refuelling points	People per alternative fuels recharging and refuelling points
Luxembourg	277	1247	12	2	0	1261	496
Ireland	221	1372	50	3	0	1425	3465
Denmark	133	4172	6	17	10	4205	1377
Netherlands	132	82615	1180	218	7	84020	204
Sweden	123	14173	52	229	5	14459	698
Belgium	122	12816	351	196	3	13366	867
Austria	121	9353	40	144	5	9542	944
Germany	119	50083	6487	886	89	57545	146
Finland	113	4371	0	70	0	4441	1248
France	102	32287	1975	206	19	34487	1893
Malta	98	96	11	0	0	107	4127
Italy	95	22471	5043	1571	3	29088	2079
Czechia	92	1424	945	227	1	2597	4124
Slovenia	90	1167	144	6	0	1317	1579
Lithuania	88	176	527	6	0	709	3840
Cyprus	88	69	8	0	0	77	15680
Estonia	87	408	94	23	0	525	2527
Spain	84	8250	837	185	5	9277	5040
Poland	77	3674	7409	33	0	11116	3405
Hungary	76	2264	516	22	0	2802	3448
Portugal	74	3443	434	24	0	3901	2614
Romania	73	747	1100	3	0	1850	10399
Latvia	71	294	267	5	0	566	3333
Croatia	70	918	532	5	0	1455	2821
Slovakia	68	1272	377	18	0	1667	3275
Greece	65	498	1195	24	0	1717	6071
Bulgaria	55	382	1890	121	0	2393	2904

In order to find out whether there is a dependence between GDP per capita in PPS and people per alternative fuels recharging and refuelling points, we used a correlation function that examines the dependence. The correlation coefficient can take values from the interval <-1, 1> „if the correlation coefficient is equal to 0, it means that there is no relationship between the investigated quantities. If it is equal to one, then the quantities are directly dependent on each other, an increase of one quantity causes an increase of the other, if it is equal to −1, an increase of one quantity causes a decrease of the other quantity. Fig. 2 shows the comparison. There is also a trend line in the graph that shows the dependency. There is also an equation and a reliability equation.

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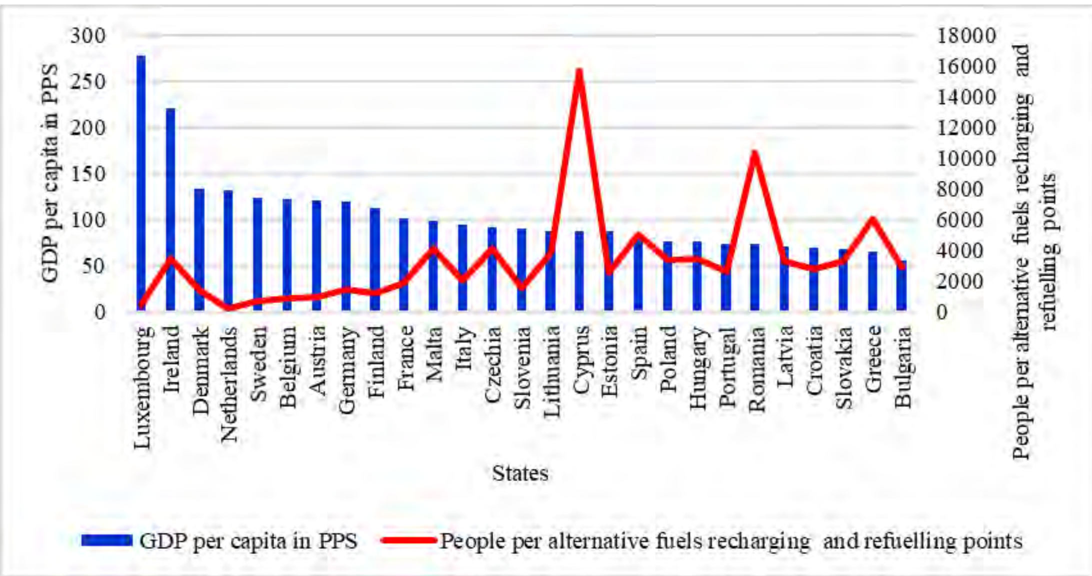

Fig. 1 GDP per capita in PPS and people per alternative fuels recharging and refuelling points in members states European Union [8-10]

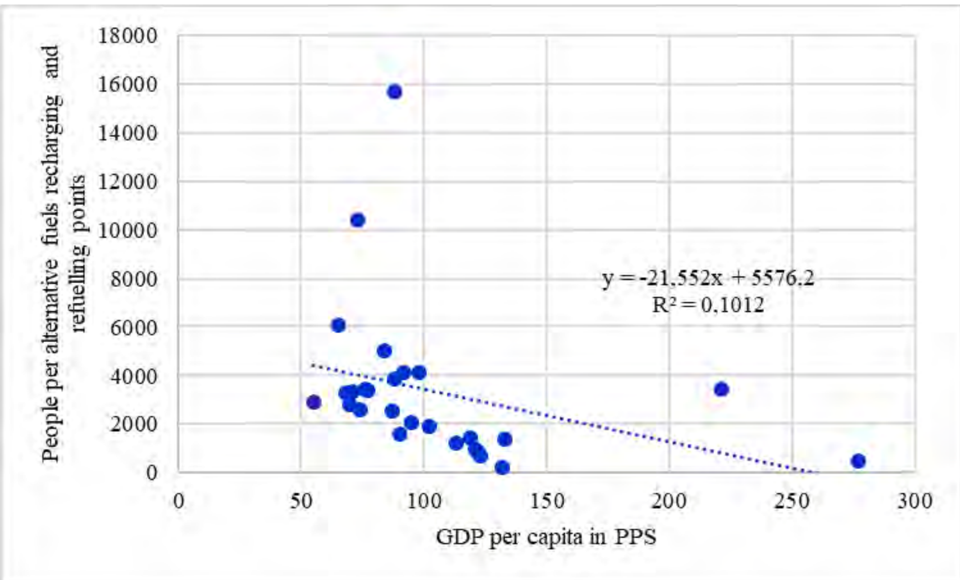

Fig. 2 Addiction between GDP per capita in PPS and people per alternative fuels recharging and refuelling points [8-10]

Subsequently, we used the function to correlate the calculated value of the coefficient. We needed this to find out the strength of the addiction.

$$\text{Correl (X,Y)} = -0{,}32 \qquad (1)$$

A weak dependence is found between the compared characters. Therefore, it can be argued that GDP for PPS is not the only criterion that has an impact on infrastructure construction with regard to alternative fuels.

4. Conclusions

Alternative fuels have an important role in road transport. Their introduction and use of products, but a number of individual states. Although the European Union is working to get all Member States to make greater use of alternative fuels, there is no freedom in all countries. The same is true when focusing on the infrastructure of charging and filling stations for alternative fuels. In this article, we examined whether there is a dependence between GDP per capita in PPS and people on places of recharging and pumping alternative fuels. There is a weak dependence between the examined elements. This means that there is more infrastructure involved in developing with respect to other fuels. The current situation, which is in a global environment, is putting pressure on faster adaptation of the possibilities of using alternative fuels. With this, the ability to charge or refuel with automotive alternative fuels should be directly improved. All states should strive to unify the availability of infrastructure for this charging. As a result, the purchase of cars with alternative drives is also evolving. If potential users were limited only to the territory of the state in which they live, they could base the purchase of a car on alternative propulsion.

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Selected Methods for Improving Public Transport

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Abstract

At present, the preference for the use of public transport with support systems is all the more current when there is an effort to suppress individual transport and an effort to improve the ecological situation in the world. The area of public transport is very large and includes a large number of essentials and functionalities that need to be considered comprehensively to create a quality and functioning public transport system. For certain parts of the solution, how to prioritize and improve the function of public transport, can be used some of the methods of linear programming, graph theory or systems analysis and decision-making. This paper presents the use of selected methods in the areas of parking, public transport preferences and integrated transport systems. Concurrently, emphasis will be placed on the coordination of individual types of these measures.
KEY WORDS: *integrated transport system, methods, parking, preferences, public transport, coordination*

1. Introduction

Public transport is an essential part of modern times and a number of measures are needed to increase its competitiveness. The above-mentioned increase in competitiveness and attractiveness is implemented through a number of measures of various natures, the key to which is the creation of integrated transport systems, the creation of preferential and support measures and the link between public transport and individual transport, specifically through modern parking systems. Within the preference for public transport, there are a number of methods of various forms by which this objective can be achieved.

2. Selected Methods

Within the framework of preferential measures, there are various methods by which their sufficient efficiency and effectiveness can be achieved. According to Gardner et al., [1] the basic types of preferential measures include physical measures, measures and intersections and integrated measures. Dedicated lanes are among the most frequently used physical or organizational measures. According to Viegas and Lu [2], these are installed where public transport vehicles are often delayed due to congestion. This measure thus increases the stability of the timetable. The disadvantage of this widely used and effective measure is the reduction of the capacity of the road or local road. This can be proved, for example, by Braess's paradox. This is a method that tells us that adding a new section to the network or increasing the throughput of an congested section can worsen the situation on the entire network as a whole. Of course, the opposite is also true, ie when capacity is reduced. In the case of the implementation of a reserved lane in a two-lane local road, it is estimated that the capacity of the local road will be reduced by 50%. This measure may worsen the traffic situation on the network as a whole, or transfer certain traffic flows to other alternative routes where congestion may occur due to their original capacity. This relationship can be expressed by the BPR function, which expresses the dependence of travel time and traffic flow intensity [3]. From this method it is possible to determine at what point in the percentage of the local road load the driving time starts to increase. Viegas and Lu [2] or Wu and Hounsell [4] deal with a compromise intermittent reserved lane, which does not reduce the capacity of a given local road to the extent that a public transport vehicle prefers to the same extent as a regular reserved lane. This raises the question of what is the percentage reduction in communication capacity in the implementation of the above solution. However, this significantly depends on the number of public transport vehicles per selected time unit (eg hour) in a given section. Zyryanov and Mironchuk [5], for example, found some results, which found the dependence of vehicle intensity on two-lane roads and the number of public transport vehicles per hour, namely the equality of 1,500 vehicles / h with a public transport interval of 3 minutes.

The just mentioned BPR function could be applied to the selected local road in the selected city. The authors selected a problematic section in Prague (Czech Republic), where there are frequent congestions and delays not only in public but also in individual transport. This is Strakonická Street in the section Mezichuchelská - Barrandovský Bridge.

This is a high-speed local road with public transport vehicles, currently facing a significant increase in traffic due to the extensive reconstruction of the Barrandov Bridge, which is one of the key arteries of the Czech capital. The daily intensity is 31,225 vehicles / day in the section and direction in question. Due to the fact that this is the main local road for commuting to the capital from the directions of Prague-Zbraslav, Prague-Radotín, Mníšek pod Brdy, Dobříš and Příbram, the highest traffic load in the morning rush hour can be expected in the period from 7 to 10 am. Intensity data are obtained when this section had 2 lanes. Assuming that drivers use both lanes proportionally, there is a daily intensity of 15,613 vehicles in one lane. In recent months, a dedicated lane for public transport vehicles has been implemented here, but it has been constructed separately by increasing the width of the local road. However, if the approach were the opposite, ie by reducing one common lane, the entire amount of intensity would be transferred to one lane, except for the number of public transport vehicles, of which there are 225 cars / day. This means that one lane would have a daily intensity of 31,000 cars / day. However, it is also necessary to realize that only a fraction of vehicles are in operation during the night, according to TSK Praha, a.s. [11] the share of night intensity is 10% of the total day intensity. We therefore start from the data that in the period from 6 am to 10 pm (16 consecutive hours) the intensity of individual car traffic is 27,900 vehicles, ie 13,950 vehicles in one lane.

The driving time α_A in the section in question is 4 minutes with a free traffic flow, taking into account the maximum permitted speed. The monitored section has a distance of 2,200 meters, the number of vehicles in the monitored section in free flow is 44 vehicles at one time, which generates about 10,560 vehicle passes in 16 hours. This value can be perceived as the capacity of a given section of road. The actual average daily intensity is 13,950 vehicles, the ratio of the intensity q_A to the capacity of the section c_A is thus 1.32. According to the relationship of the BPR function given in the source [3] below, the driving time at the worst moment of the traffic load of the section in question is 6.28 minutes. The coefficients β_A and γA take into account the load of the road and its type, in this case it is a high-speed local road.

$$t_A = \alpha_A \left(1 + \beta_A \left(\frac{q_A}{c_A} \right)^{\gamma A} \right). \tag{1}$$

If the capacity of a given section of the road were reduced by a dedicated lane for public transport, if we consider a constant value of the number of vehicles (if there is no alternative section), then the driving time at the worst moment of traffic load of the section according to the above relationship could be up to 41 minutes, which is basically equivalent to congestion with an almost motionless traffic flow (Fig. 1).

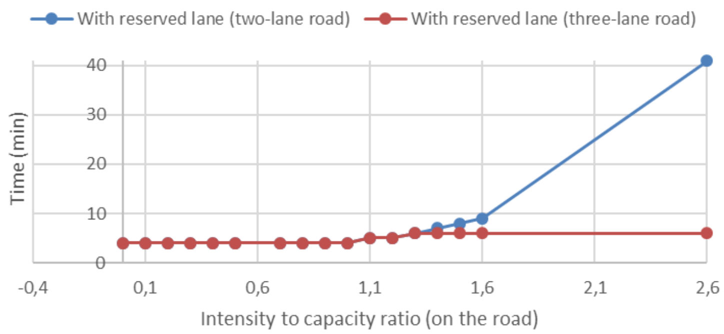

Fig. 1 The course of the BPR function for selected section in Strakonická Street (source: authors based on [3])

Such a significant increase in the driving time of passenger cars at the price of public transport vehicle preferences is unacceptable. In addition, it is clear that the given congestion of passenger cars in these basic cases would also affect the adjacent lanes and would also complicate the collision-free passage of a public transport vehicle when entering a reserved lane.

Some methods can also be encountered in public transport and integrated transport systems. An integral part of this area is the tariff and the offer of travel documents. The composition of travel documents can be presented using the so-called tariff chart. Borndörfer et al. [6-7] present the use of this tariff graph to illustrate the composition of travel documents on several examples of transport associations in Germany. In essence, these are graphs showing the possibilities of travel documents in a given system, from the basic options to the maximum price of an individual fare. The nodes of these graphs present specific travel documents of the system (eg ticket for a certain number of zones, short-distance ticket, public transport tariff of certain cities) and the edges between them contain transitions between individual tickets (eg limitation of the number of stops or zones). Such an overview can be used to assess the status of travel documents, eg whether the system is comprehensible to passengers or not, or whether the offer of travel documents is sufficient or unnecessarily complicated. It is also easy to show all possible adjustments in the composition of tickets. Optimizing the composition of travel documents can serve as one of the tools that can make public transport more attractive if the system is more comprehensible to passengers.

The use of the tariff graph can be illustrated by the example of the Czech Republic, specifically the possibilities of travel documents in Public Transport of Pardubice. The example shows all tickets and specific prices that are available on a working day as part of passenger check-in directly in vehicles using contactless payment by electronic wallet or credit card. The input data for the tariff chart are as follows (Table):

Table

Input data for the tariff chart of electronic passenger check-in in Pardubice public transport [8]

basic fare for zone I	15 CZK
basic fare for zone I and II	19 CZK
basic fare for max. 3 stop sections in zone I	8 CZK
basic fare for max. 3 stop sections in zone I and II	10 CZK
all-day fare (so far only paper ticket)	50 CZK
for one transfer within 45 minutes after the first check-in, a 50% discount on the fare for the subsequent journey is provided	

Based on the input data, the authors prepared a tariff chart of the possibilities of travel documents for electronic check-in on working days in Public Transport of Pardubice. This tariff chart is shown in Fig. 2.

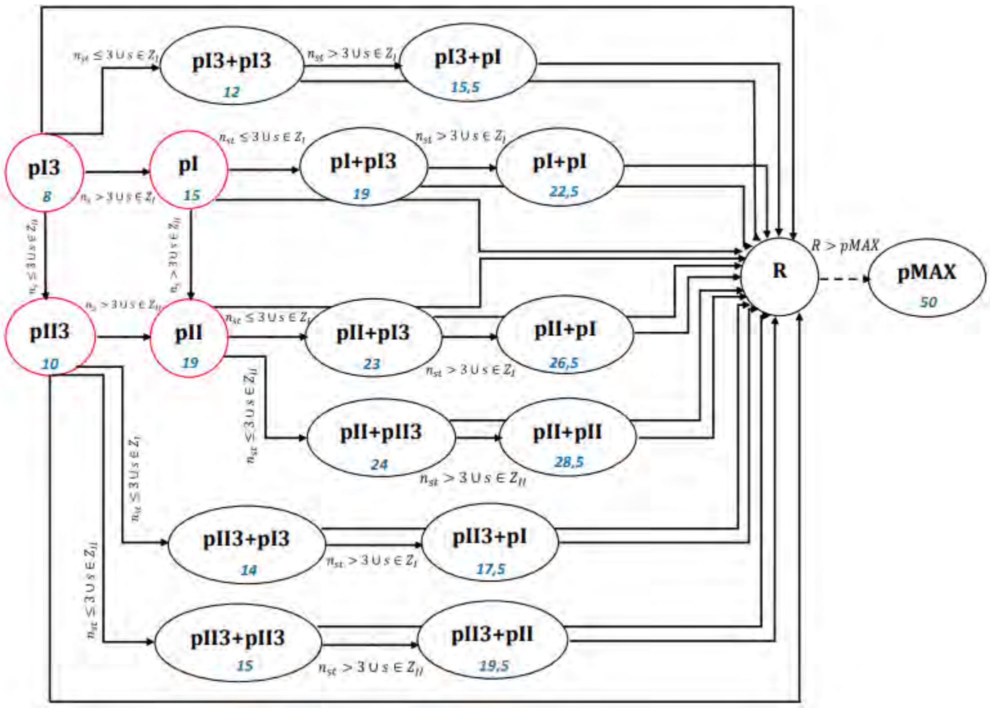

Fig. 2 Tariff chart of travel document options for electronic check-in on working days in Public Transport of Pardubice

Explanations to the tops of the tariff chart:

- *p* marking of a ticket for public transport Pardubice;
- I, II validity in zones (either only in zone I or in zones I and II);
- 3 ticket for max. 3 stop sections;
- \+ representation of the transfer;
- *R* all ther rides during the day;
- MAX maximum ticket price (all-day ticket).

Explanations to the edges of the tariff chart:

- n_s number of traveled sections;
- n_{st} number of stopped sections after the transfer;
- *s* stops belonging to zones;
- Z_{I} set of stops in zone I;
- Z_{II} set of stops in zones I and II;
- *R* total price of all rides per day;
- *p*MAX maximum ticket price.

From the tariff chart it is possible to determine the basic ticket options (highlighted in red), which consist of tickets for max. 3 stop sections in zone I (*p*I3) or in zones I and II (*p*II3) and tickets for more than 3 sections, again in these zone variants (*p*I, *p*II). The other peaks of the graph represent all fare options when changing. For example, the node *p*I + *p*I3 indicates the basic ticket for zone I and the subsequent transfer in zone I, but when driving to 3 stop sections. At the edges of this graph is the condition of transition from one node to another, respectively. from one ticket option to another. Peak R shows the possibilities of additional passenger rides during the day. The link between the R and pMAX peaks is not strong, as the all-day ticket is currently only in paper form and is not available at electronic check-in. In the future, it would be appropriate to introduce the condition that if the price of all journeys in one day exceeds the maximum price, ie the price of a full-day ticket, the passenger will be deducted the price for the all-day fare. The numbers for the individual nodes indicate the price in CZK according to the valid tariff in May 2022. From the overall view of the structure shown in the tariff chart, a seemingly simple structure of electronic check-in options can be seen in all contexts. It is obvious that in the current possibilities there is no roofing with the maximum price in the form of an all-day ticket even within this check-in.

Based on a search in the field of public transport, the authors found several methods that could be used to evaluate, compare or streamline the preference of public transport as a whole to individual transport. However, it should also be mentioned that, unfortunately, limited resources must always be worked on and, based on this basic limitation, it is not possible to allocate these resources within the whole transport network (country, region) and therefore in some parts to be able to compete with individual transport. For this reason, it is necessary to design points of contact between individual car transport and public transport. And to try to allocate resources between these points and the city centers in such a way as to force drivers to leave their cars here and continue by public transport. And just one of the best solutions to this problem seems to be parking lots. This system is able to accommodate a large number of passenger cars on the outskirts of large cities and then transport their passengers to the city center by public transport. It should be noted that the system is highly dependent on the frequency of connecting public transport and the tariff policy.

A 1998 study in Washington state in the USA [10] points to the dependence between the use of car parks and the frequency of public transport connections. It is clear from the picture that passengers are willing to use 80% of the intercepted car parks even with a period of 40 minutes for rail transport, but only 40% with a period of 30 minutes for bus transport (Fig. 3).

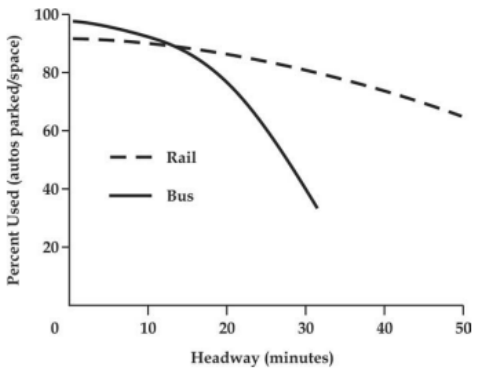

Fig. 3 Dependence of P + R utilization on the frequency of public transport connections [10]

As mentioned above, another significant effect is price. The above study found that only 35% of drivers are willing to pay more than \$ 2.00 for all-day parking (\$ 3.59 in 2022 prices). This study is supported by many other studies, such as a representative study by the Chinese study Shen et al. when the best type of connecting public transport appears to be the fast railway. The worst results are then achieved by bus stops.

However, for the highest possible diversion of people from individual car transport to public transport, a solution in car parks or within public transport is not enough. This must also be addressed in cooperation with the quiet transport tariff policy in urban centers. Here we offer to use the mathematical disciplines of game theory. Namely, then the use of Stackelberg's game. This is a game that, unlike other games, is sequential. Player A (urban transport authorities) determines the rules of the game and player B (passenger) responds to them. Moreover, it is not a zero-sum game because player A's intentions are not in analysis with player B and vice versa. However, player A follows the system optimum (quality of life in the city) and player B follows his subjective optimum (maximizing the benefits of the realized journey). The authors describe below the design of a mathematical model of the Stackelberg game for the solution of tariff policy in the city center, so that there is as much diversion as possible to the intercepting car parks, but at the same time there is no reduction in the attractiveness of the city center.

Objective function of the city transport authority:

$$\max_{V} Z_S = \sum_{i=1}^{N} R_i X_i \ , \tag{2}$$

where R_i – coefficient of willingness to choose strategy and urban transport authorities (it is a non-dimensional unit that shows the preference of the city's transport authority or its transport ideology); X_i – proportion of people who prefer strategy i (this is a percentage that shows what part of the population, within the urban transport authorities, is willing to choose a stratégy i); Z_s – objetive function showing the benefits of urban transport authority (in essence, it is a payout function that is typical of game theory. However, there are two dimensions to how to look at this number; the first is purely pragmatic, ie how much the implemented strategy manages to fulfill the transport strategy of the urban transport authority; the second is more economical, but all the more abstract; it is the subjective feeling of the individual who decides on the application of the strategy); V – the share of passengers that the urban transport authority wants to reduce within the traffic flow.

Objective passenger function:

$$\min_{X} Z_P = \sum_{i=1}^{N}\left(X_i - \frac{1}{A}\sum_{a=1}^{A} \frac{e^{U_i^a(V)}}{\sum_{j=1}^{N} e^{U_j^a(V)}} \right)^2, \tag{3}$$

where Z_p – objective function that demonstrates user benefits (again, in this case, it is a payroll function; in this case, it is an economic view that represents the subjective satisfaction of the needs of users who decide to use the P + R car park before reaching the city center by car); A – number of trips made (the number of trips made by people X_i to the city center); U_i^a – user j benefits from strategy choice a (in this case, it is the benefit of the users who choose strategy a; the benefit as such is expressed by a combination of time and financial savings. In addition, subjective factors, such as the approach to the environment, may be involved).

Restrictive conditions of population completeness:

$$\sum_{i=1}^{N} X_i = 1. \tag{4}$$

Restrictive conditions of non-negative population share:

$$0 \le X_i \le 1, \forall i. \tag{5}$$

Restrictive conditions restrict parking spaces in the city center

$$0 \le V \le 1. \tag{6}$$

3. Conclusions

In conclusion, it can be stated that in the field of preference of public transport over individual transport, it is possible to find a whole host of methods. However, it is always to be expected that the company has limited resources that need to be spent as efficiently as possible in order to move as many people as possible from individual transport to public transport. These methods need to be applied both at the point of contact of individual transport with public transport and then within public transport itself.

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Efficiency of the Hydrogen Compression Facility Based on the Metal-Hydride Technology for Fueling Hydrogen Powered Transport

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Abstract

The problem of efficient and safe hydrogen compression for hydrogen powered transport supply is reviewed. It is shown that the most effective way is using the metal-hydride technology for hydrogen compression up to high pressure. The experience of previous research and development, the analysis of different conventional and advanced solutions and the results of my own experiments gave the reason to apply a technological solution with metal-hydride compressors for continuous operation. The high efficiency of the facility is approached through solar energy usage for energy supplying and low grade heat recovery. The technical and economic efficiency of this facility is proven. The advantages of the proposed technical solutions are shown.
KEY WORDS*:* *hydrogen: compression; metal-hydride; continuous operation cycle; hydrogen fueling; efficiency; safety*

1. Introduction

At present hydrogen is the most perspective energy carrier for transport systems including automotive vehicles, marine vessels, aviation etc. Implementation of the hydrogen powered transport is the best way for fully refusing on carbon energetics. One of the main problems for wide hydrogen usage is its storage on the transport vehicle board.

At present the most spread storage methods and devices are the following: high pressure vessels, cryogenic vessels and metal-hydride tanks. All of these have certain advantages and disadvantages and can be effective used for specific transport vehicle. Hydrogen fuel can be applied as highly efficient environment friendly additions to carbon fuels especially to heavy diesel fuels in low speed marine diesels [1,2,3], as well as to gas fuel for gas turbines [3,4,5] and for reciprocating gas engines gained a wide application in integrated energy systems [7] or trigeneration [8].

One of the key devices into technological line for hydrogen filling of storage tanks is compression facility. At present, the efficiency of modern hydrogen compressors remains insufficiently high despite significant progress in this area. Energy expanses for hydrogen compression up to high pressure are significant that is caused physical and chemical properties. At present conventional mechanical compressors have satisfactory efficiency if hydrogen pressure is less than 25 MPa. Efficiency of the compression facility significant is decreasing if compression pressure is more than 25 MPa. Decreasing of its efficiency connected with heat losses at intercooling processes and hydrogen leakages through rotating shafts seals. Last circumstance has significant influence on fire and explosive safety.

Increasing efficiency and safety of the hydrogen compression facilities can be reached on the base of metal-hydride technology. This technology is basing on the fundamental properties of special alloys to sorb and desorb hydrogen reversible. Sorption capacity of these alloys is high enough and depends on metal composition. Hydrogen sorption processes are accompanied by the heat release and reverse desorption processes need the heat input. Hydrogen desorption pressure depends on heat potential and can be reaching up to 100 MPa. These peculiarities of fundamental properties formed the basis for the hydrogen thermal sorption compressors development [9].

Important feature of the metal-hydride technology is the selectivity - exclusively hydrogen sorption from gas mixtures and desorb from alloy atomic hydrogen, which recombines into molecular one. Thus hydrogen from metal-hydride compressing facility has purity up to 99.99 that is especially important for fuel cell electric and vehicles vessels [10-18.

2. Problem Statement

Efficient hydrogen storage on the transport vehicle board is one of the most complicated problems. Gaseous hydrogen has extremely low density – 0.084 {kg[m^3]} at normal conditions and liquid one – 71 {kg[m^3]} at boiling point (20 K and 0.1 MPa). Compressed gaseous hydrogen can be stored in fiberglass composite tanks under pressure up to 100 MPa. The main source of the green gaseous hydrogen is electrolysis with typical output pressure 2.0 MPa. The theoretical electricity for hydrogen compression from 2.0MPa to 35.0 MPa is 1.05 {kWh[kgH_2]} H_2 and 1.36 {kWh[kgH_2]} H_2 for 70.0 MPa.

Raising hydrogen storage efficiency can be reached by increasing hydrogen storage pressure up to 120 MPa. It is really possible with advanced fiberglass tanks type IV produced by Hexagon Purus GmbH and RayScan Technologies GmbH [1, 2].

Analysis of the different publications allows to obtain some specific indexes of the high pressure gaseous hydrogen storage systems. Fiberglass tanks type IV with volume 160L and pressure 50 MPa allows to reach the following indexes: empty tank specific mass are 0.93 {kg[L]} and hydrogen storage specific mass 30 {kg[kgH_2]}. For 300 L tanks these indexes are 0.8 {kg[L]} and 25 {kg[kgH_2]}, respectively. These tanks are using for transport vehicles with energy installation with small and middle power and short distance range. For instance, to small passenger vessels, road vehicles etc.

More efficient are fiberglass tanks type IV with operation pressure 70 MPa and 100 MPa. These tanks some expensive compare with 50 MPa pressure tanks but allow use them for more powerful installation and long distance range objects. Their storage indexes for 300L tanks are the following: empty tank specific mass are 1.15 {kgH_2[L]} and hydrogen storage specific mass is 22 {kg[kgH_2]}. For 100 MPa hydrogen pressure tanks – 1.55 {kgH_2[L]} and 20 {kg[kgH_2]}, respectively.

The next is energy consumption for hydrogen compression up to high pressures. Real compression electricity is required to fill hydrogen tanks connected with energy losses and lay in a range 1.7 to 6.4 {kWh[kgH_2]} [3]. Additional required energy connected with hydrogen cooling in operation processes is 0.15 {kWh[kgH_2]} [4].

Liquid method hydrogen storage connected with the following problems: hydrogen has been compressed and cooled below the inversion temperature of 202 K and its expansion up to cryogenic hydrogen liquid at boiling point of 20 K; energy required for hydrogen liquefaction in an ideal thermodynamic cycle is high enough 3.29 {kWh[kgH_2]}. The real energy consumption would be 10 {kWh[kgH_2]} [5]. It is possible to decrease this energy consumption by modification of the thermodynamics cycle, but total efficiency increasing is doubtful. In addition liquid hydrogen storage needs the special cryogenic tanks and systems of gas evaporation.

Analysis of above allows making the conclusion of high energy consumption both methods: hydrogen gas compression up to 100 MPa and liquefaction at 20 K. These energy expenses make a significant amount into hydrogen cost at fueling facilities. But hydrogen gas storage at high pressure in fiberglass composite tanks under pressure up to 100 MPa has specific advantages over hydrogen liquid storage. One of the benefits is opportunity to partial recovery compression energy in expansion machine. Its opportunity is possible to hydrogen high heat capacity 33.33 {kWh[kgH_2]} and high potential of the compressed hydrogen and low-grade heat recovery of engine exhausted.

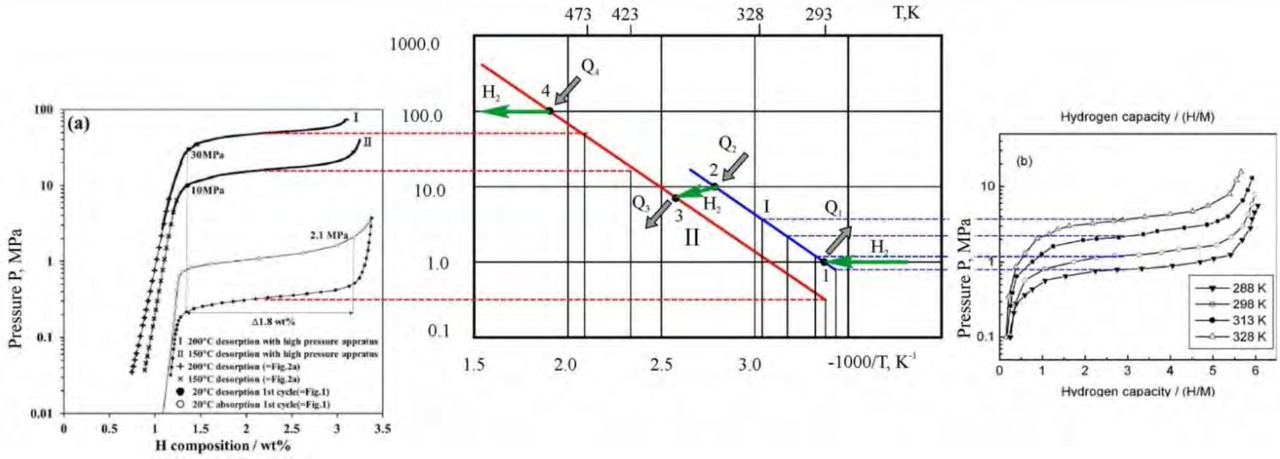
Further efficiency increasing of the hydrogen compression facilities can be reached by usage the metal hydride technology and renewable energy sources like solar and wind. Thermosorption hydrogen compression technology is basing on the fundamental properties of some intermetallic alloys reversible absorb and desorb hydrogen on dependence of heat removal or supply, accordantly. Desorb hydrogen pressure depends on intermetallic alloy properties (material content) and heat potential. At present industry produce wide nomenclatures of intermetallic alloys which have hydrogen desorb middle pressure (5.0…30 MPa) and high pressure up to 100 MPa in temperature range 350…550 K.

2.1. The Materials and the Results of the Research

At present the most prevalent are metal hydride compressors of the cycled operation, which have some advantages and. The main advantages are the following: absence of mechanical rotating and moving devices, high pressure hydrogen producing and possibility of low-grade heat usage. The main disadvantages – high mass and dimension, uneven operation and great cost due to high mass of costed metal hydride alloy. The most efficient are metal, which are free of metal hydride compressors of the cycled operation disadvantages. They have significant low mass and dimensions and cost, accordantly, have no rotating elements, except special pumps for metal hydride slurry transportation. But these hydride compressors of the continuous operation don't allow to produce hydrogen with pressure up to 100 MPa due to some design and technological problems.

The creation of the energy efficient high pressure and productivity hydrogen facility is possible on the base of combining continuous and cycled operation processes. First stage is continuous operation and produce middle pressure (up to 10…15 MPa) hydrogen and the second stage is cycled operation and increase hydrogen pressure up to 100 MPa. Results of previous research and development allow to define possible most effective intermetallic alloys for two stage combined hydrogen compression facility. on the lanthanum-cerium base $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ is effective enough for first continuous operation hydrogen compression unit. Intermetallic alloy $V_{0.4}Ti_{0.2}Cr_{0.4}$, based on vanadium-titanium-chromium, is chosen as effective complimentary couple. The simplified operation process of two stage metal hydride hydrogen compressor on is shown on Fig. 1. Represented original data for intermetallic alloys properties is taken from [6, 7] Fig. 1, a and c, accordantly. Linearized Van't Hoff plots for intermetallic alloys $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ and $V_{0.4}Ti_{0.2}Cr_{0.4}$ was defined on the base of desorption pressure-transmission-isotherms Fig. 1, b. Hysteresis of absorption and desorption processes is not taken into account for picture simplification.

Hydrogen compression process up to 100 MPa is following. Hydrogen with pressure 1.0 MPa from electrolyzer or other device flows to the first compression stage. Hydrogen absorption reaction heat Q_1 is removing into environment and saturation process is describing by a line 1–2. Hydrogen desorption from saturated hydride $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ needs on heat input Q_2 and hydrogen pressure depends on its potential. Hydrogen outlet pressure 10 MPa is reaching with heat temperature at 365 K, approximately. Hydrogen flows to the second stage and its pressure is decreasing to 7.0 MPa due to absorption process in intermetallic alloy $V_{0.4}Ti_{0.2}Cr_{0.4}$. Absorption process heat Q_3 is removing into environment and saturation process is describing by a line 3–4. Hydrogen desorption from saturated hydride $V_{0.4}Ti_{0.2}Cr_{0.4}$ is carried out by heat input Q_4. Hydrogen outlet pressure up to 100 MPa is reaching at temperature 525 K, approximately.



a b c

Fig. 1 The simplified operation process of two stage metal hydride hydrogen compressor

The simplified diagram of two stage metal hydride hydrogen compressor on is shown on Fig. 2. The first stage is basing on continuous operation cycle and metal hydride slurry as substance for hydrogen compression and transportation. This stage is using for low pressure hydrogen compression from 1.0…1.5 MPa up to 10 MPa. Metal hydride continuous operation cycle has significant advantages compare with metal hydride cyclic action, reciprocating and turbine machines. These advantages connected with mechanical rotating devices absence, low hydrogen losses and energy consumption. The second stage is basing on metal hydride cyclic action possess. The main advantage cyclic action possess is super high pressure hydrogen extra low losses connected with fully hermetic system without shafts and seals. This stage is compressing hydrogen from 10 MPa up to 100 MPa and supplies it to storage tanks.

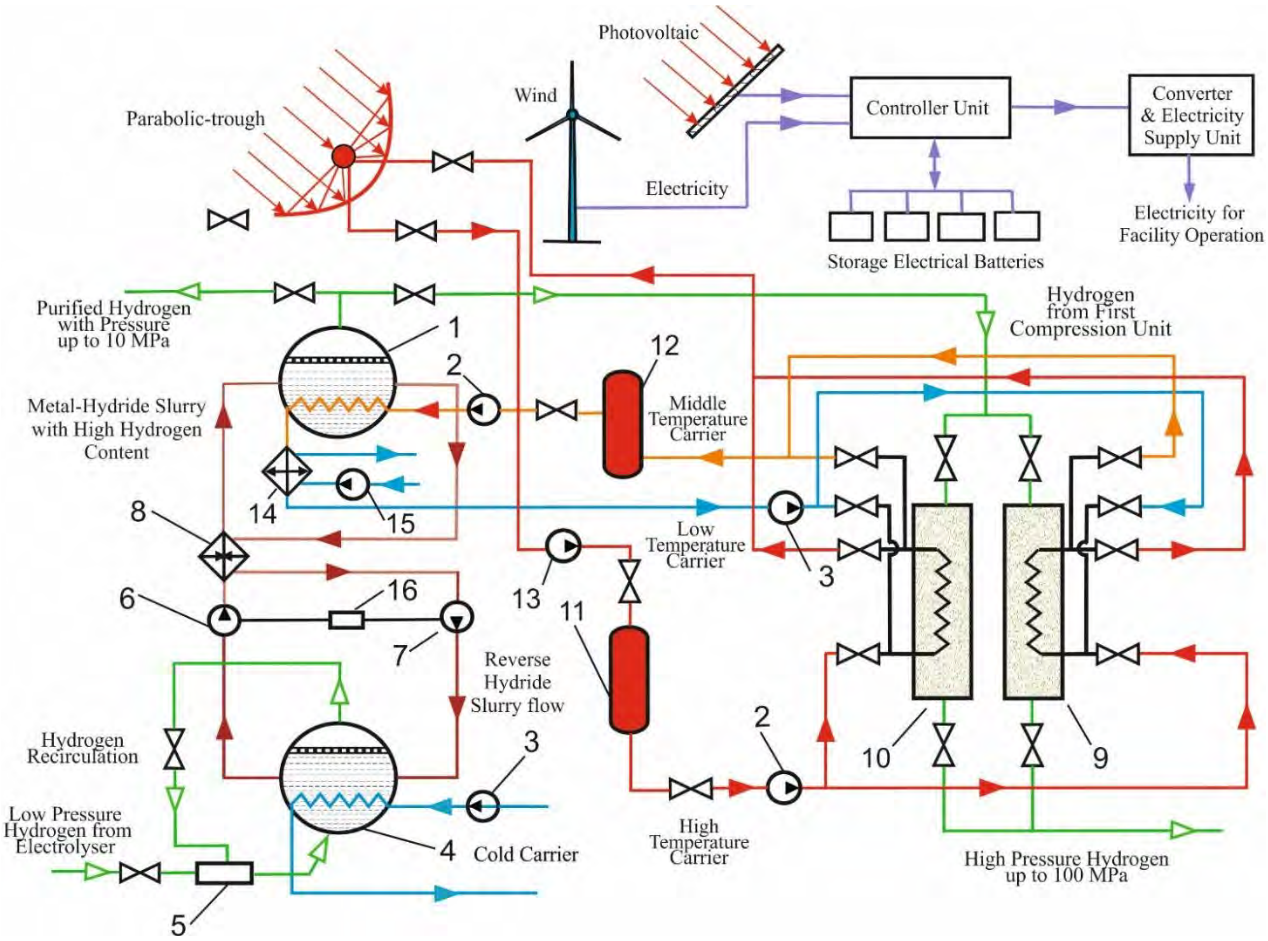


Fig. 2 The simplified diagram of two stage metal hydride hydrogen compressor

Common advantages both stages are the opportunity of low-grade energy usage for operation and hydrogen purification up to 99.999. The last one is basing on molecular hydrogen dissociation to atomic state and selective its absorption and desorption without any admixtures. Production of high purity hydrogen is especially important for fuel cell long-live operation. Expenses on this facility operation decreases due to renewable energy sources usage – solar and wind power. Energy supply unit includes solar parabolic trough where liquid energy carrier heating up to 600 K or more, photovoltaic panels and wind turbine for electricity production and supplying all facility's consumers, and controlling, converting and electricity storage equipment. Hot heat carrier circulates consequentially through the second compressing stage and then first one. This flow circulating diagram is explaining by necessity of highest heat potential for the second compression stage and less high potential for the first one.

Therminol® 66 is chosen as hot and warm liquid carrier. It is the world's most popular high-temperature, liquid-phase heat transfer fluid, has high temperature thermal stability in temperature range 160…620 K [20]. Polydimethylsiloxane (PDMS) is chosen as liquid carrier slurry with hydride concentration 0.176 of volume. It has moderate viscosity, good mixing with intermetallic (hydride) powder and excellent stability [21]. Both liquids are not expensive and not aggressive to metallic and plastic details.

The main operation principals of the metal hydride hydrogen compression facility are the following. Low pressure hydrogen from electrolyzer of other sources comes in controlling and distribution unit *5* and then to absorber *4* where it absorbs by intermetallic alloy $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ in organic liquid slurry form. Hydrogenation reaction heat is outlet by cold water with pump *3*, and the hydride slurry is transporting by pump 6 through recovery heat exchanger *8* to desorber *1*. Hydride slurry pump *6* needs high energy consumption enough and partial energy compensation implemented through the hydro motor *7* which is driving this pump and recovering reverse hydride slurry flow energy. Warm liquid carrier from the cooling system of the second compressor stage is heating in auxiliary electrical heater *12* and pumped *2* into desorber *1*. Hydrogen reach hydride slurry is desorbing hydrogen due to reaction heat input from liquid hot carrier and hydrogen pressure is reaching 10 MPa at 365 K, approximately (see Fig. 1, b). The liquid warm carrier from the desorber *1* enters to cooler *14*, where its temperature decreases and goes there to cooling system of the second compression stage through pump *3*.

Compressed and purified hydrogen whit pressure 10 MPa enters into the second stage which is cyclic operated. This stage includes two symmetric devises *9* and *10*, which contain intermetallic hydride alloy as solid powder. Device 9 operates as absorber at first half-cycle operation and as desorber at second half-cycle operation. Device *10* operates out of phase – as desorber at first half-cycle operation and as absorber at second half-cycle operation. Suppose, device *9* is fully empty of hydrogen and device *10* is fully saturated with hydrogen and controlling electric driving valves opened/closed in due order. Hydrogen is supplied in device *9* at first half-cycle, where intermetallic alloy $V_{0.4}Ti_{0.2}Cr_{0.4}$ absorbs hydrogen at pressure some less than 10 MPa and reaction heat is outputting by cooling liquid (water) with pump 3 into the environment. At the same time, hydrogen is desorbing from device *10* due to heat inputting by hot liquid carrier from parabolic trough with pumps *13* and *2* through heat storage device *11*. Hydrogen output pressure is 100 MPa at hot liquid carrier temperature 525 K, approximately and then hydrogen goes to high pressure storage tank. First half-cycle is finishing when hydride device *9* is fully saturated by hydrogen and hydride device *10* is fully empty of hydrogen.

Controlling electric driving valves is switching to another position and the second half-cycle is starting. Hydrogen goes to device *10* and is absorbing by intermetallic alloy, reaction heat outlet with cooling carrier from the first stage. Hot liquid carrier goes to device *9* and hydrogen is desorbing with pressure up to 100 MPa. Half-cycles are repeating and thus the general compression cycle is closed. Duration of the half-cycle is depending on hydride devices *9* and *10* design, intermetallic alloy quantity. Rational of the half-cycle duration is in a range 30…60 minutes.

Fundamental working capacity of main equipment and devices efficiency were determined as a result of experimental studies conducted in National Shipbuilding University laboratories. Energy efficiency of the presented hydrogen compression facility is basing on the renewable energy sources usage – solar and wind power. Hydrogen compression facility on base of PDC 13 series two-stage diaphragm compressor, discharging pressure 100.1 MPa providing a flow up to 40 kg/h with power consumption of 150 kW, which is producing by PDC Machines, LCC [19] was chosen for comparison. This facility has world-wide implementation for bus, medium and heavy duty truck and vehicle fueling.

Complex mathematic model of the combined facility with continuous and cyclic operation stages was applied for performance evaluation as a part of more generalized one [22]. This mathematic model is a part of the most demoralized moles which was researched and developed for detailed intermetallic hydride installation. Thermodynamics and kinetic properties of intermetallic alloys $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ and $V_{0.4}Ti_{0.2}Cr_{0.4}$ were taken from [23, 24], hydraulic machines efficiency and heat exchangers recovery were accepted as 0.9 and 0.5, accordantly. Modelling results were determined heat consumption of the compressing facility first stage from as 274 kW. This is the hydration reaction heat, which is outputting from the second compression stage. The second stage heat required amount from parabolic-trough is 318 kW, which corresponds to the isentropic efficiency of the compression process in one stage – 0.156. This efficiency value generally corresponds to the known indicators of real metal hydride compressors [23]. The parabolic-trough efficiency is 0.70...0.75 in the range of heating temperatures 400K ... 500K [25] and allows producing requirement heat energy amount at solar insolation condition 1000 W/m^2 and its surface 454 m^2.

General electricity consumption for facility operation is 9 kW and is generating by wind turbine and photovoltaic panels with surface of 45 m^2, approximately. Wind turbine electricity generator is chosen with 10 kW power. An experience is recommends to increase parabolic-trough, photovoltaic panels surface and power of wind turbine electricity generator capacities on 30…50% considering the unevenness of solar radiation during the day and season, as well as the variability of wind speed.

3. Conclusions

The metal-hydride two stage compression facility which includes the continuous operation unit as the first stage, the cyclic operation unit as the second stage with energy supply from renewable energy souses like as solar and wind is regarded as a promising installation of hydrogen compression for fueling stations. We focused on a combined metal-hydride facility because it allows united advantages of continuous and cycle operation devises and get rid of their disadvantages which are belong to them separately. Rational properties selection like as $La_{0.35}Ce_{0.45}Ca_{0.2}Ni_{4.95}Al_{0.05}$ for the first middle pressure stage and $V_{0.4}Ti_{0.2}Cr_{0.4}$ for the second stage allows reaching effective hydrogen compression up to 100 MPa. Due to the unique properties of these intermetallic alloys, it became possible to use low-grade renewable energy sources for facility operation.

The comparison energy efficiency of diaphragm compressor PDC 13 series with analogous discharge pressure and productivity, which was described above, with the comparison energy efficiency of diaphragm hydrogen compressor PDC 13 series with analogous discharge pressure and productivity, which was described above, with the presented two stage metal-hydride facility indicates the following. The energy consumption of the PDC 13 compressor is 150 kW and significantly less than the energy consumption of 318 kW. But PDC 13 compressor is consuming high potential electricity and the metal-hydride facility is consuming the low-grade renewable energy from solar and wind, which cost is significantly low.

Based on these results, we believe that the presented two stage metal-hydride compression facility should be an effective for hydrogen fueling stations.

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Mathematic Modelling of Towing Operation

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Abstract

A very important role in marine service operation takes the tug when assistance is necessary to help the vessel maneuver during entering and leaving port also in mooring and unmooring situations. Due to this main factor to ensure safety takes to tugs. Any fault of towlines or other equipment during towing operations could cause serious mechanical damage to the vessel, also employee injuries and ecological disasters as well. In many cases tug operation needs well prepare and evaluate by many factors. This paper presents research studies of towing system mathematic modeling where the large vessel is assisted by multiple tugs including evaluating towlines properties, vessels parameters and external conditions which can make an impact on port navigation safety results.
KEY WORDS: *Tugs, Towing, Safety in the port*

1. Introduction

Big impact for safety into ports takes good prepared and equipped tug as well as precisely planed towing operation. It's very essential to have well prepared equipment's such as winch, all types of lines and ropes which is using into towing operation while help ship maneuvering as well while mooring and unmooring procedures. All together this factors take account into generally safety environment and takes place at least in one line with such factors as low training of personal and bad sailing skills, big speed during operation, bad weather conditions when we talking about reasons of ship accidents. In principle general it's very important to develop and improve existing shipping models based on theoretical and practical support to ensure safety in towing operations as well as develop and optimize process and procedures which could become as safety standard in many ports. Demand to identify various problems related with towing procedures which should be study and solved dictated that safety in topic is popular subject of many scholars [4, 5]. According to statistics, between 2011 and 2018, there were 25614 shipping incidents in the Baltic Sea and inside of Baltic Sea ports, in which 230 ships sank, 7694 people were injured and 696 people died [1]. Navigational safety at sea and in ports is a relevant and wide discuss topic in the world in several aspects: the impact of human factors, equipment failures, and the characteristics of infrastructure and ship maneuvering [2]. The interaction between the vessel and the tug, as well as safety, is highly dependent on several factors: the location of the towing point, the reliability of the towing equipment and the type and condition of the tow rope. There is a strong link between these factors in terms of safe work in ports during towing operations.

Mane research object takes mathematical model of towing vessel and two assisting tugs connected with towing line. This is very related with such parameters of towing line connecting point, material and type which towing cable is made of, mechanical elastic parameters and properties as well as external forces impact.

2. Situation Analysis and Literature Overview

Nowadays port tug researches in the word we can divide in following four branches as safety study's related with different aspect such as mechanical equipment failure, poor training and qualification of tug operators, weather and other aspects. Next branch could be various modeling study's such as hydrodynamic modeling of tug movement while operating, modeling of optimum hull shape and design. Third branch related with practical tug problems in the port such as scheduling in big container hubs, operating when maximum size vessel is entering and maneuvering into port. Finally decarbonization, green energy, alternative fuel source, automatization and autonomies studies is another big part where many study's are focusing on. Basically, port tug researches has practical impact for port tug safety and operations quality as well it reflects changing situation in the market while environment friendly and more effective technologies becoming available.

Problematic of port tug influence for ship maneuvering into ports while mooring and unmooring, research on work methods for tugs in ports represent V. Paulauskas ir D. Paulauskas [3]. Research of vessel maneuvering properties and relations with ports infrastructure limit parameters represent D. Paulauskas where he make conclusions of importance of port tug while accommodate maximum size vessels into port [4]. Optimum number of port tugs studies make V. Paulauskas with team where focus was made on methodology to calculate necessary quantity of tugs for every operation this question as well mightily related with decarbonization question as well since we have optimum number of tugs it means we are not using more then we need. VLCC, VLCS and UCLS vessels maneuvering into ports wide represent researches from all the word. Authors L. Kang, S. Gao, and Q. Meng represent in the articals detail analysis of towing capacity based on modeling results. To better understand all nuances and properties of tug-ship proceed and interplay, a

6-DOF time domain simulator was developed to better understand propulsions dynamics specialy across towing line. This type of method is universall and includs many factors and parameters with focus on the tug handling as well as effectiveness and reaction times. As investigtions reviels it's also very important evaluate and include into model forces which are generated by ship's during escort proccess [5]. Moreover looks towars to other acctual research area which includes multi-tug-assisted large ship maneuvering calculations methods. This cases are common into biggest container ports and large hubs where sheduling problems is become complex question and dictaded by nowdays global transport and logistic chains issues. In multi-tug and ship systems maneuverability and force analysis model is developing by G. Wu where is looking connections and links of acting forces which impact maneuverability during such towing interactions [6].

Breakthrough in the experiments was made by evaluating the mathematical model using the linear method, and by evaluating the real characteristics of the toeing system, the connection between the experimental theoretical test and the real operation was confirmed. Generally, the conclusions were formed that the stability and efficiency of the towing process depends on the length of the line and toeing point position. Changing this parameters coincided and correlations has direct impact into safety parameters and system stability [7-8]. As well scholars use linear system mathematical theory to study and describe towing system parameters such as course stability and towing system stability under different conditions [9-10]. Other kind of researches when we are talking about towing line impact factory is assuming that towing line is symmetric. It means that line in front and in back has same properties when we have balance in towing operation. Mathematical model of the towing system is obtained by using the disturbance of the towline in the towing process. Results and conclusions summarized connections and impacts between such properties as quality, elasticity of the streamer and stability of the towing motion [11].

Concerning the safety of towing, a slack towline condition on tug-towed ship motions interaction during turning is important target of research. The results revealed that the tug was vulnerable to lose handling of towing with respect to the towed ship that led to the towline falling into the slack condition [12]. Authors N. M. Quy, K. Łazuga, L. Gucma, J. K. Vrijling, and P. H. A. J. M. van Gelder in paper presents generalized models of ships maneuvering. Those models are needed for better understanding of the safe navigation process in ports areas and its approaches and for risk analysis when no full information about the ships behavior is available [13].

3. Theoretical Basis for the Tugs Using in Ports

To calculate minimum required quantity of port tugs during mooring and unmooring operations where hydrodynamic forces affecting vessel and part of this forces can be compensate by vessel screw and steering complexes another part can be compensated by port tug. To evaluate minimum quantity of tug and minimum required power all acting forces must be analyzed. General all forces can be expressed by following equations [14]:

$$m\frac{dv_x}{dt} + R_x + P_x + F_{xa} + F_{xsr} + F_{xs} + F_{xv} + F_x = 0\,; \tag{1}$$

$$m\frac{dv_y}{dt} + R_y + P_y + F_{ya} + F_{ysr} + F_{ys} + F_{yv} + N_y = 0\,; \tag{2}$$

$$M_{in} + M_R + M_p + M_a + M_{sr} + M_s + M_v + M_n = 0\,, \tag{3}$$

where v_x – vessel longitudinal speed; R_x – vessels hull resistance when vessel moves into longitudinal direction; P_x – rudder resistance force; F_{xa} – longitudinal aerodynamic force; F_{xsr} – longitudinal stream force; F_{xs} – longitudinal "wing" force; F_{xv} – longitudinal tug force; F_x – screw propulsion force; V_y – vessel direction y; R_y – vessels hull resistance when vessel moves into traverse direction; P_y – rudder traverse resistance force; F_{ya} – traverse aerodynamic force; F_{ysr} – traverse stream force; F_{ys} – traverse "wing" force; F_{yv} – traverse tug force; N_y – traverse steering force; M_{in} – moment of inertia; M_R – moment of vessel hull force; M_p – moment of rudder force; M_a – moment of aerodynamic force; M_{sr} – moment of stream force; M_s – moment of "wing" force; M_v – moment of tugs force; M_n – moment of additional steering force.

To adjust trajectory of vessel while tug is operating is very important angle β. This angle is between tug towing line and vessels moving direction. Vessel turning moment can express by this equation [14-15]:

$$M_v' = F_v \cdot sin\,\beta \cdot l_1'\,. \tag{4}$$

Tug bollard power efficient while towing line in vessel is connected upper then in tug can be expressed by this equation:

$$F_v' = F_v \cdot cos\,\alpha\,. \tag{5}$$

Tug creating turning moment which is related with vessel handling options and vessels turning properties evaluating towing line vertical angle α and horizonal angle β can be expressed by this equation:

$$M_v = F_v \cdot cos\,\alpha \cdot sin\,\beta \cdot l_1^{'}, \tag{6}$$

where M_v – moment of tug force, F_v – tug bollard power, $cos\,\alpha$ – towing line vertical angle, $sin\,\beta$ – towing line horizontal angle, $l_1^{'}$ – force shoulder.

In case to prevent port tug efficient loses due to towing line connection high difference general towing line must be longer, but in this case operation time is longer due to trajectory changing maneuver. On the other hand vessel push – pull without towing line could be effective when vessel speed is low. Generally port tug is very important in operation when we changing vessel trajectory but to make this process efficient, we must evaluate vessel characteristic, tug bollard power, vessel pivot point.

Towing force shoulder could be finding on basis the abscissa of the ship's turning power point (x_0) and towage rope length (l_{tr}). Power point of the ship depends ships movement direction that means ship move ahead or astern and can be calculating as follows [16]:

$$x_0 = L\left(0.4 + 11.5\frac{T_{1g} - T_{lp}}{L} - 0.004 \cdot \alpha_r^0\right). \tag{7}$$

Finally towing force shoulder could be calculated as follow:

$$l_{tug} = \left(\left(x_0 + \frac{L}{2}\right) + l_{tr} \cdot cos\,\beta\right) \cdot sin\,\alpha\,. \tag{8}$$

On basis presented methodology made theoretical calculations possibilities ships entry and departure, manoeuvring, mooring and unmooring in complicate conditions and minimum request tugs (bollard pull). For the checking theoretical calculations were used full mission simulator “SimFlex Navigator” (Force technology product) and analysed similar manoeuvres in same place of the real ships.

4. Mathematical Modelling and Simulation

In paper was developed Lagrange interpolation based research which includes tree vessels – 2 tugs and containership mathematical dynamic model which evaluated vessel mass and inertial moment, towing lines damping and stiffens coefficient. The dynamic model is used to calculate the six state variables - vertical displacements of vessels (q_1, q_2 ir q_3) and the rotation of the vessels about the axes of their center of gravity (φ_1, φ_2, φ_3). The mathematical model of a dynamic system consists of six second-order differential equations. Calculation program for deriving the above six differential equations was used Matlab software. The system of differential equations was modify in matrix form: matrices of masses $\{M\}$, damping $\{D\}$ and stiffness $\{K\}$, and vectors of state variables $\{q\}$ and external forces $\{F\}$ were composed.

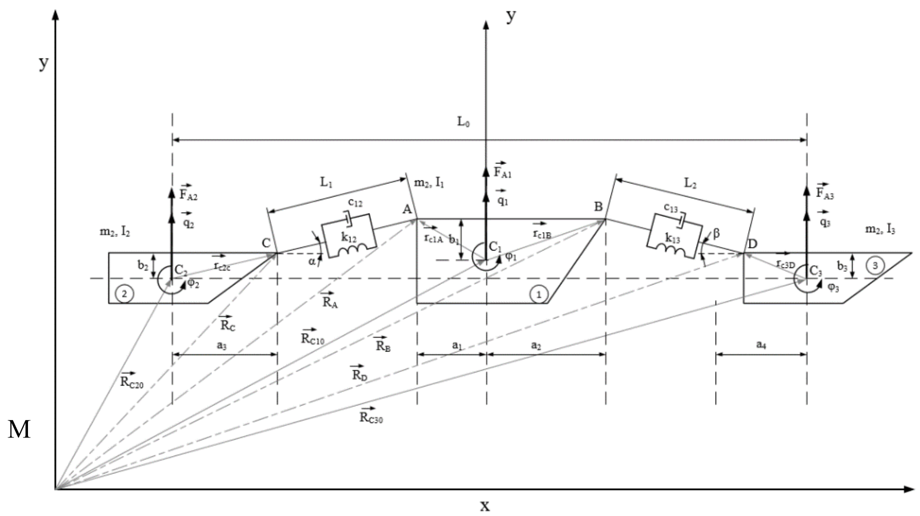

Fig. 1 Vector scheme of towing system where operating two tugs (number 2 and 3) connected with vessel (number 3) with elastic rope

Mathematical model of movement of the system expressed in matrix. For simulation was using Matlab programme and parameters of vessels was taken of existing tugs in Klaipeda port TAK10 and TAK11 as well towed vessel was taken MSC TOPAZ which is one of the biggest accommodated in Klaipeda port. The aim was to make the simulation and mathematical modeling as realistic as possible to be closest to real situations and scenarios.

$$[M]\{\ddot{q}\}+[D]\{\dot{q}\}+[K]\{q\}=\{F\}; \tag{9}$$

$$\{q\}=\begin{bmatrix} q_1(t) \\ q_2(t) \\ q_3(t) \\ \varphi_1(t) \\ \varphi_2(t) \\ \varphi_3(t) \end{bmatrix}\{F\}=\begin{bmatrix} F_{A1}-m_1 g \\ F_{A2}-m_2 g \\ F_{A3}-m_3 g \\ 0 \\ 0 \\ 0 \end{bmatrix}\{M\}=\begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & J_1 & 0 & 0 \\ 0 & 0 & 0 & 0 & J_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & J_3 \end{bmatrix}; \tag{10}$$

$$[D]=\begin{bmatrix} C_{12}+C_{13} & -C_{12} & -C_{13} & 2\left(C_{12}r_{C1A}+C_{13}r_{C1B}\right) & -2C_{12}r_{C2C} & -2C_{13}r_{C3D} \\ -C_{12} & C_{12} & 0 & -2C_{12}r_{C1A} & 2C_{12}r_{C2C} & 0 \\ -C_{13} & 0 & C_{13} & -2C_{13}r_{C1B} & 0 & 2C_{13}r_{C3D} \\ 2\left(C_{12}r_{C1A}+C_{13}r_{C1B}\right) & -2C_{12}r_{C1A} & -2C_{13}r_{C1B} & 4\left(C_{12}r_{C1A}^2+C_{13}r_{C1B}^2\right) & -4C_{12}r_{C1A}r_{C2C} & -4C_{13}r_{C1B}r_{C3D} \\ -2C_{12}r_{C2C} & 2C_{12}r_{C2C} & 0 & -4C_{12}r_{C2C}r_{C1A} & 4C_{12}r_{C2C}^2 & 0 \\ -2C_{13}r_{C3D} & 0 & 2C_{13}r_{C3D} & -4C_{13}r_{C3D}r_{C1B} & 0 & 4C_{13}r_{C3D}^2 \end{bmatrix}; \tag{11}$$

$$[k]=\begin{bmatrix} k_{12}+k_{13} & -k_{12} & -k_{13} & 2\left(k_{12}r_{C1A}+k_{13}r_{C1B}\right) & -2k_{12}r_{C2C} & -2k_{13}r_{C3D} \\ -k_{12} & k_{12} & 0 & -2k_{12}r_{C1A} & 2k_{12}r_{C2C} & 0 \\ -k_{13} & 0 & k_{13} & -2k_{13}r_{C1B} & 0 & 2k_{13}r_{C3D} \\ 2\left(k_{12}r_{C1A}+k_{13}r_{C1B}\right) & -2k_{12}r_{C1A} & -2k_{13}r_{C1B} & 4\left(k_{12}r_{C1A}^2+k_{13}r_{C1B}^2\right) & -4k_{12}r_{C1A}r_{C2C} & -4k_{13}r_{C1B}r_{C3D} \\ -2k_{12}r_{C2C} & 2k_{12}r_{C2C} & 0 & -4k_{12}r_{C2C}r_{C1A} & 4k_{12}r_{C2C}^2 & 0 \\ -2k_{13}r_{C3D} & 0 & 2k_{13}r_{C3D} & -4k_{13}r_{C3D}r_{C1B} & 0 & 4k_{13}r_{C3D}^2 \end{bmatrix}. \tag{12}$$

Results were generated into graphic of angular velocity, displacement and rotation graphic schemes of towing operation with two tugs and container vessel. Model is universal and it's possible to generate various results and graphics according variable parameters of towing line elasticity as well as various vessels parameters.

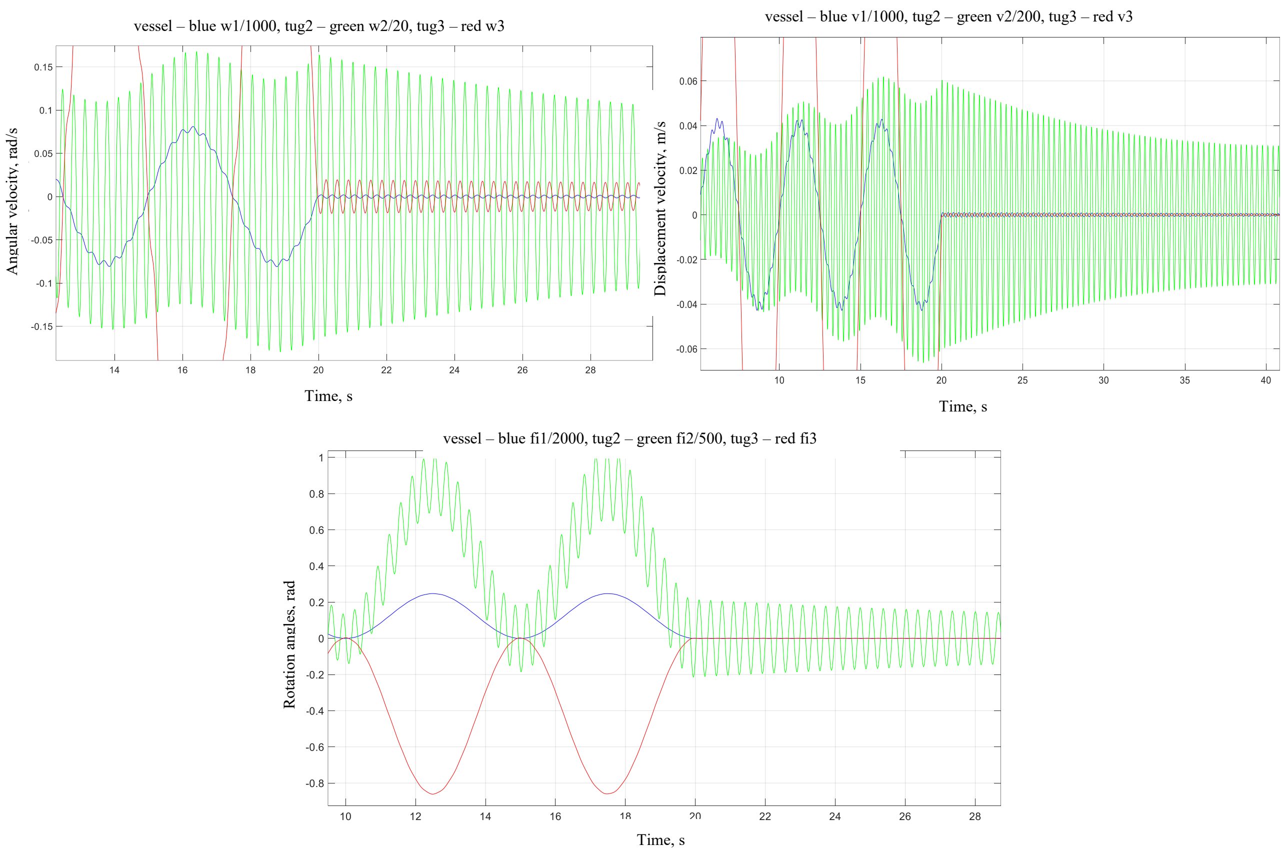

Fig. 2 Angular velocity, displacement and rotation graphic schemes of towing system with two tugs and container vessel

Graphics and results explain how the whole towing vessel is massive and to change velocity and trajectory needs very big external forces which generate tugs. This operation requires the skills of the tug crew as well a very good preparation from port authority to ensure safe vessel maneuver.

5. Conclusions and Disccusions

Modeling and simulating was calculated using the Matlab program which includes programming solution of differential equations and presenting the answers in both numerical and graphical form. The ODE23 method was used in the program, a three-step Runge-Kutta method. The maximum step of the simulation was not more than 0.01 s. The relative accuracy of the modeling is 10^{-4}.

The results show that the model is designed correctly, when the forces are removed and the system enters into steady state and remains in it and only additional external force which affected are waves. When external effects and forces are eliminated, the system returns to a steady state over time and remains in it. Therefore, it can be confirmed that the studied dynamic system is stable.

The addition of an external effect to the third member (tug) of the system, the periodic force on the vertical axis, has been found to have the greatest effect on that tug and, due to the high mass and inertia of the main vessel, the shifts and turns are relatively many times smaller. Only small displacements and oscillations are observed between the second tug and the main vessel, and higher harmonics in the movement of the tug also occur, i.e. the vessel vibrates as the rope between the second tug and the main vessel.

The phases of the steering angles between the main vessel and tug 3 are opposite and the phases of the displacement coincide. When external forces are eliminated, the damping oscillation oscillations are small and the phases are different, but not opposite. Varies in appropriate sizes due to system parameters.

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Integral Assessment of the Technical Condition of Pad Brakes

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Abstract

The safe operation of cranes is determined by the reliable operation of crane mechanisms, and among them, the operation of pad brakes. Pad brakes of the normally-closed type have become the most widely used lifting cranes. The article examines the issue of evaluating the technical condition of the pad brake using the Harrington desirability function, which allowed to move to one comprehensive (generalized) indicator of the technical condition instead of several separate indicators.
KEY WORDS: *pad brake, technical condition, diagnostic parameters, Harrington desirability function*

1. Introduction

The statistics of failures of crane mechanisms show that failures of pad brakes, for example, of tower cranes, make up 47...48% of the total number of failures [1], of bridge type cranes 50...75% [2].

The technical condition of pad brakes is determined by diagnostic parameters such as braking torque, activation time, opening time, braking time. Each of them is important as a parameter that ensures the reliability of operation, and the non-compliance of any of them with the established norms can lead to an emergency situation.

Braking torque is considered the main diagnostic parameter of a pad brake. Its value depends on the force of the clamping spring and the coefficient of friction of the contact bodies: a friction pad is a brake pulley. The value of the braking torque is a standardized value and is regulated by the length of the clamping spring. The range of changes in the braking torque depends on the standard size of the pad brake [3].

The time of activation of the pad brake is also a standardized value and its range of changes depends on the standard size of the brake. The brake activation time is affected by the force of the clamping spring, the setting gap between the brake pads and the pulley, and the viscosity of the working fluid of the electrohydraulic pusher.

The brake release time depends on the lifting force and stroke of the electrohydraulic pusher rod, the amount and viscosity of the working fluid of the electrohydraulic pusher. The brake release time affects the acceleration speed of the mechanism's electric motor, and the shorter it is, the better.

Braking time depends on the force of the clamping spring and the coefficient of friction of the contact bodies: friction pad - brake pulley. The coefficient of friction of contact bodies can change both due to the influence of the ambient temperature in the contact zone and the state of the contact surfaces, for example, due to oiling or dusting. Such phenomena significantly increase the braking time and, as a result, the brake cannot ensure the accuracy of stopping the mechanism. The range of braking time change is determined by the amount of braking torque.

To make a decision about the technical condition of the pad brake, it is desirable to have an integral (complex) indicator that takes into account information about the quantitative values of individual parameters of the technical condition of the pad brakes. This is especially important when it is necessary to evaluate and compare the technical condition of several units of pad brakes.

The analysis of a priori information indicates the possibility of applying Harrington's desirability function [4] to solve this problem, which is confirmed by the research of scientists in various fields, including engineering and technology [5, 6]. Harrington's desirability function has a number of advantages, namely: it is quantitative; is unambiguous; expressed by one number; is universal; comprehensively characterizes the object; provides transformation of indicators using one graph for all criteria.

The purpose of the article is to develop a methodology for comprehensive assessment of the technical condition of a pad brake based on the application of Harrington's desirability function and to develop a device for its implementation. The purpose of assessing the technical condition of the pad brake is to determine the feasibility of its repair or replacement.

2. Research Results

The method of comprehensive assessment of the technical condition of the pad brake consists of the following stages:

1. Determination of the list and selection of criteria (parameters) of the evaluation object (pad brake).

2. Establishing with the help of technical documents (passport, instructions, standards, norms and rules) the limit of permissible values of all parameters of the technical condition.

In the absence of such data, which may be due to the innovative nature of the pad brake design, the limits of such parameters are set expertly based on the experience and intuition of the researcher.

3. Choice of desirability scale.

Desirability di means one or another desired level of a parameter. On a special scale (see Figs. 1 and 2), the value of d_i can vary from 0 to 1. To construct a scale of desirability, the method of quantitative assessments is used with an interval of values of desirability *d* from zero to one. Intermediate values of desirability and their corresponding numerical marks are given below.

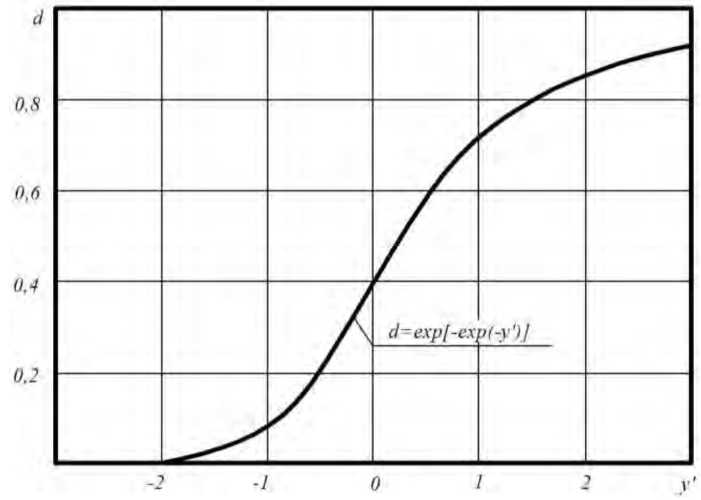

Fig. 1 Scale of desirability for parameters with one-sided restriction

The numerical intervals of the scale look like:

d = 1,00 – the maximum possible value of the parameter;

d = 1,00-0,80 – the best and permissible value of the parameter;

d = 0,80-0,60 – acceptable and good value of the parameter;

d = 0,60-0,37 – permissible and satisfactory level;

d = 0,37-0 – unsatisfactory quality level.

The value of *d* on the desirability scale can be shifted up or down depending on specific situations.

4. Determination of the level of desirability according to the Harrington scale for each evaluation parameter y_i.

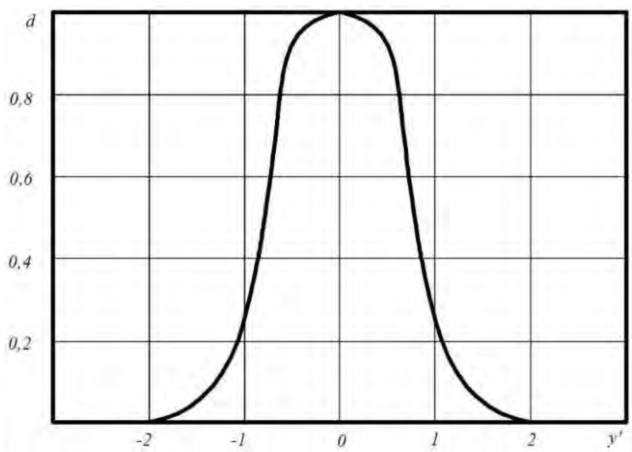

Fig. 2 Scale of desirability for parameters with two-sided restriction

The values of the private functions (parameters) of desirability d_1, d_2, d_3...d_i are found by converting the measured values of the selected parameters of the technical condition according to formula (1) into dimensionless quantities:

$$d_i = e^{-\left(e^{-y'_i}\right)}, \qquad (1)$$

where y'_i – some dimensionless quantity related (often linearly) to the response y_i:

$$y_i' = a_0^* + a_1^* y_i . \tag{2}$$

Coefficients a_0^* and a_1^* are determined by assigning two values of the response function corresponding to the basic (boundary) value of the private desirability function d_i, that is, the following technique is used: the worst value is assigned a desirability value equal to 0,37, and the best value is assigned a desirability value equal to 0,98.

Formula (1) is applicable when the parameter has a one-sided restriction. If the constraints for the parameter are two-sided, that is, they have the form $y_{min} \le y \le y_{max}$, that convenient to set the desirability function by a formula:

$$d_i = e^{-\left(\left|y_i'\right|\right)n} , \tag{3}$$

where n – a positive number,

$$y_i' = \frac{2y_i - \left(y_{max} + y_{min}\right)}{y_{max} - y_{min}} . \tag{4}$$

The degree index n can be calculated by setting a value d to some parameter y (mostly in the interval $0,6 < d < 0,9$), calculating (3) the corresponding value using d_i, and then using the formula:

$$n = \frac{ln\, ln \frac{1}{d}}{ln\left|y'\right|} . \tag{5}$$

By choosing different values of n, you can set different curvature of the desirability curve. This circumstance allows us to take into account the special importance of certain parameters of the technical state: for them, n will have a greater value, and a small change in the parameter near the limiting boundaries will correspond to a sharp change in desirability.

5. Calculation of the generalized criterion of the technical condition of the pad brake.

A generalized desirability function (D) is formed, which is the geometric mean of the desirability of individual parameters of the technical state

$$D = \sqrt[g]{d_1 \cdot d_2 \ldots \cdot d_g} , \tag{6}$$

where g – the number of selected parameters of the technical condition of the pad brake.

As a result, the generalized desirability function turns out to be the only parameter for evaluating the technical condition instead of many. The same preference scale is used for the generalized indicator as for the private optimization parameters. Formula (6) allows you to make a decision about the unacceptable level of technical condition of the pad brake if at least one private desirability $d_i = 0$. In this case, the generalized function will also be equal to zero. At the same time, the generalized function $D = 1$ only when all individual desirability $d_i = 1$.

Thus, the conducted theoretical studies allow us to draw a conclusion about the possibility and expediency of using Harrington's desirability function to solve the problem of complex (integral) assessment of the technical condition of the pad brake.

For the practical implementation of the application of Harrington's desirability function to evaluate the technical condition of the pad brake, a device is proposed, the block diagram of which is shown in Fig. 3.

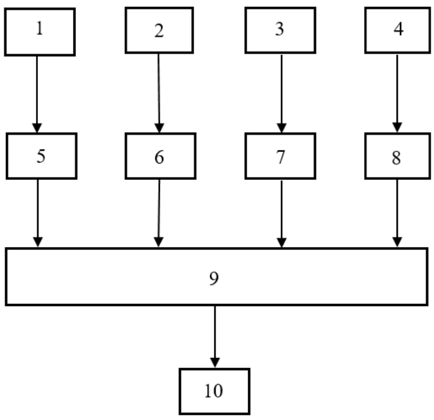

Fig. 3 Block diagram of the device

The device contains sensors for parameters of the technical condition of the pad brake, namely: *1* – brake torque sensor, *2* – brake activation time sensor, *3* – braking time sensor, *4* – brake release time sensor; *5*, *6*, *7*, *8* – analog-digital converters (ADC); *9* – microprocessor device; *10* – display unit.

The device works as follows. From sensors of parameters of the technical condition *1-4*, which are directly installed on the pad brake, analog parameter signals are sent to the inputs of analog-digital converters *5*, *6*, *7*, *8*, respectively. In them, analog signals are converted into digital format and fed to the inputs of the microprocessor device *9*, in which the private desirability d_1, d_2, d_3 and the generalized desirability function (D), which is the geometric mean of the desirability of individual parameters of the technical state, are calculated according to the program. The obtained results are displayed on the panel of the display unit *10*. The device can work both in continuous mode and in express control mode [7-8].

3. Conclusions

To solve the problem of a complex (integral) assessment of the technical condition of a pad brake or to compare the technical conditions of several units of pad brakes, it is possible and appropriate to use Harrington's desirability functions on the basis of which technical means of monitoring and assessing the technical condition of pad brakes can be developed.

Acknowledgement

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Internal Structural Defects Determination of Polymer Composite Using Lock-in Thermography

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Abstract

Today, polymer composites are widely used materials in the construction of various types of vehicles. Their high strength and low weight are mainly used. They thus become an alternative to classic metal materials. Composite parts of vehicles are stressed during operation by various forces that can cause internal (hidden) defects. The problem is to locate these defects without the disturbing the structure of c,omposite parts. The possibility of solving this problem is the use of a suitable non-destructive method - for example infrared (IR) thermography. IR thermography shows the distribution of heat fields on the monitored surface. It is a method of obtaining information (in the form of a thermogram) about the structure of the surface and/or subsurface layers. We know two types of IR thermography - passive and active. This article describes the use of active IR thermography for defectoscopy of glass composite plates.
KEY WORDS: *thermography, defectoscopy, nondestructive testing (NDT), discrete Fourier transform (DFT)*

1. Introduction

Lock-in thermography (LiT) is a type of active thermography [1-3, 6, 7, 9] that uses thermal excitation of the material (Fig. 1). This excitation takes the form of a thermal wave with a sinusoidal character. As a result, the change of phase of the excitation and observed thermal wave is measured (observed wave is a result of interference between excitation and reflected wave). Phase or specifically phase angle has the advantage of being independent of local changes of illumination and emissivity.

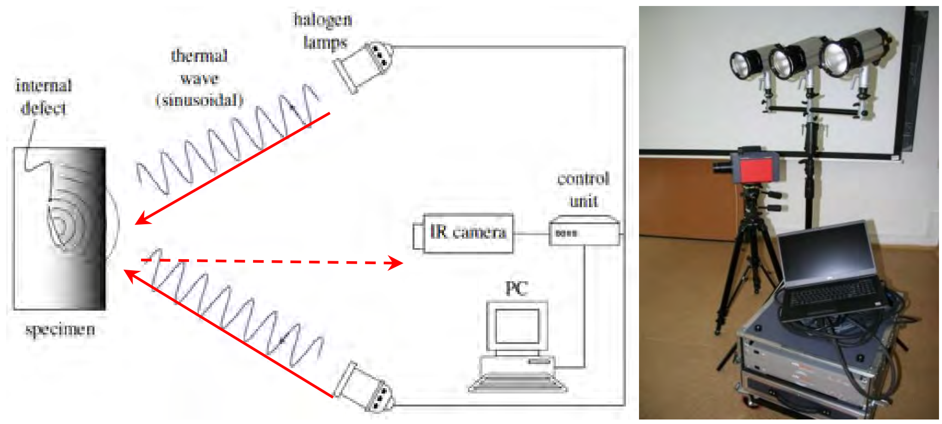

Fig. 1 a – Principle of Lock-in thermography [1]; b – Edevis-OTvis/Infratec thermography system [1]

2. Theory of Thermal Wave

The thermal wave used in LiT [3] has a sinusoidal shape. The advantage of a sinusoidal input (excitation wave) is that the output has an unchanged shape with the same frequency. The output wave has a changed amplitude and phase. From the source the thermal wave propagates through the air by thermal radiation. After contact with the solid material, further heat propagation (inside the material) is carried out by conduction. Internal defects affect the propagation of heat in the material and cause a change in the amplitude and phase of the output wave propagating from the material back to the source.

Heat diffusion through a solid material can be described by Fourier's law as:

$$\nabla^2 - \frac{1}{\alpha}\frac{\partial T}{\partial t} = 0\,, \tag{1}$$

where α – thermal diffusivity (of the tested material); k – thermal conductivity; ρ – density; c_p – specific heat (at constant pressure).

Assume a semi-infinite homogeneous solid material. The propagation of a periodic thermal wave in this environment is described by Fourier's law for a one-dimensional solution:

$$T(z,t) = T_0 e^{\left(-\frac{z}{\mu}\right)} cos\left(\frac{2\pi z}{\lambda} - \omega t\right). \tag{2}$$

where T_0 – initial change in temperature produced by the heat source; ω – modulation frequency; f – frequency; λ – thermal wavelength; μ – is the thermal diffusion length.

The rate of decay of the thermal wave during its penetration through the material is defined by equation:

$$\mu \equiv \sqrt{\frac{2\alpha}{\omega}} = \sqrt{\frac{\alpha}{\pi f}}. \tag{3}$$

If the heat wave is to penetrate deeper into the material, it must be modulated with a lower frequency.

Fig. 2 shows the input signal I and the output signal S. Both signals have the same sinusoidal character.

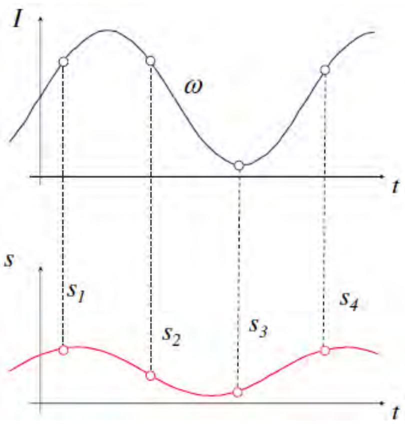

Fig. 2 Input (blue) and output (red) thermal waves

The changed amplitude and phase of output signals is calculated with using following formulas

$$A = \sqrt{(S_1 - S_3)^2 + (S_2 - S_4)^2}; \tag{4}$$

$$\varphi = tan^{-1}\left(\frac{S_1 - S_3}{S_2 - S_4}\right). \tag{5}$$

This 4-point method is only used for sinusoidal excitation wave. In addition, the output signal is distorted by thermal noise. This noisy output signal can be denoised, for example, by a greater number of cycles. From output data informations about amplitude and phase are obtained by discrete Fourier transform (DFT).

$$F_n = \Delta t \sum_{k=0}^{N-1} T(k\Delta t) e^{(-i2\pi nk/N)} = Re_n + Im_n, \tag{6}$$

where i – imaginary number ($i^2 = -1$); n – frequency increment ($n = 0, 1, ... N$); Δt – sampling period.

The value of amplitude and phase of output signal is obtained from real and imaginary parts of DFT.

$$A_n = \sqrt{Re_n^2 + Im_n^2}; \tag{7}$$

$$\varphi_n = tan^{-1}\left(\frac{Im_n}{Re_n}\right). \tag{8}$$

Considering the existence of a relationship between the depth of the defect and the thermal diffusion length, it is possible to formulate an empirical relationship for the depth of the defect as a function of the initiating thermal wave frequency (Fig. 3).

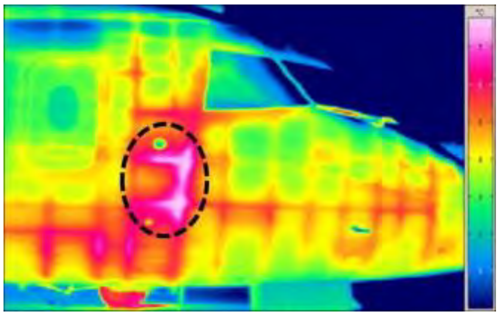

Fig. 3 Example of IR defectoscopy - defect in aircraft's fuselage [8]

3. LiT of Polymer Composite Material

A common polymer composite is a system of polymer matrix and reinforcing fabric. By combining these two components, mechanical properties are achieved that the individual components do not have. Reinforcing part is often glass, aramid (Kevlar) or carbon fabric (Fig. 4). The matrix is usually epoxy resin.

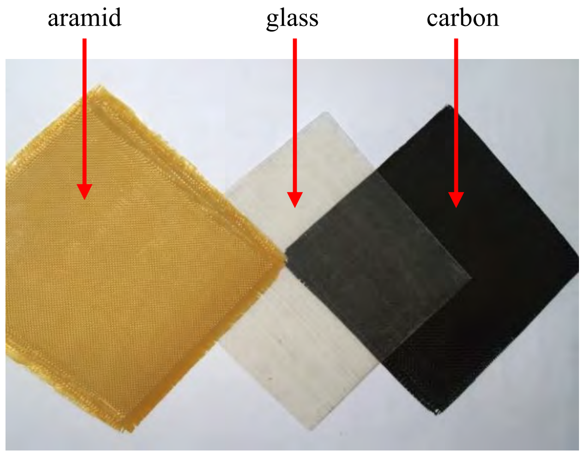

Fig. 4 Composite plates [1]

The resulting mechanical properties of the polymer composite are primarily determined by the properties of the fabric, the matrix, their mutual volume ratio and the geometry of the fibers in the reinforcing fabric.

Subject of interest [1] in connection with LiT at Department of mechanical engineering of our university (Armed Forces Academy Liptovský Mikuláš, Slovakia) is defectoscopy of polymer composites material [4-5, 10]. These materials are widely used in advanced military technologies of ground and aerial vehicles (manned and unmanned). The problem can be the hidden defects of composite materials. Hidden defects can occur in the production process of these materials or by operational stress by external forces, which have an negative impact on the mechanical properties. Therefore, it is important to detect these defects. One option is to use the active thermography.

4. Experimental Thermography Measuring of Glass Polymer Composite

For experimental purpose was made experimental specimen (glass composite plate 300 × 300 mm) consisting from ten layers of glass fabric (with weight per unit area 163 g/m^2). By inserting of impurity particles, between neighboring layers, was created ten localities of artificial defects - each location is at a different depth (Fig. 5).

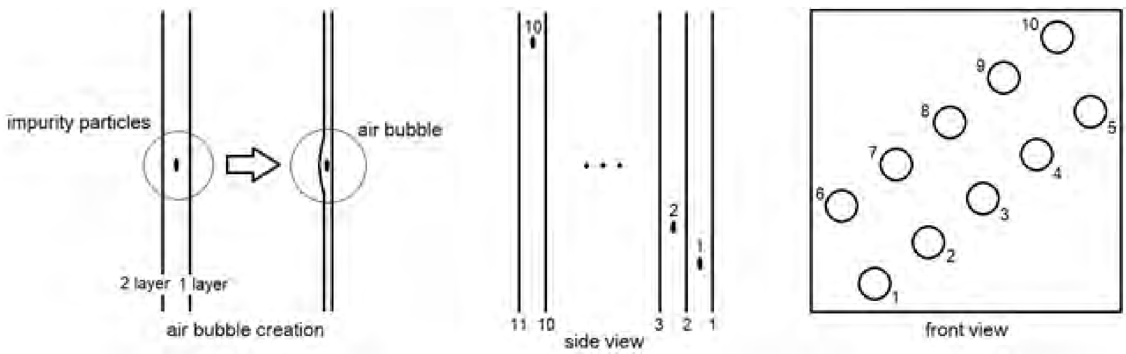

Fig. 5 Structural arrangement of the specimen

In these locations, inserted impurity particles, prevented connection of layers - in the same areas, air bubbles were created. Placement of defects 1 thru 10 in specific depths of composite plate is shown in following Table 1.

Table 1

Depth of artificial defects

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
h [mm]	0.155	0.31	0.465	0.62	0.775	0.93	1.085	1.24	1.395	1.55

Depth thermal wave penetration depends on its frequency. For finding this dependency (for layered glass composite plate) was used Edevis-OTvis/Infratec thermography system.

The tested sample was initiated by a thermal wave with a power of 6 kW. The following picture shows the situation when the sample was exposed by thermal wave with the frequency of 0.43 Hz. At this frequency, defect No. 5 shows optimal contrast (red arrow) (Fig. 6).

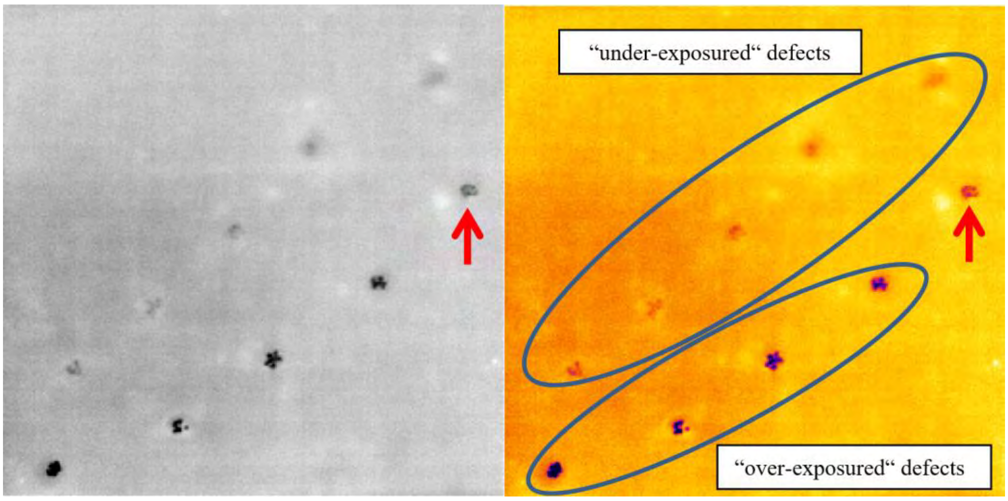

Fig. 6 Example of specimen thermogram (right is thermogram in the false color)

Table 2 shows the measured frequencies where the contrast of individual defects is optimal.

Table 2

Measured frequencies for individual defects

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
h [mm]	0.155	0.31	0.465	0.62	0.775	0.93	1.085	1.24	1.395	1.55
f [Hz]	0.55	0.5	0.47	0.46	0.43	0.38	0.35	0.21	0.16	0.13

The measured frequencies dependent on the defects depth were processed by the method of least squares, according to the following equations.

$$a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} x_i y_i \,; \tag{9}$$

$$a\sum_{i=1}^{n} x_i + bn = \sum_{i=1}^{n} y_i \,; \tag{10}$$

$$\begin{bmatrix} \sum_{i=1}^{n} x_i^2 & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & n \end{bmatrix} \cdot \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} x_i y_i \\ \sum_{i=1}^{n} y_i \end{bmatrix}; \tag{11}$$

$$\begin{bmatrix} 9.249625 & 8.525 \\ 8.525 & 10 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} 2.4955 \\ 3.64 \end{bmatrix}; \tag{12}$$

$$\begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} 9.249625 & 8.525 \\ 8.525 & 10 \end{bmatrix}^{-1} \cdot \begin{bmatrix} 2.4955 \\ 3.64 \end{bmatrix}; \tag{13}$$

$$a = -0.3065\,;\; b = 0.6253\,. \tag{14}$$

Resulting dependency has the form

$$y = -0.3065x + 0.6253\,; \;\; f = -0.3065h + 0.6253\,. \tag{15}$$

The result is the dependence of the frequency of the initiating thermal wave on the depth of the monitored defect (calibration line) (Fig. 7). Of course, this dependence is only valid for a composite made of concrete epoxy resin, reinforced with glass fabric with a surface weight of 163 g/m^2. For other glass laminates (manufactured from other components), it is necessary to determine a new dependence by LiT measurement.

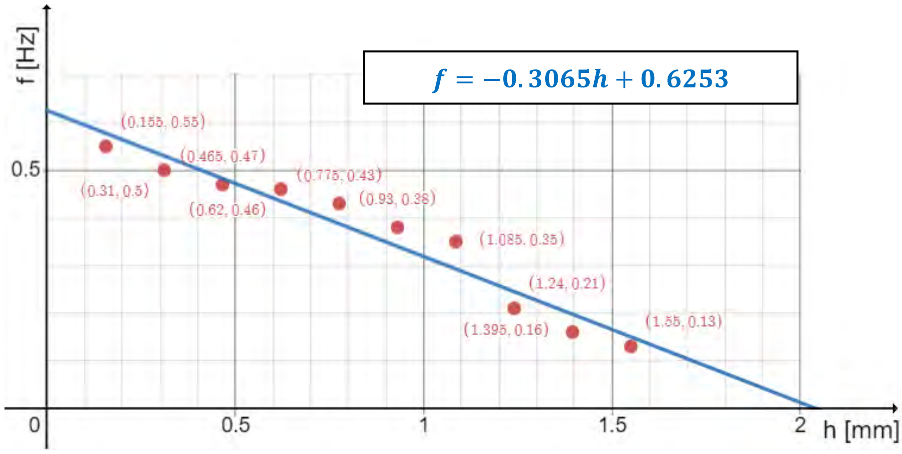

Fig. 7 Calibration line for experimental specimen

Dependence represented by equation (16) can then be used for IR defectoscopy (LiT method) of composite materials made from the following components - epoxy resin LH 287, hardener H 513 and glass fabric Aeroglass 163g/m2 (Havel Copmosites, Czech Republic).

5. Conclusions

Active thermography is a useful method for structural study and detecting internal (invisible) defects. The advantage of the thermography method (including LiT) is the fact that it is an NDT method without mechanical damage to the tested surface. The method described in this work can be used for any polymer composite materials.

Acknowledgements

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Structural Design, Simulation and Numerical Comparison of the Dynamic Analysis of High-Speed Railway Bridges Using ABAQUS and Caldintav 3.0 Software

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Abstract

Structural analysis of high-speed railway bridges is crucial to estimate the dynamic behaviour of the bridge due to external loads with extreme velocities. It is for this reason numerical simulations are performed to ensure the structural integrity of the bridge before actual construction. This research aims at analysing a short railway bridge of span 4 m, 6 m in width and 0.4 m in height in two different software, ABAQUS (an advanced finite element analysis software suite) and Caldintav 3.0 (Special software developed by the Computational Mechanics group, Polytechnic University of Madrid, Spain) comprising dynamic moving loads varying from 250 – 300 km/hr. The motive of the research is to numerically solve the bridge individually in each software and conclude with the comparative results of acceleration in PYTHON. The main objective is to manifest, how precise Caldintav 3.0 can provide solutions compared to an advanced finite element suite with a more user-friendly interface. In conclusion, the difference in the obtained solutions visualized is explained with appropriate remedies.
KEY WORDS: *Structural Integrity, Dynamic Analysis, Numerical Simulation, High-speed railway bridge, Finite Element Analysis, Acceleration*

1. Introduction

Structural dynamics is a type of structural analysis which covers the behaviour of a structure subjected to dynamic (actions having high acceleration) loading [1]. Structural analysis is important as it provides a basis for structural design, and it evaluates whether a specific structural design will be able to withstand external and internal stresses and forces [3].

For instance, Structural failure of bridges may arise due to several external and natural factors. Some of them include volume of traffic to be carried, climatic conditions of the area, nature and bed condition of the river and inappropriate hydraulic data collected [2]. It is for this purpose prior numerical simulations are carried out to evaluate the structural behaviour of the bridge and authenticate its structural integrity [5].

Scrutinizing the significance of structural analysis due to dynamic loads, the methods applied to solve these intricate numerical simulations plays a vital role in field [4]. Some methods require complex parameters for simulation to provide solutions whereas others may not require such and might have a user-friendly interface to draw the same results [6-14].

This research renders one of these cases where the results obtained from the numerical simulation an advanced finite element suite (ANSYS) is graphically compared to the simulation feasibly carried out in Caldintav 3.0 (Software developed in MATLAB and PYTHON by the Computational Mechanics group at the Polytechnic University of Madrid, Spain). A valid point to be considered, only beam model of the railway bridge is considered for numerical analysis in a 2D model to better assess the beam characteristics of the bridge in the form of bending and torsion. 3D Model possibly could be designed in ABAQUS but cannot be appropriately defined in Caldintav 3.0 as it is pre-programmed with PYTHON codes.

Conclusive evidence of the preciseness of Caldintav 3.0 in numerically solving a complex dynamic problem enhances the main objective of the research and promotes its usage in such dynamic analysis of railway bridges.

2. Methodology Applied in ABAQUS

A simple short railway bridge of length 4 m is structurally designed as a 2D beam model in ABAQUS FEM Suite. Considering 2D beam model, the bridge is subjected to only bending characteristics neglecting the torsional behaviour.

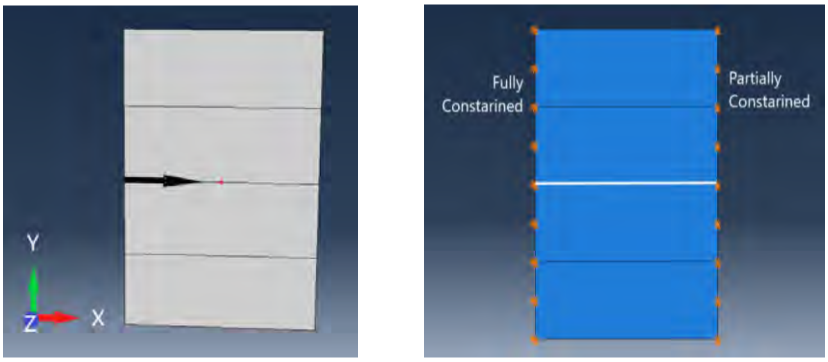
Table 1

Bridge Properties

1.	Length	4 m
2.	Width	6 m
3.	Height of section	0.4 m
4.	Youngs Modulus	34 e^9 Pa
5.	Poisson Ratio	0.25
6.	Shear Modulus	10e^9 Pa

The train s112 5 AVRIL with a velocity of 300 km/hr is considered as the moving load for analysis. These loads tend to be pre-programmed in PYTHON accordingly which when applying appropriate keywords can be read by ABAQUS and respective motion can be provided.

The below Fig. 1, a presents the top view of the bridge designed in 3D modelling space with a rectangular shape which is of deformable type. A red dot in middle of the bridge can be visualized in Fig. 1, a, all the obtained solutions are based on the respective point. The direction of the train acts with respect to the black arrow seen in the center of the bridge along x-axis.



a b

Fig. 1 a – Top view of the bridge; b – Boundary conditions of the bridge

In Fig. 1, b, boundary conditions are set in such a way that the initial deck indicating the entry of train to the bridge is fully constrained leaving free rotation about z-axis whereas the point leaving the bridge is partially constrained leaving free motion along x-axis and rotation about z-axis. The section of the bridge is designated as beam with a rectangular profile, the dimensions are assigned corresponding to the data specified in Table 1. The white line highlighted in the center of the bridge in Fig. 1, b marks the path of the train considering wire frame 2D analysis.

2.1. Finite Element Description

Table 2

FE Properties

1.	Element size	0.04 m
2.	No.of.elements	15200
3.	Element shape	Quad-dominant
4.	Mesh Technique	Structured

The above Table 2 presents the finite element description implied to discretize the model for numerical solving. A considerably small element size 0.04 m to numerically solve these high-speed train bridges is applied for analysis, as this element size is estimated to be ideal for this specific type of problem after a mesh sensitivity test, Increasing the element size or any other mesh parameter in the above-mentioned Table 2 resulted substantial changes in the results of acceleration ending up with a significant error rate between them

Applying the all the required parameters for numerical simulation, the mathematical model of the bridge is numerically solved. The concentrated force distribution at some particular moment, that tend to displace the bridge in y-axis during the motion of the moving loads is shown in Fig. 2, observations can clearly reveal the bending characteristics of the bridge disregarding torsion as it is constructed as a 2D model but is visualized in a 3D view.

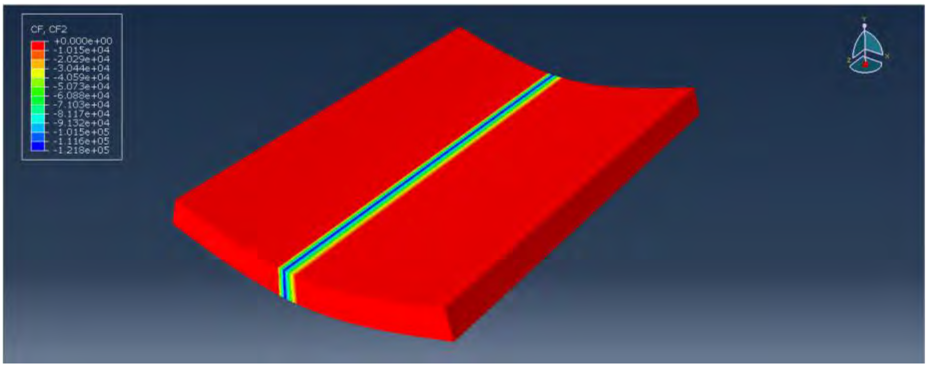


Fig. 2 Concentrated force distribution at some particular moment, displacing the bridge in y-axis

2.2. Results Obtained in ABAQUS

The concentrated forces to deform the bridge in y-axis are obtained with the velocity of the train being at 300km/hr. The total distance between the front and last axle of the s112 AVRIL train is 391.58 m in length. The total length of the train is estimated at 400 m.

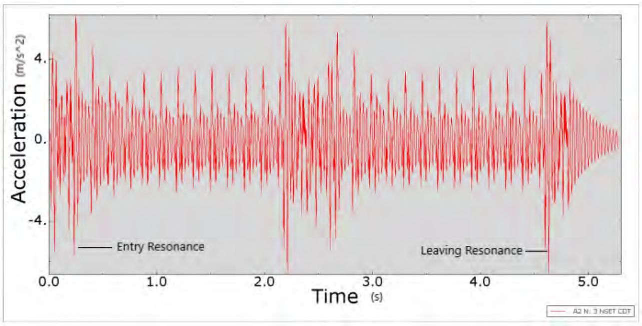


Fig. 3 Acceleration of the bridge in ABAQUS

The above Fig. 3 presents the dynamic results of the acceleration of the bridge numerically solved in ABAQUS. Previously mentioned, the solutions obtained are based on the point marked at the center of the bridge. The initial and final resonance observed in the graph represent the stages where the train enter and leaves the bridge.

3. Methodology Applied in Caldintav 3.0

Caldintav 3.0 is an advanced software developed with PYTHON and MATLAB codes to solve the dynamic analysis of railway bridges feasibly with a considerably less computational time when compared to ABAQUS. The main justification for this is due to the fact that all complex estimations to be declared are pre-programmed in the form of PYTHON and MATLAB codes including train data, distance between the axles, loads acting between them, etc... Some simple adequate parameters and analytical estimations stand to be enough to solve complex problems in this field.

3.1. Analytical Estimations

Mass of the bridge and Bending stiffness are two main parameters to initially describe the bridge data in Caldintav 3.0 and be obtained:

$$Bending\ Stiffness = E * I, \tag{1}$$

where E – Young's Modulus and I – Inertia of Cross-section.

$$I = bh^3 / 12, \tag{2}$$

where b – breadth of Cross-section = 6 m; h – height of Cross-section = 0.4 m,

$$Bending\ Stiffness = 1088\ e^6\ \ Nm^2 (3).$$

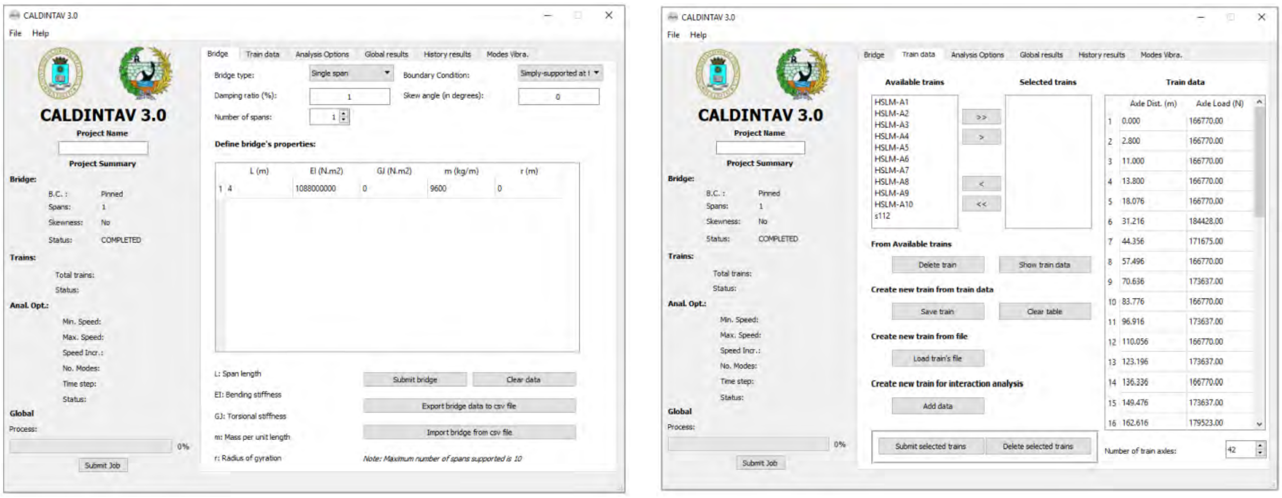
Distributed mass of the bridge:

$$M = Density * b * h, \tag{4}$$

where *Density* = 4000 kg/m^3, b = 6 m and h = 0.4 m.

The distributed mass of the bridge is estimated as:

$$M = 9600 \text{ kg/m}. \tag{5}$$



a b

Fig. 4 a – Bridge data in Caldintav 3.0; b – Train data in Caldintav 3.0

Other fundamental parameters are essential to describe the bridge in Caldintav 3.0 as shown in Fig. 4, a. The bridge type similarly as in ABAQUS model is considered as a simply supported short span bridge of length 4 m and damping ratio 1%. These parameters can be altered as per the requirements of the bridge to be constructed. Caldintav 3.0 has been pre-programmed with some high-speed trains currently active in Spain with their respective axle distances and axle loads accordingly, Fig. 4, b presents the data of each train that has been loaded and options to select it.

The process is carried on the analysis section, A moving load dynamic analysis is opted with 1 mode and 0.001 s time increment level. The trains maximum and minimum speed are defined as 300 and 250 km/h respectively with a 10 km/hr increment rate. Conclusively, the job is submitted for analysis and the required solutions are obtained in the global results and history results section.

3.2. Results obtained in Caldintav 3.0

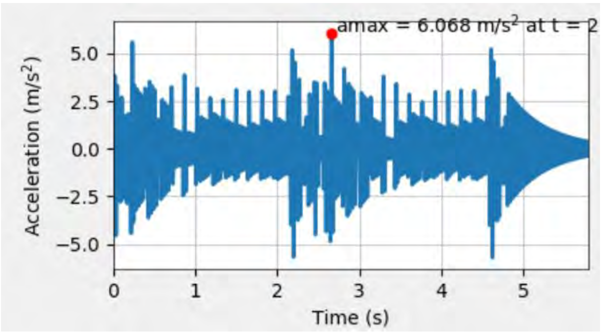


Fig. 5 Accelaration of the bridge in Caldintav 3.0

The above Fig. 5 presents the dynamic solution of the acceleration obtained in Caldintav 3.0. Visualising the results, it almost resembles the solutions obtained in ABAQUS informs of resonance and time dynamic fluctuation in solutions. The maximum acceleration observed is found to 6.068 m/s^2 at the time interval 2.6 s.

4. Comparison of ABAQUS and Caldintav 3.0

Fig. 6 presents the graphical comparison of acceleration of the bridge obtained from ABAQUS and Caldintav 3.0. The comparison was generated by PYTHON codes, the similarities in the wave forms of the solutions obtained can be evidently observed.

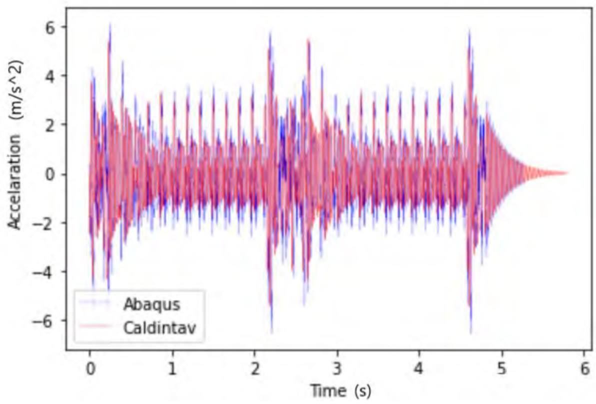


Fig. 6 Graphical comparison of the acceleration

5. Conclusions

The dynamic analysis of a short 4 m high-speed railway bridge was solved in two software encompassing different algorithms for solving. ABAQUS tends to be an advanced finite element suite to numerically solve mathematical models, whereas Caldintav 3.0 is a software package developed with an analytical algorithm by the Computational Mechanics group at UPM, Madrid to solve dynamic problems of railway bridges. The main objective of the research was to approximate how precise Caldintav 3.0 could provide results when compared to a FEM suite entirely solved with a different algorithm. In this analysis, the amplitude of acceleration is mainly compared with ABAQUS and Caldintav 3.0. The amplitude of the acceleration obtained in ABAQUS resembles Caldintav 3.0 solutions by 82-87% as compared to PYTHON. Especially the resonance tends to peak linearly in the two methods. This tends to be ideal to estimate the structural behaviour of the bridge with moving loads equivalent to real loading conditions. This research has manifested the precision of Caldintav 3.0 and influences its usage to solve the dynamic analysis of high-speed railway bridges. A user-friendly interface, less computational time and feasible parameter defining make Caldintav 3.0 an effective package that can be applied as an alternative to ABAQUS specifically in these types of problems.

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Assessment of the Readiness of the Selected Object of Transport Infrastructure for Violent Attacks

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Abstract

The article is focused on the assessment of the readiness of a selected transport infrastructure object for a violent attack. The protection of soft targets is an area that has been addressed as a priority in security for several years. Transport infrastructure is one of the most endangered destinations due to its attractiveness, a large number of passengers, openness and often also due to its international character. The article aims to show the assessment of the readiness of the security system, both from a technical and human point of view, on one selected object. Based on the risk analysis, the threat of the given object, vulnerabilities and weak points will be evaluated. Subsequently, we will focus on improving the system with an emphasis on the human factor, which is often neglected.
KEY WORDS: *readiness, violent attack, soft targets, transport infrastructure, protection*

1. Introduction

Transport infrastructure is an integral part of our lives. Each of us travels, transports from place to place, and no longer perceives it as something that might not be common and accessible. The article we present is mainly focused on railway transport. In the last year of this conference, we published a paper on the methodology we are creating and called it Identification and protection of soft targets of transport infrastructure [1]. One part of it deals with rail transport and we would like to follow up on that.

In recent years, the issue of soft targets and their protection has been addressed very actively and in detail. The aim is to assess the current state of security and preparedness for violent attacks. Honestly, most objects turn out badly, but the positive thing is that they are trying to improve their current condition and are looking for ways to strengthen their security. When planning security measures, it is important to look at security from a comprehensive perspective. Sometimes we encounter the approach that the owner of the object only follows the path of technical protection, but no longer decides who will respond to the alarm, whether the measures can stop the attacker, etc. Therefore, this article focuses on both our methodology is used and the design of safety measures - technical and non-technical. Recently, attention has been focused more and more on the employee and his readiness. Therefore, part of the article is devoted to their preparation, training and exercises.

2. Olomouc Central Train Station

For this article, we chose the main railway station in Olomouc, where we want to show how to work with our methodology. The general framework of the methodology was presented in an article [1] that was published in the previous year of this conference. Therefore, we will not describe the theoretical basis of the methodology and we will immediately show its application. Olomouc was chosen for several reasons. It is a large railway station, which is very busy, international and close is public transport and bus transport.

The data presented in the analysis are only illustrative, for some issues we had to change the information for security reasons. However, the aim of the article is not to present exact values, but to the process of creating an analysis.

Olomouc is a regional city and the railway station is a very busy place. The daily number of passengers is 11,000 and there are 17 routes [2]. The security incidents that occur here are related not only to the station but also to the adjacent public transport and bus stops and to the park, which is close. Thus, there are homeless people, verbal and light physical skirmishes, mass arrivals of fans of important sports matches, etc. are solved.

Within the building of the railway station, there is a cafeteria (Fig. 4), a waiting room (Fig. 5), of course, a platform (Fig. 6) and an underpass to the platforms (Fig. 7). All these places need to be addressed in the risk analysis because a high concentration of people can be expected here.

Fig. 1 Olomouc [3]

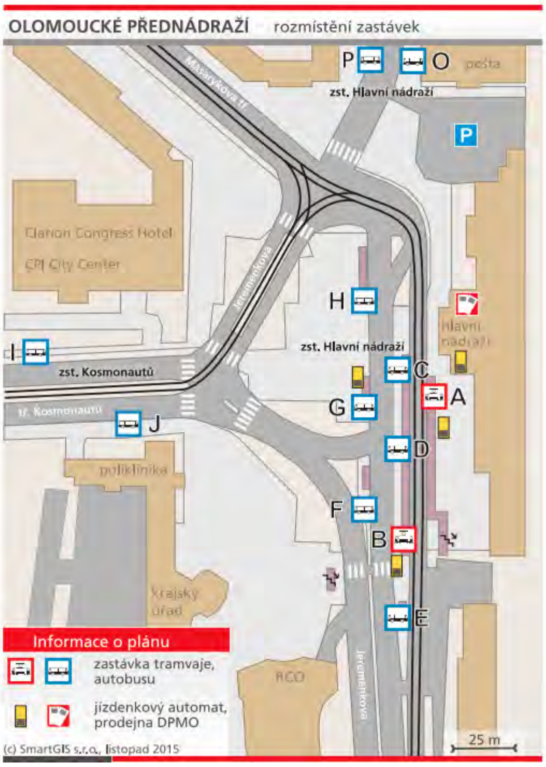

Fig. 2 Plan of train station [4]

Fig. 3 Olomouc central train station [5]

Fig. 4 Cafeteria

Fig. 5 Waiting room

Fig. 6 Platforms

Fig. 7 Underpass to the platforms

3. Demonstration of Work with Methodology of Identification and Protection of Soft Targets of Transport Infrastructure

The methodology is used to determine the riskiness of the object. It works with three aspects - identification, analytical and application aspect. All of them have a list of questions that must be answered YES / NO. Based on this, the resulting risk is calculated. A detailed description of the methodology is in the article Methodology of Identification and Protection of Soft Targets of Transport Infrastructure - an initial study, which was published last year at this conference.

The following chapter shows the work with the methodology on a selected building of the central railway station Olomouc.

3.1. Identification Aspect

Table 1

Identification aspect

ID	Controlled area	YES/NO
1.	**Coefficient expressing the number of connections per day (P_{sd})**	
1.1	Is the number of transport connections per day greater than 72 within the soft target (on average 3 connections per hour)?	YES
2.	**Coefficient expressing the number of passengers/people per day (P_{ld})**	
2.1	Does the total daily number of passengers exceed 5000/day?	YES
3.	**Coefficient expressing the number of passengers per hour (P_{lh})**	
3.1	Does the number of passengers exceed 200/h within the selected hourly interval?	YES

If the criterion is met and the answer Yes is given, the value 1 is assigned to the given variable, if the answer No is answered, the value 0.

$$A_{id} = \sum_{j=1}^{m} P_j v_j = P_{sd} \cdot v_{sd} + P_{ld} \cdot v_{ld} + P_{lh} \cdot v_{lh} \ . \tag{1}$$

Table 2

Standard weighting coefficients for calculating the risk identification aspect of the soft target of transport infrastructure [1]

	v_{sd}	v_{ld}	v_{lh}	Σ
v_j	0,20	0,35	0,45	1,0

Calculation of the resulting identification aspect:

$$A_{id} = 1 \cdot 0,2 + 1 \cdot 0,35 + 1 \cdot 0,45 = 1 \ . \tag{2}$$

Evaluation of the identification aspect: **<u><1;0,5> = large analytical aspect</u>**.

3.2. Analytical Aspect

Table 3

Analytical aspect

ID	Controlled area	YES/NO
1.	**Threat identification coefficient (K_{ih})**	
1.1	Does the soft target's owner identify and categorize threats?	YES
2.	**Asset identification coefficient (K_{ia})**	
2.1	Does the soft target's owner identify and categorize assets?	YES
3.	**Risk analysis coefficient (K_{ar})**	
3.1	Is the method and process of risk analysis described and implemented?	YES
4.	**Risk prioritization coefficient (K_{pr})**	
4.1	Are the risks, as an output of the risk analysis, prioritized?	YES
5.	**Object security documentation coefficient (K_{dz})**	
5.1	Does the soft target's owner have technical protection systems with a description (documentation) of the security of the building?	YES
6.	**Coefficient of regime and organizational measures (K_{ro})**	
6.1	Are regime and organizational measures set by the soft target's owner?	YES
7.	**Physical security coefficient (K_{fo})**	
7.1	Is physical security formalized within the soft target's owner and part of the physical protection system?	YES
8.	**Coefficient of insurance (K_{po})**	
8.1	Does the soft target's owner have insurance covering insurance risks specific to the protection of soft targets?	YES

In the case of a positive answer, the value 0 is set, in the case of a negative value 1.

$$A_{an} = \sum_{j=1}^{m} P_j v_j = K_{ih} \cdot v_{ih} + K_{ia} \cdot v_{ia} + K_{ar} \cdot v_{ar} + K_{pr} \cdot v_{pr} + K_{dz} \cdot v_{dz} + K_{ro} \cdot v_{ro} + K_{fo} \cdot v_{fo} + K_{po} \cdot v_{po} . \quad (3)$$

Table 4

Standard weighting coefficients for calculating the analytical aspect of the risk (vulnerability) of the soft target of transport infrastructure [1]

	v_{ih}	v_{ia}	v_{ar}	v_{pr}	v_{dz}	v_{ro}	v_{fo}	v_{po}	Σ
v_j	0,10	0,10	0,15	0,10	0,10	0,20	0,15	0,10	1,0

Calculation of the resulting analytical aspect:

$$A_{an} = 0 \cdot 0{,}1 + 0 \cdot 0{,}1 + 0 \cdot 0{,}15 + 0 \cdot 0{,}1 + 0 \cdot 0{,}1 + 0 \cdot 0{,}2 + 0 \cdot 0{,}15 + 0 \cdot 0{,}1 = 0 . \quad (4)$$

Evaluation of the analytical aspect: **<0,249;0> = large analytical aspect**

3.3 Application Aspect

Table 5

Application aspect

ID	Controlled area	YES/NO
1.	**Security management structure coefficient (K_{sb})**	
1.1	Does the soft target's owner have an established internal security management structure?	NO
2.	**Security Manager Coefficient; (K_{bm})**	
2.1	Is the position of security manager determined within the soft target's owner in connection with the issue of protection of soft targets?	NO
3.	**Object manager coefficient (K_{so})**	
3.1	Are facility managers appointed within the soft target's owner?	YES
4.	**Security Services Outsourcing Coefficient (K_{bs})**	
4.1	Are the soft target's owner's security services outsourced?	YES
5.	**Employee Liability Ratio (K_{oz})**	
5.1	Does the soft target's owner determine the responsibilities and tasks of employees in relation to the protection of soft targets?	YES
6.	**Coefficient of training and education (K_{sv})**	
6.1	Does the soft target's owner provide training and education of employees in connection with the protection of soft targets?	NO
7.	**Coefficient of control of security measures (K_{kb})**	
7.1	Is a security control process created and implemented within the soft target's owner?	NO
8.	**Security incident / incident resolution factor (K_{rb})**	
8.1	Does the soft target's owner have a process for resolving / reporting security events / incidents?	YES

In the case of a positive answer, the value 0 is set, in the case of a negative value 1.

$$A_{ap} = \sum_{j=1}^{m} P_j v_j = K_{sb} \cdot v_{sb} + K_{bm} \cdot v_{bm} + K_{so} \cdot v_{so} + K_{bs} \cdot v_{bs} + K_{oz} \cdot v_{oz} + K_{sv} \cdot v_{sv} + K_{kb} \cdot v_{kb} + K_{rb} \cdot v_{rb} . \quad (5)$$

Table 6

Standard weighting coefficients for calculating of the application aspect of the risk of the soft target of transport infrastructure [1]

	v_{sb}	v_{bm}	v_{so}	v_{bs}	v_{oz}	v_{sv}	v_{kb}	v_{rb}	Σ
v_j	0,10	0,15	0,05	0,15	0,10	0,15	0,10	0,20	1,0

Calculation of the resulting application aspect:

$$A_{ap} = 1 \cdot 0{,}1 + 1 \cdot 0{,}15 + 0 \cdot 0{,}05 + 0 \cdot 0{,}15 + 0 \cdot 0{,}1 + 1 \cdot 0{,}15 + 1 \cdot 0{,}1 + 0 \cdot 0{,}2 = 0{,}5 . \quad (6)$$

Evaluation of the application aspect: **<1;0,5> = small application aspect**

3.4. Results

According to the relation, the calculation and evaluation of the risk of the soft target of the transport infrastructure are realized as an arithmetic average of the values of the above steps, according to the relation (7).

$$R = \frac{1}{n}\sum_{i=1}^{n} D_i = \frac{A_{id} + A_{an} + A_{ap}}{3} . \tag{7}$$

Categorization of the vulnerability of the soft target of transport infrastructure:

<1; 0,5> = large vulnerability
<0,499; 0,250> = average vulnerability
<0,249; 0> = small vulnerability

In our case study at the railway station in Olomouc, the final calculation is:

$$R = \frac{1+0+0,5}{3} = 0,5 . \tag{8}$$

The final categorization of the vulnerability of the soft target of transport infrastructure: **<1;0,5> = large vulnerability**.

4. Security Measures

Securing an object such as a train station is not an easy task. Due to the frequency of passengers and the need for public access, this task cannot be approached by making it a so-called hard target. It is necessary to find a compromise between a sufficient level of security and the continuity of the main task of the building - the transport of people associated with a higher concentration of people. Although in the context of terrorist attacks on soft targets in Europe, states are looking for radical solutions, such as the installation of detection frames, random checks of passengers and their luggage and others [6], the functionality of the facility itself is limited, which can have a negative impact on the core station. Experience from security best practice shows that any security measure only makes sense if it is sufficiently well thought out in advance and embedded in a comprehensive security system that is thoughtfully designed. The architecture of the security system should reflect the fact that no individual security measure is effective until it is linked to other security elements, its conceptual application to the system is ensured, its advantages and disadvantages are taken into account and ways of further response to the stimuli obtained from this measure are defined.

Security measures can be divided into four basic segments:

- Physical security;
- Regime measures;
- Technical security;
- Security management.

Physical security is an important element of security. It is a human force that can appropriately evaluate situations on the basis of knowledge and experience and, in particular, has the ability to react. Other segments of security measures are mainly support systems that facilitate people's work and make it much more effective. It mainly contains security guards, but also includes any human staff who are available in the building and with whom we can work methodically, train them and give them roles and tasks in the security system. Not every train station can afford to be guarded by human staff. Especially smaller local stations do not have this option. Some are guarded by shared security guards that pass between stations. Such a security system has, in particular, a preventive effect. An offender who intends a more serious violent attack traces the regime of his target in advance and attacks out of the time when the guard is here. However, we can also use not security staff such as dispatchers, cashiers and others. These people do not have the potential to replace a guard, but with appropriate training they can detect dangerous situations quickly and respond appropriately (whether by direct response, triggering connections or effective information).

Regime measures are an important tool for achieving security. It is a set of rules of conduct that is allowed and prohibited. This makes it easy to identify and respond to unwanted behaviour. Without set rules, it is true that "what is not forbidden is allowed", which makes it very difficult to evaluate situations and require compliance with the rules. The regime measures also include the described scenarios, which are applied in the case of specific type situations. Thanks to the fact that these procedures are already prepared in advance, in the event of a security incident, there is no need to think creatively about how to behave. However, this requires an appropriate form of procedures and, in particular, thorough training and regular training of the staff concerned. This area is closely related to security management, which should evaluate the security situation, analyse the risks and apply appropriate settings and procedures. Frequent output of regime measures is operating and visiting rules with defined rules, safety guidelines and procedures and information signs.

Technical measures are the most common way to ensure the safety of most objects of a similar type. In many cases, however, they are not connected with other elements of the security system and their effectiveness is only presumed. If it is not precisely defined what the individual technical means are used for, whether the technical security architecture really meets the needs and set a system of response to possible negative events, which are detected by technical means, it is not an effective security system, which in this case serves mainly as a mild prevention (eg visible placement of cameras).

The potential of technical means is also seldom used. The most common representative in this category of measures is the camera system. On many buildings, cameras are installed in places with expected efficiency. The recording from these cameras is recorded on a recording device and a server, where it is stored for a set period of time and then continuously overwritten in a loop. Active camera surveillance is often not addressed. It only serves to trace the incident after we learn back that something happened. Today, however, camera systems have financially and technically available functions that will raise the level of the system and can partially replace the work of a human operator. Already the basic series of cameras support motion detection, which can monitor the entry into the restricted zone. However, in cooperation with a suitable server repository, a wide field of possibilities opens up, which is limited only by the imagination of the security architect. Here are some convenient features to use:

- Subject abandonment detection;
- Sudden change of direction of people (eg scattering on more sides during an attack);
- The fall of a person;
- Crossing the line;
- Remaining in a defined space;
- and more.

However, it is necessary to set how and who will react to the case when the camera system detects any of the set situations.

Security management covers and sets all segments of the security system. It should examine the security situation of the facility, analyse the risks and set measures that reduce or eliminate these risks. An integral part is also ensuring the safety awareness of all staff. Trained personnel are a key aspect of the security system, which is often neglected but plays a crucial role in the event of an attack and can mitigate its impact. Training should take place repeatedly and on the basis of an appropriate syllabus and content. It is recommended to train procedures regularly and practically. It is essential not only to know the procedures, but also subconscious root the reactions. In the case of a security incident, it is a highly stressful, fast and dynamic situation. One must act promptly and automatically. Training in the form of a short lecture and subsequent establishment of a procedure in a folder among other operational documents is not a suitable way.

5. Conclusions

The aim of the article was to show the work with the methodology we invented on a model example and to outline its practical applicability. The building of the main railway station in Olomouc was chosen due to its size, attendance and internationality. Based on the results of the methodology, the possibilities of security measures of both technical and non-technical nature were discussed.

Acknowledgement

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Efficiency of the Project of Using a Crushing Cleaning Machine

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Abstract

Scientific organization of track works provides effective use of mechanization and automation of production processes, high quality of their execution at the lowest cost of labor, materials and energy. It is proposed to use the track machine "RM-80" for mechanized cleaning of crushed stone ballast contamination, for all types of track repairs and its current maintenance. Economic calculations of the RM-80 project implementation project showed and crushing stone machine "RM-80" will ensure efficient operation of the track.
KEY WORDS: *track work, crushed stone ballast, mechanized cleaning, pay-back period, profitability index*

1. Introduction

For efficient maintenance of the track, it is necessary to reduce manual labor and introduce machines that would be able to provide mechanized cleaning from contamination of crushed ballast of the track and turnouts, transportation (movement) of crushed stone back into the track or into a wagon, or to the roadside with a complete cut of ballast and laying of crushed stone cleaning in the track grid during all types of repair and ongoing maintenance of the track, as well as the construction of new railways. It is proposed to determine the effectiveness of the introduction of crushed stone cleaning machines for mechanized cleaning of crushed stone from ballast pollution, for all types of track repair and its current maintenance.

2. Analysis of Achievements in this Area

Innovative activity is the most important component of the process of successful functioning and development of any enterprise, as well as one of the basic elements of an effective strategy and an important tool for creating and maintaining competitive advantages. This activity does not bypass railway transport enterprises and is primarily aimed at the safety of train traffic, which depends on the state of the track superstructure. Contaminated crushed stone ballast is a mixture of mineral particles and pollutants (coal, cement, clay, ore, soil, petroleum products, etc.) compacted by the train load, which reaches 30% or more, while it should be taken into account that the degree of clogging of ballast in sleeper boxes is significantly higher , than under the sole of the sleeper. Periodic restoration of the physical and mechanical characteristics and geometric parameters of the ballast prism is carried out by cleaning the crushed stone or, in case of non-compliance of the ballast placed in the track with the required characteristics, by replacing it completely with crushed stone of hard rocks by machines for cleaning and replacing it. In this regard, great attention is paid to deep cutting and cleaning of ballast prism, creation of modern high-performance rubble cleaning machines.

The effectiveness of track work is aimed at the use of means of mechanization and automation of production processes, with the lowest costs of labor, materials and energy.

A wide range of issues and methods of solving them, related to the evaluation of the effectiveness of innovation and investment projects of business entities, is highlighted in the works of domestic and foreign economists:

G. Birman, I. Blank, M. Bakanov, V. Bocharov, A. Bystryakov, P. Vilenskyi, L. Gitman, V. Hrynyov, A. Zagorodniy, L. Lakhtionov. A. Marshall, A. Mertens, E. Chetyrkina, V. Sheremet, U. Sharp, E. Shilov, S. Shmit, A. Sheremet and other. Innovation and investment projects of Ukrzaliznytsia enterprises have not been considered in full.

The aim of this work is to evaluate the effectiveness of the investment project of introducing crushed stone cleaning machines into the production process to ensure high-quality performance of track works.

3. Materials and Methods of Research

The development of Ukraine's economy was mainly due to the restoration of the old technical base and loading of free production capacities. Now the economic situation is worsened by military actions: people are dying, infrastructure and industry are being destroyed. After the end of the war, we will be in completely different economic circumstances than before it, so a different economic policy will be needed, and the circumstances provide a chance to create a new structure of the economy, to move from a raw material-agrarian type to an innovative-technological one in order to sell society products / services / with high added value.

JSC "Ukrzaliznytsia", which plays a leading role in the country's economy because it is a system-forming factor and affects the standard of living and the development of productive forces, will also undergo changes.

In Ukraine, the level of wear and tear of all 21.7 thousand km of tracks of JSC "Ukrzaliznytsia" in general has already reached 50%, and 27% of all highways require complete reconstruction. In addition, the situation with other elements of the railway infrastructure is extremely difficult. So, for example, the fleet of special equipment for repairing railway tracks has already worn out by 78% [1].

Higher requirements will be imposed on the technical condition of the railway track, namely on its stability. This, in turn, involves the performance of a large and high-quality volume of repair work of the upper track structure.

In this situation, only innovations can lead the economy to the path of stable development, which would become an adequate task that should be solved by railway transport enterprises. One of the most problematic aspects of the development of innovative activities of JSC "Ukrzaliznytsia" was and is the uncertainty of the institutional foundations of the formation of the innovation system, the lack of perfect regulatory and legal regulation of innovative development, and favorable conditions for the development of innovations have not been created.

In order to ensure the growth of the effective operation of the track, it is proposed to introduce the RM-80 crushed stone cleaning machine [2] for the mechanized cleaning of crushed ballast contaminants from tracks and turnouts with a load of contaminants into a specialized mobile warehouse or its discharge down the slope and stacking of cleaned crushed stone

The RM-80 machine is equipped with a chain - for cutting out contaminated ballast, which falls into a freely moving vibrating screen. For the track on the run, the machine is equipped with a planning device that ensures an even distribution of crushed stone falling onto the track. The chain is located in two lateral inclined and one horizontal guide. The machine is equipped with a device for distributing clean ballast. A plow ejector is used to clean crushed stone from rails and sleepers. The technical characteristics of the RM-80 crushed stone cleaning machine are given in Table 1 [3].

Table 1

Technical characteristics of the crushed stone cleaning machine "RM-80"

Characteristic	Values
Length over buffers	30 m
Basic length	23 m
The distance between the axles of the carts	1,83 m
The weight of the car	96 t
The load on the axle of the wheel pair is no more than:	20 t
Total engine power	698 kW (946 hp)
Maximum speed at its own pace	80 km/h
Cleaning width	4 m
Cleaning width (when cleaning railroad switch)	7,7 m
Maximum cleaning depth	1 m
The height the chain	290 mm
Chain drive power	320 kW
Ambient temperature for operation	from -20 to +40 °C
The length of the beam of the chain	2,9 m

To change or increase the cutting depth and bypass obstacles, the machine is equipped with a lifting and moving device, as well as measuring systems for controlling the depth of cleaning and the transverse inclination of the cutting knife. To remove the compacted and contaminated ballast from the sleeper boxes, an ejector punching device is used. The machine is equipped with a special device for stacking textile rolls under the slatted grate.

The studies that were conducted on the Zhytomyr section of the track showed that the overhaul of the track takes place with a significant use of manual labor, that is, it is very labor-intensive and time-consuming. In developed countries, track overhaul works are carried out entirely with the use of machines, the latest tools that minimize the cost of manual labor. With the introduction of the "RM-80" machine, the number of operations, which had been carried out by people until now, significantly decreased. The total duration of the capital repair for the repair by fitters was 2203.8 man-hours, and with the introduction of "RM-80" - 254.2 man-hours. That is, the repair time will be reduced by almost 9 times [4].

Today, evaluating the effectiveness of investment projects is one of the urgent tasks of the enterprise. The effectiveness of the investment project is an indicator that reflects its compliance with the goals and interests of the participants. We will determine whether the project of introducing the "RM-80" machine into the production process is effective and how long the investment will pay off.

The main indicators of the effectiveness of investment activities at the micro level in the implementation of direct production investment include:

1. Net present value (NPV);
2. Internal rate of return (IRR);
3. Pay-back period (PP);
4. Rate index (RI). [5].

Net present value, or net discounted value, is the difference between the amount of cash flow discounted at an acceptable rate of return and the amount of investments. In economic terms, it is the discounted profit that the investor will receive after the implementation of the investment project [5].

The investment costs required for the purchase of the RM-80 crushing stone machine amount to UAH 27,696,000. For example, in Austria, when using the RM-80 machine, 3 fitters, 1 foreman and 3 drivers are involved in the process of repairing 1 km of track. And the work is completed in 3 days, depending on the territory where the work is carried out. [4]. If the "RM-80" machine will work only on working days (an average number of 250 days), then in a year it is possible to repair 83,333 km of track.

The calculations showed that the total costs for major track repairs using the automated track machine "RM-80" amount to UAH 195,225.16, and using manual labor - UAH 330,001.2. That is, when buying "RM-80" you can save UAH 134,776.04 per kilometer [4]. So, if you repair 83,333 km per year with a savings of UAH 134,776.04 per kilometer, the profit is UAH 11,231,288,000. According to the Tax Code of Ukraine, profit is taxed at the rate of 18%. The annual net profit is UAH 9,883,533,000

Net cash flow in the project is defined as the sum of net profit and depreciation deductions after taxation.

Ukrainian accounting standards 7 "Fixed assets" defines amortization as a systematic distribution of the amortized value of non-current assets over the period of their useful use (exploitation) [6]. In Ukrainian accounting standards 7 "Fixed assets" and in the Tax Code of Ukraine the following methods of amortization of fixed assets (except for other non-current tangible assets) are defined: straight-line, reduction of residual value; accelerated reduction of residual value; cumulative; industrial.

The international accounting standard 16 "Fixed assets" directly indicates three methods (paragraph 62): the straight-line method, the method of reducing the balance, the method of the sum of production units (similar to our production method) [7].

Enterprises can choose the amortization method themselves and calculate the rate at which fixed assets will be depreciated.

According to the Tax Code of Ukraine, the minimum allowable amortization period for cars is five years. For simplicity of calculations, we assume 10 years and use the straight-line amortization method. According to the passport data, the weight of the car is 96 tons. At a scrap metal price of UAH 4.5 per 1 kg [8], the liquidation value is UAH 432,000. The amortizable value is UAH 27,264,000, so UAH 2,726.4 thousand is amortized per year

To evaluate the effectiveness of investments in the project, it is necessary to bring the future value of cash flows to the current value using the discount rate. Determining the discount rate is a rather difficult task from a methodological point of view, since it is not directly observable on the market. Therefore, the reliability of setting the discount rate directly depends on the results of the cash flow discounting method. From this arises the need for a correct approach to accepting this rate. Therefore, the discount rate ¬ is a dynamic interest rate determined by the change in risks, sources of financing and their ratio, and, therefore, by the expected profitability, and is used to bring future cash flows to the current moment [9].

The discount rate is used to determine the amount an investor would pay today for the right to assign future cash flows. In the economic sense, the role of the discount rate is the rate of return required by investors on invested capital in similar risk-level investment objects, or it is the required rate of return for available alternative investment options with a comparable level of risk as of the valuation date. [10]. There are the following methods and approaches for determining the discount rate:

- a model for evaluating capital assets of CAPM;
- calculation of the discount rate based on the weighted average cost of equity capital (WACC);
- cumulative method;
- constant growth dividend model (Gordon's DDM);
- method of expert evaluations.

All of the above methods are based on the rule that the discount rate should be greater than the risk-free investment.

In developed countries, the risk-free rate is the rate on bonds of the domestic government loan, which are considered the most reliable securities

In the assessment activity, one of the most common methodological approaches to the assessment of both enterprises and individual projects is the income approach. As part of the income approach, the method of direct capitalization and the method of discounting cash flows are used. To use the direct capitalization method, the capitalization rate is determined, to determine which the discount rate is calculated, which is adjusted for the periodic rate of income growth or decline. Thus, in order to use the specified methods, it is necessary to determine the discount rate. The value of the discount rate significantly affects the results of the evaluation, and as a result, the decision to invest in the object of evaluation or the choice of an investment project. There are many methods of determining the discount rate, each of which has certain advantages and disadvantages. The choice of the method for determining the discount rate depends on the purpose of the assessment, the type of cash flow, the availability and reliability of information about the market environment, the very specifics of both the internal and external environment of the object of assessment. Due to the large number of methods for determining the discount rate, the factors affecting it, and the significance of its influence on the final evaluation results, there is a need to analyze, generalize, and determine the most acceptable method in the current state of economic development of Ukraine [11].

The cumulative method of determining the discount rate involves the assessment of factors that accumulate the risk of not receiving the planned income. It, like the CAMP method, is calculated using the risk-free rate of return, but it is devoid of the latter's disadvantages associated with the underdevelopment of the country's stock market. From an economic point of view, the use of the cumulative method is based on the assumption that the higher the risk level of the project, the higher the investor's requirements for its profitability.

$$r = r_f + r_p + I, \tag{1}$$

where r – discount rate according to the cumulative method; r_f – risk-free rate; r_p – risk premium; I – the inflation rate.

The disadvantages associated with setting the risk-free rate are described in the description of the CAMP method for determining the discount rate. To determine the premium for the risk of investing in a certain project or enterprise, the following factors are taken into account: the size of the enterprise, the capital structure of the enterprise, the diversification of the main consumers of the enterprise's services/goods, production and territorial diversification, the level of the enterprise's profitability and the predictability of its profits, the quality of the enterprise's management, specific factors risk inherent in both conducting business in the country as a whole and the industry and region in which it operates. In fact, as in the CAMP model, the risk premium takes into account both systematic and unsystematic risks. The use of the cumulative method in countries with an unstable macroeconomic situation and an underdeveloped stock market is the most common. Actually, the fact that the use of the method does not require specific data on the conclusion of the agreement, retrospective information on stock quotations is its advantage. However, all components of the risk premium are exclusively a subjective assessment of experts, which is the result of the low reliability of the results obtained with its help. In addition, in the conditions of the economic situation in which Ukraine is now, the inflation index is difficult to predict, which adds subjectivity and reduces the reliability of determining the discount rate by the cumulative method [11].

In order to level the subjective assessment of experts in this paper, the discount rate is based on the interest rate on possible company loans [12].

So, according to the Ministry of Finance of Ukraine [13], as a rule, the discount rate consists of three components:

– the interest rate on borrowed funds is the reward that the creditor would receive if he provided a certain amount of funds for use for a certain period;

– interest rate of credit risk - the risk that the creditor takes into account in case of non-return of the borrowed amount;

– the expected interest rate of inflation.

When determining the discount rate, the risks that were taken into account when determining future cash flows are not taken into account.

According to the National Bank of Ukraine [14], the cost of loans according to the statistical reporting of Ukrainian banks (excluding overdrafts) is 21.1% (the average rate for January 2022 – the month preceding the assessment date of February 1, 2022).

When calculating the discount rate, it is necessary to take into account the expected interest rate of inflation for 2022. according to [15], the consumer price index (December to December of the previous year) is 106.2% in 2022.

Using the Fisher equation [16], the discount rate is:

$$r = \frac{1+i}{1+\pi} - 1 = \frac{1{,}211}{1{,}062} - 1 = 0{,}14\ , \tag{2}$$

where r – real interest rate; i – nominal interest rate (cost of loans); π – inflation rate

The following formula is used to calculate net present income (NPV):

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} - IC_t\ , \tag{3}$$

where CF_t - net cash flows in the t-th year; IC_t - investment costs in the i-th year; i - discount rate or required rate of return; t - serial number of the year of the calculation period; n - is the number of years.

The calculation of the net reduced income is summarized in Table 2:

Let's determine the internal rate of return, which shows the maximum value of the discount rate above which the project becomes unprofitable. and makes it possible to establish the maximum allowable relative level of costs during project implementation. That is, the IRR reflects the discount rate at which the net reduced income is zero and shows at what interest rate the investor must invest his capital so that the efficiency of the financial investment is equal to the efficiency of the given investment project. For investment projects, there is a strict relationship between the net present value and the discount rate: the higher the discount rate, the lower the NPV [5].

Table 2

Calculation of net reduced income

Indicator	Years				
	1	2	3	4	5
Cash flow, thousand UAH	12609,933	12609,933	12609,933	12609,933	12609,933
Discount at a rate of 14%	0,8772	0,7695	0,6750	0,5921	0,5162
Discounted cash flows, thousand UAH.	11061,433	9703,343	8511,705	7466,341	6509,247
Amount of discounted cash flows, thousand UAH.	43252,070				
Net adjusted income, thousand UAH.	43252,070 – 27696 = 15556,070				

The internal rate of return can be obtained from the formula:

$$IRR = i_1 + \frac{NPV_1 \cdot (i_2 - i_1)}{NPV_1 - (NPV_2)}, \tag{4}$$

where i_1 – the discount rate at which the NPV value is positive; i_2 – the discount rate at which the project becomes unprofitable and the NPV becomes negative; NPV_1 – value of the net present value at i_1; NPV_2 – the value of the net value carried out at i_2.

Calculations showed that at a discount rate of 36%, the net reduced income has a negative value - UAH 197.52 thousand.

$$IRR = 14 + \frac{15556,07 \times (36 - 14)}{155556,07 + 197,52} = 35,7\,\%. \tag{5}$$

Therefore, at a discount rate exceeding 35.7%, the project ceases to be profitable.

Payback period - shows the period for which the investment amount will be reimbursed. With relatively equal annual cash flows, the payback period is determined by the ratio of the amount of investment to the average expected amount of cash flow:

$$PP = \frac{IC}{\overline{\Pi}}, \tag{6}$$

where PP – payback period; IC – amount of investment capital, UAH; $\overline{\Pi}$ – average annual profit from the implementation of an innovative project.

If the income is unevenly distributed, then the PP is calculated by direct calculation of the number of years during which the investment will be repaid with cumulative income.

The payback period with uneven distribution of projected income is determined by a step-by-step calculation and was 2 years and 10 months.

Profitability Index of an innovative project is the ratio of discounted (adjusted) net cash flows from the innovative project to discounted (adjusted for the same date) investment expenses. It characterizes the level of net cash flow per unit of innovation costs or characterizes the amount of income per unit of costs

The investment profitability index (PI) gives the investor a clear idea of the feasibility of investments when choosing projects. This indicator shows the level of return on the invested amount of investment. It is defined as the ratio of the amount of discounted income to the initial investment in the project, i.e.:

Calculation of the return on investment index (Profitability Index, PI):

$$PI = \frac{1}{IC} \times \sum_{1}^{n} \frac{\Gamma\Pi_t}{(1+i)^t} = \frac{43252,07}{27696} = 1,56. \tag{7}$$

If the amount of income is less than the amount of investment, then the project does not pay for itself and cannot be considered for use. If $PI > 1$, the project can be accepted. In our case, each hryvnia of investment brings 1.56 hryvnias profit.

4. Conclusions

It is recommended to accept the project of introduction of the RM-80 gravel cleaning machine into the production activities of JSC "Ukrzaliznytsia". This is indicated by the obtained indicators of project efficiency. At a discount rate of 14%, the net discounted income is UAH 15,556.07 thousand, the payback period is 2 years and 10 months, the profitability index is 1.56. The internal rate of return is 35.7%.

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Assessing the Ecological and Technical Performance of the New DFDS Ferry

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Abstract

This paperwork represents the environmental friendliness and the efficiency of the technical parameters of the new ferry „Aura seaways“ on the Klaipeda – Kiel line. Evaluation of energy efficiency design index (EEDI) showing compatibility with the latest IMO requirements in terms of CO_2 pollution from engines and calculations of the technical parameters, taking into account the vessel‘s maximum loading and ability to fit into a 24-hour voyage period. In this paperwork was calculated whether the new DFDS ferry „Aura seaways“ achieves new IMO requirements for new build vessels. Results that were achieved, „Aura seaways“ meets new IMO MARPOL requirements and in order to reach the Klaipeda-Kiel line, an increase in the ship's speed of about 2 knots is needed to allow sufficient time for loading operations.
KEY WORDS: *Ro-pax, EEDI, ecology, technical parameters*

1. Introduction

The climate crisis remains the most important challenge of our time. The last five years have been the warmest on record. In 2019, the global average temperature was 1.1 °C higher than in the pre-industrial era. The effects of global warming are undeniably evident in the increasing frequency of droughts, storms and other extreme weather events. The International Maritime Organization (IMO) [3] adopted an initial strategy to reduce greenhouse gas (GHG) emissions from ships in London in 2018. This strategy outlined targets for how GHG emissions could be reduced and in what steps they could be achieved. Under the "ambition levels" set, the initial strategy for the first time envisages a reduction in total greenhouse gas emissions from international shipping, which it says should peak as soon as possible, and a reduction of at least 50% in total annual GHG emissions by 2050 compared to 2008, while at the same time making efforts to phase them out completely. The initial strategy sets out the levels of ambition for the international shipping sector, noting that technological innovation and the global deployment of alternative fuels/energy sources for international shipping will be an integral part of achieving the overall ambition.

2. „Aura Seaways“ Ferry Main Technical and Voyage Data

To calculate the EEDI compliance with the new requirements [1], it is necessary to map the baseline data of a ship already built (Basic vessel data shown in Table 1).

Table 1

Basic vessel data

Parameter	Data
Vessel name	Aura Seaways
IMO number	9851036
Year of construction	2021
Vessel type	Ro-Pax
LOA	230 m
Breadth	31.6 m
Draught	7 m
Gross tonnage	56043 t
Deadweight	12000 t
Speed	23 kn
Cargo capacity	4500 l/m
Main engines	4 x Wartsila W7L46

The propulsion plant of this vessel consists of four Wärtsilä W7L46 main propulsion engines. This engine complies with ISO 8217 (ISO-F-RMK 700) and has a specific fuel consumption of ~175 g/kWh.

3. Methodology of EEDI Calculation

The *EEDI* is calculated for new buildings or ships undergoing major modifications. The calculations are based on the formula (1) from the MARPOL annex VI, resolution MEPC 245(66):

$$EEDI = \frac{\left(\prod_{j=1}^{M} f_j\right)*\left(\sum_{i=1}^{nME} P_{ME(i)} * C_{FME(i)} * SFC_{ME(i)}\right)+\left(P_{AE} * C_{FAE} * SFC_{AE}\right)}{f_i * Capacity * V_{ref} * f_w} +$$

$$\frac{\left(\prod_{j=1}^{M} f_j\right)*\left(\sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} * P_{AEeff(i)} * C_{FAE} * SFC_{AE}\right)-\left(\sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * C_{FME} * SFC_{ME}\right)}{f_i * Capacity * V_{ref} * f_w}, \quad (1)$$

where n, f_j – correction factor based on the vessel design; nME, $P_{ME(i)}$ – the number of main engines and the power output of each of them [kW]; $C_{FME(i)}$, C_{FAE} – non-dimensional conversion factor between fuel consumption [g] and CO_2 emissions [g] based on the carbon content of the main and auxiliary engines; $SFC_{ME(i)}$ – specific fuel consumption at 75% load for the main engines, derived from the specification provided by the engine manufacturer; SFC_{AE} – specific fuel consumption at 50% load for auxiliary engines, derived from the specification provided by the engine manufacturer; P_{AE} – the auxiliary engine power [kW] theoretically required to power the vessel at maximum load; n_{PTI}, $P_{PTI(i)}$ – the number of devices that consume power and the amount of power consumed [kW] (e.g. shaft generator); n_{effE}, n_{effP}, $f_{eff(i)}$ – the sum of the number of innovative technology factors that generate (save) electricity (e.g. heat recovery systems) or save propulsion power (e.g. hull lubrication with air bubbles, sails, kites); $P_{eff(i)}$ – the propulsive power output of the innovative technology at 75% load of the engines; $P_{AEeff(i)}$ – the power generated by the innovative technology allowing energy savings for the auxiliary power plant; *Capacity* – for passenger ships, gross tonnage; f_j – correction factor for the specific ship design which results in a reduced capacity; f_i – capacity correction factor, resulting in a reduction due to ice class structural improvement; f_l – correction factor for general cargo ships fitted with lifting cranes, which results in a reduction in deadweight; V_{ref} – design speed of the vessel at ideal environmental conditions; f_w – non-dimensional coefficient indicating the reduction in speed at various environmental conditions compared to the ideal conditions. This coefficient shall be taken as 1 in the calculations.

The formula essentially consists of four factors that influence CO2 emissions, the main propulsion engines and their emissions, the auxiliary power unit engines and their emissions, and innovative technologies.

The formula below gives the ratio of CO_2 to useful work done by the traction motors:

$$\frac{\left(\prod_{j=1}^{M} f_j\right)*\left(\sum_{i=1}^{nME} P_{M(i)} * C_{FME(i)} * SFC_{ME(i)}\right)}{f_i * Capacity * V_{ref} * f_w}, \quad (2)$$

where $P_{ME(i)} = 0{,}75 MCR_{Me}$; $f_j, f_i = 1$ (according to HELCOM recommendations [2]),

Formula below shows the influence of the auxiliary engines on the EEDI, obtaining the ratio of CO_2 from the auxiliary engines to the useful work done:

$$\frac{\left(P_{AE} * C_{FAE} * SFC_{AE}\right)}{f_i * Capacity * V_{ref} * f_w}, \quad (3)$$

where $P_{AE} = (0.025 MCR_{ME}) + 250\text{kW} = (0.025 * 33600) + 250\text{kW} = 1090\text{kW}$. The auxiliary power parameter depends on the load, loading aspects, safety aspects (emergency generator) and is normally fixed as a proportion of the power of the traction motors (2.5% of the total power of the traction motors + 250 kW).

From formula below, we can calculate the impact on EEDI of innovative technologies that generate electricity and contribute to the auxiliary or main power plant:

$$\frac{\prod_{j=1}^{M} f_j * \sum_{i=1}^{nPTI}\left(P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} * P_{AEeff(i)} * C_{FAE} * SFC_{AE}\right)}{f_i * Capacity * V_{ref} * f_w}. \quad (4)$$

One such technology could be heat recovery systems. "AURA SEAWAYS has 7 heat recovery units on board, which generate 7% of the total power of the propulsion engines. This would total 33600·7% = 2352 kW $33600 \cdot 7\% = 2352\ kW$

The formula below shows the benefits of innovative technologies for *EEDI*. Such technologies can be solar panels, sails, etc. There are no such technologies on board this vessel:

$$\frac{\sum_{i=1}^{nPTI}\left(\sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * C_{FME} * SFC_{ME}\right)}{f_i * Capacity * V_{ref} * f_w}. \tag{5}$$

4. „Aura Seaways“ EEDI and Voyages Calculations (Case Study)

Deadweight and vessel tonnage are appropriate values for calculating the *EEDI* for most ship types, but for Ro-Ro (Ro-Pax) vessels, the more relevant values are Lane Meters and Passenger Numbers, but as these values can be volatile in the drawing of the baseline, Gross Tonnage is a more appropriate value, as per information from The Third IMO Greenhouse Gas Study 2014.

From the (2) formula we can get results of the ratio of CO_2 to useful work done by the traction motors:

$$\frac{1*((33600*0.75)*2.152*175)}{1*56043*23*1} = 7.362. \tag{6}$$

From the formula (3) we received results as follow:

$$\frac{(1090*2.152*196)}{1*56043*23*1} = 0.356. \tag{7}$$

From the formula (4) we received results as follow:

$$\frac{1*(0-1*2352)*2.152*175}{1*56043*23*1} = -0.687. \tag{8}$$

The overall energy efficiency design index for AURA SEAWAYS would be:

$$EEDI = 7.362 + 0.356 + \left(-0.687\right) = 7.031. \tag{9}$$

4.1. Calculation and Comparison of EEDI Levels

Next, we need to calculate the levels of *EEDI* required, of which there are 3 and they are sorted by year. First we need to calculate the reference point for our chosen vessel:

$$NeededEEDI_{level0} = a * b^{-c}. \tag{10}$$

The values of *a*, *b* and *c* are derived from the IMO requirements (Table 2).

Table 2

Ship type descriptions in IMO requirements

Vessel type	*a*	*b*	*C*
Bulker	961,79	Deadweight	0,477
Gas carrier	1120,00	Deadweight	0,456
Tanker	1218,80	Deadweight	0,488
Container ship	174,22	Deadweight	0,201
General cargo	107,48	Deadweight	0,216
Ro-Pax	780,36	Deadweight	0,471

The result is:

$$EEDI_{level0} = 780.36 * 12000^{-0.471} = 9.354. \tag{11}$$

We calculate three levels, which come into effect from 2015, 2020 and 2025 respectively. Level 1 refers to a 5% reduction for Ro-Ro vessels from level 0. Level 2 is a 15% reduction and Level 3 a 30% reduction.

Adding everything up:

$$EEDI_{level1} = 9.354 * 0.95 = 8.8863 \tag{12}$$

$$EEDI_{level2} = 9.354 * 0.85 = 7.9509 \tag{13}$$

$$EEDI_{level3} = 9.354 * 0.70 = 6.547 \tag{14}$$

It can be concluded that AURA SEAWAYS fully meets and even exceeds the $EEDI_{level2}$ which came into force from 2020.

5. Aura Seaways Technical Feasibility Study

Baseline data for the Victoria and Athena Seaways ferries operated by DFDS:

- Athena Seaways vehicles have a capacity of 2496 linear meters;
- Victoria Seaways has a vehicle capacity of 3063 linear meters.

The actual loading time of the vessels according to DFDS statistics is 100-120 minutes. The length of one cargo vehicle is 18 m.

Athena Seaways loading calculations:

Fastest possible loading time per linear meter:

$$t_1 = 100 \div 2496 = 0.04 \text{ min} \approx 2.4 \text{ s}$$

Slowest possible loading time per linear meter:

$$t_2 = 120 \div 2496 = 0.048 \text{ min} \approx 2.9 \text{ s}$$

Victoria Seaways loading calculations:

Fastest possible loading time per linear meter:

$$t_3 = 100 \div 3063 = 0.032 \text{ min} \approx 1.9 \text{ s}$$

Slowest possible loading time per linear meter:

$$t_4 = 120 \div 3063 = 0.039 \text{ min} \approx 2.4 \text{ s}$$

Average loading time per linear meter:

$$T = (t_1 + t_2 + t_3 + t_4) \div 4 = (0.04 + 0.048 + 0.032 + 0.039) \div 4 = 0.04 \text{ min} \approx 2.4 \text{ s}$$

Line capacity of the new DFDS ferry Aura Seaways L = 4500 m. Based on the data calculated above, a preliminary loading time is made for this vessel:

$$t_5 = T * L = 4500 * 0.04 = 180 \text{ min} = 3 \text{ h} .$$

Currently the total time of the ferry in port is 4 hours including loading and unloading times, for these reasons the time of the vessel in port should be extended in order to fully integrate this vessel into the ferry line in Klaipeda. This can be achieved by increasing the speed of the vessel during the passage between ports.

5.1. Calculation of Voyage Time

The average sailing speed of the Aura Seaways ferry is 17.5 knots (according to marrinetraffic.com). The maximum possible speed according to the technical specification is 23 knots.

The sailing distance Klaipeda - Kiel is 387 nautical miles and the sailing time is about 20 h. Based on the set sailing schedule and the existing distance, the average speed of Aura Seaways would be:

$$V_{average} = \frac{\text{S}}{\text{t}} = \frac{387 \text{nm}}{1200 \text{min}} = 0.3225 \text{ nm/min} = 19.35 \text{ kn} .$$

If the loading time of the ship is calculated to be about 3 hours, the total loading and unloading time would be about 6 hours. This means that the sailing time of the Aura Seaways should be no more than 18h. The required speed of the vessel to be able to sail in the specified time would be:

$$V_{needed} = \frac{S}{t} = \frac{387\text{nm}}{1080\,\text{min}} = 0.3583\ \text{nm}/\text{min} = 21.5\ \text{kn}\ .$$

Thus, the vessel would have to increase its speed by more than 2 nm/h in order to be able to maintain the schedule of a liner and to fully load and unload the Aura Seaways vessel on the route Klaipeda-Kiel.

6. Conclusions

The analysis showed that the engines of the DFDS Ro-Pax Aura Seaways fully comply with IMO requirements in terms of CO_2 reduction strategy (*EEDI* calculations). „Aura Seways“ *EEDI* index has to be less than $EEDI_{level2}$ = 7,9509 and the received result was *EEDI* = 7,031. It means that with the same vessel design DFDS can built sister vessels till 2025, when the new *EEDI* level should be achieved and should be even more environmentally friendly.

The technical study showed that in order to reach the Klaipeda – Kiel line, an increase in the ship's speed from 19,35 knots to 21,5 knots would allow sufficient time for loading operations. The increased speed means, that vessel will consume more fuel and probably the emissions will be higher than in the current sailing and vessel standing in port schedule. In order to fully use “Aura Seaways” vessel capacity between Klaipeda and Kiel DFDS company should increase vessel speed or to make changes in switching destinations between port of Kiel and port of Karlshamn.

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The Position of Eigenvalues in the Gaussian Complex Plane Depending on the Change of the Coefficients of the Homogeneous Linear Differential Equation in Transport Application Using Matlab

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Abstract

The mathematical solution of vibration of a single-degree-of-freedom dynamical system always leads to the construction and solution of a second-order linear ordinary differential equation with constant coefficients. The coefficients of this equation correspond to the mass of the body, the damping coefficient of the damper, and the stiffness of the spring in a given system. The paper examines how changes of these coefficients influence the position of eigenvalues in the Gaussian complex plane. For the eigenvalues of the second-order homogeneous linear differential equation, it is derived and proved that the product of their distances from the origin of the Gaussian complex plane is constant and equal to the numerical value of the natural circular frequency of the corresponding mass-damper-spring system. It is further shown and proved that these eigenvalues follow the rules of conformal mapping of circular inversion with respect to a reference circle with its center at the origin of the Gaussian complex plane and a radius equal to the square root of the natural circular frequency of the corresponding system. Furthermore, third and higher order homogeneous linear differential equations are also investigated, and a similar property is derived and proved, namely that the product of the absolute values of the eigenvalues is linearly dependent on the coefficients of the differential equation. This issue has been used in the teaching of the applied mathematics and numerical methods in transport at the Faculty of Transport Engineering, University of Pardubice.

KEY WORDS: *Applied Mathematics in Transport, Linear differential equation, single-degree-of-freedom dynamical system, eigenvalues, circular inversion*

1. Introduction

The study of changes in physical quantities with respect to time, such as temperature, pressure, deflection, velocity, stress, concentration, etc., can be realized by simulation using differential equations. It is important for engineers to be able to model technical problems using mathematical equations and then solve these equations so as to make it possible to study the behavior of the corresponding systems based on the obtained results. Differential equations and their systems are an essential part of mathematical analysis. They make it possible to solve a wide range of practical technical tasks. The theory of solving differential equations and their systems is described in detail, e.g., in [1, 4, 5, 7, 8]. This article deals with an issue which is only rarely discussed in the theory of solving differential equations or in the theory of single or higher degree-of-freedom dynamical systems – the position of eigenvalues in the Gaussian complex plane depending on the change of the constant coefficients of the differential equation.

2. Motivation Model

Modeling of single-degree-of-freedom dynamical systems led us to the idea of examining the relationships between the eigenvalues of homogeneous linear differential equations (HLDE).

2.1. The Response of a Single-Degree-of-Freedom Dynamical System and Its Conversion

A single-degree-of-freedom dynamical system can be modeled using the mass-damper-spring mechanical system. From [1-3, 6, 9-11] we will get the equation of motion for a single-degree-of-freedom dynamical system $m\ddot{x}+b\dot{x}+kx=F(t)$, where $F(t)$ is a known forcing function (its equal to zero - unforced oscillations), m is the mass of the body, b is the damping coefficient of the viscous proportional damper, k is the stiffness of the spring, x is the deflection and $\dot{x}$ and $\ddot{x}$ are the first and second derivatives of the deflection with respect to time.

This is a second order HLDE with constant coefficients, which may be converted into:

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ -\dfrac{k}{m} & -\dfrac{b}{m} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}. \tag{1}$$

2.2. M-File for Calculation and Graphic Representation of Eigenvalues

Calculation and graphical representation of eigenvalues was performed using the script below (Fig. 1). The % character is always followed by a commentary describing the current stage of the calculation.

```
% input data setup
m=10;
k=1000;
b=linspace(0,500,51);
% computation of eigenvalues
n=length(b);
for i=1:n
    S(:,i)=eig([0 1; -k/m -
b(i)/m]);
    AHVl_c(:,i)=abs(S(:,i));

KI(i)=AHVl_c(1,i)*AHVl_c(2,i);
end

% extraction of results
S
V=[AHVl_c ;KI]
r=AHVl_c(1)
p=KI(end)
x=max(max(abs(real(S))));
y=max(max(abs(imag(S))));

% graphical representation of the
results
set(gcf,'WindowState','Maximized'
);
```

```
subplot(4,1,1)
plot(b,KI,'*')
grid on
title('a)','FontSize',12)
axis([-2 502 88 112]);
yticks([90 100 110])

subplot(4,1,[2 3 4])


col={'b' 'g' 'r' 'c' 'm' 'y' 'k'}; % every pair of the eigenvalues use other
colour
for i=1:n
        b=mod(i,7)+1;
        plot(real(S(1,i)),imag(S(1,i)),'*','color',col{b},'linewidth',4,…
        'markersize',6);
        hold on;
        plot(real(S(2,i)),imag(S(2,i)),'*','color',col{b},'linewidth',4,…
        'markersize',6);
        set(gca,'YAxisLocation','origin');
        set(gca,'XAxisLocation','origin');
        axis equal
        axis([-x-1 2 -y-0.5 y+0.5]);
        xlabel('Real axis','Position',[-x+5 0.3 1']);
        ylabel('Imaginar axis','Position',[-0.5 4 1']);
        title('b)','FontSize',12);
        grid on;
    drawnow;
end
```

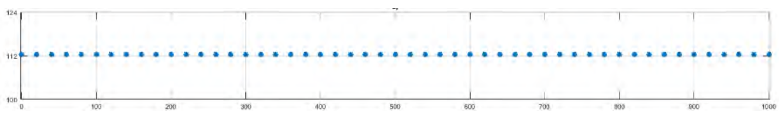
Fig. 1 The script

3. Numerical Results

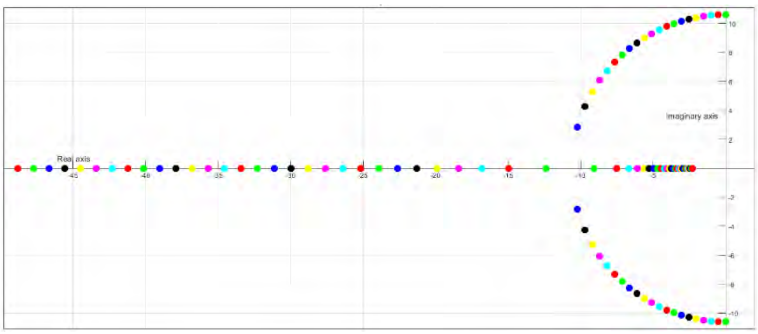
We will apply the computational model to selected input data, which in our case are coefficients *k*, *m* and *b*. The conditions for these coefficients are determined according to technical practice $k,\ m,\ b \in R^+$. In each experiment, parameters *k*, *m* will be fixed, because $\frac{k}{m} = \omega_0^2$ and their ratio plays a role. Parameter *b* will always be changed in a given interval with a given number of subintervals *p*, because its value is given by the relationship $b = 2b_k\sqrt{km}$.

3.1. Example 1

In example 1, let us choose $k = 2200$ N/m, $m = 19{,}572$ kg, $p = 51$ and $b \in \langle 0; 1000\rangle$ [N·sec·m^{-1}]. We will calculate eigenvalues for each value of *b* and plot them in the Gaussian complex plane.



a



b

Fig. 2 Eigenvalues from Example 1: a – product of the absolute values of the eigenvalues; b – position of eigenvalues in Gaussian complex plane

The results are shown in Fig. 2. The eigenvalues are either two negative real numbers, one double real or two complex conjugate numbers, which lie on a semicircle with radius $\omega_0 = \sqrt{\dfrac{2200}{19.57}} \doteq 10.6$ with the center at the origin. The product of the absolute values of the eigenvalues is always equal to the value $\omega_0^2 = \dfrac{2200}{19.57} \doteq 112.4$.

4. Conclusions of Mechanical and Numerical Analysis of a Single-Degree-of-Freedom Dynamical System

From the results presented above, we can see that the eigenvalues always lie either on the real axis or on a circle, and the product of their absolute values is constant. We will generalize the whole issue and propose a hypothesis, which we will prove later. First, lets us recall the definition of circular inversion. Circular inversion, as shown in Fig. 3, determined by a reference circle $\omega(S, r)$, is an involuntary and conformal mapping, which to each point $X \neq S$ assigns point X', as follows:

$$X' \in SX \text{ and } |SX| \cdot |SX'| = r^2 . \tag{2}$$

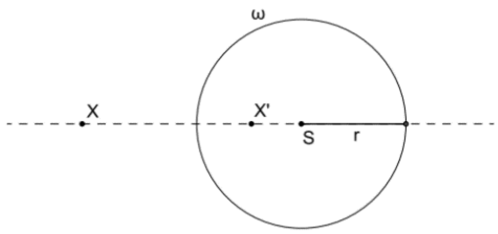


Fig. 3 Circular inversion is an involuntary mapping, which means the image of point X' is point X

4.1. Hypothesis

Let us consider any linear homogeneous second-order HLDE with constant coefficients

$$a_1\ddot{x} + a_2\dot{x} + a_3 x = 0 . \tag{3}$$

where the coefficients a_1, a_2, a_3 correspond to the coefficients in Eq. (3), therefore $a_1 = 1$, $a_2 = \dfrac{b}{m}$ arba $a_3 = \dfrac{k}{m}$, and which can be any real number. We will only exclude the possibility of $m = 0$. The product of the absolute values of the eigenvalues is then constant and its numerical value is equal to coefficient a_3, which, in the case of a single-degree-of-freedom dynamical system, corresponds to the square of the natural circle frequency of the undamped system. Furthermore, the distribution of the eigenvalues in the Gaussian complex plane is controlled by a circular inversion with a reference circle having a center at the origin and a radius equal to the square root of the product of the absolute values of the corresponding eigenvalues, which, again, is the value corresponding to the natural circle frequency of the undamped system.

4.2. Proof

We can approach the whole issue in terms of Viet formulas [13], i.e., relations between the roots and coefficients of a quadratic equation. The characteristic equation $\lambda^2 + \dfrac{b}{m}\lambda + \dfrac{k}{m} = 0$, has either two real solutions $\gamma, \delta \in R$, which do not necessarily have to be different, or two complex conjugates $\alpha + \beta i,\ \alpha - \beta i \in C$. When we perform root factors decomposition $(\lambda - \gamma)(\lambda - \delta) = \lambda^2 - (\gamma + \delta)\lambda + \gamma\delta = \lambda^2 + \dfrac{b}{m}\lambda + \dfrac{k}{m}$, it follows that $\gamma\delta = \dfrac{k}{m} = \omega_0^2$, or $(\lambda - \alpha + \beta i)(\lambda - \alpha - \beta i) = \lambda^2 - 2\alpha\lambda + \alpha^2 + \beta^2 = \lambda^2 + \dfrac{b}{m}\lambda + \dfrac{k}{m}$, and this implies $\alpha^2 + \beta^2 = (\alpha + \beta i)(\alpha - \beta i) = \dfrac{k}{m} = \omega_0^2$. The roots lie on a circle with radius ω_0, as follows from the relationship $|\alpha + \beta i| = \sqrt{\alpha^2 + \beta^2} = \omega_0$.

5. HLDE of Higher Orders with Constant Coefficients

So far, we have considered only second-order linear homogeneous differential equations with constant coefficients. Below, we will demonstrate further similarities regarding differential equations of the third and higher order. Let us consider a third-order linear homogeneous differential equation

$$a\dddot{x}+b\ddot{x}+c\dot{x}+dx=0\,. \tag{4}$$

with constant coefficients *a*, *b*, *c*, *d*, where $a\neq 0$. We can construct the corresponding characteristic equation $a\lambda^3+b\lambda^2+c\lambda+d=0$. The eigenvalues $\lambda_1,\lambda_2,\lambda_3$ are the roots of the cubic equation. We can calculate the product of their absolute values and the result is same in all possible cases $\left|2q+\frac{b^3}{27a^3}+p\frac{b}{a}\right|$. If we further replace $\frac{3ac-b^2}{9a^2}$ and $\frac{b^3}{27a^3}-\frac{bc}{6a^2}+\frac{d}{2a}$ with *p* and *q*, see (13), and simplify, we get:

$$2q+\frac{b^3}{27a^3}+p\frac{b}{a}=\frac{2b^3}{27a^3}-\frac{2bc}{6a^2}+\frac{2d}{2a}+\frac{b^3}{27a^3}-\frac{3ac-b^2}{9a^2}\cdot\frac{b}{a}=\frac{2b^3+9abc+b^3-3b^3}{27a^3}-\frac{2bc}{6a^2}+\frac{d}{a}=\frac{bc}{3a^2}-\frac{bc}{3a^2}+\frac{d}{a}=\frac{d}{a}\,,$$

which is the absolute term in Eq. (4) if we divide the whole equation by value *a*. This finding must be consistent with Vieta's formulas [13].

5.1. Example 2

In Example 2, for a third-order HLDE, we will firstly divide Eq. (4) by coefficient a and choose $p=\frac{b}{a}=1$, $q=\frac{c}{a}=1$, and $r=\frac{d}{a}$ in the interval $\langle -100;\,100\rangle$ which we will divide into 51 parts. For each value *r*, we will calculate the eigenvalues and the product of their absolute values. The situation is shown in Fig. 4 – part a) shows the product of absolute values of eigenvalues (we can see its linear dependence on the given parameters); part b) shows the corresponding eigenvalues connected in a triangle, and in part c) we can see the position of eigenvalues, and the curves along which the eigenvalues move are visible.

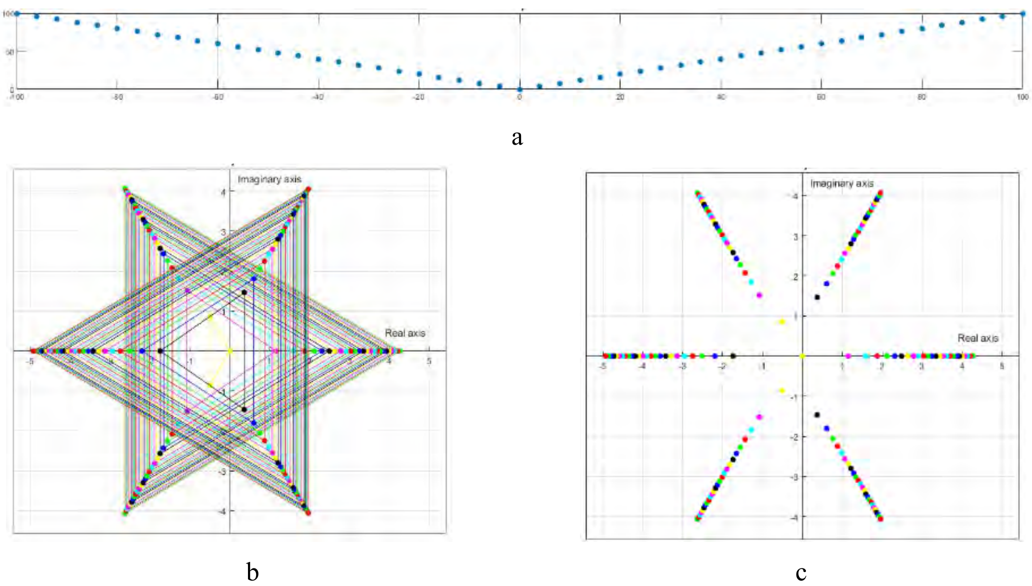
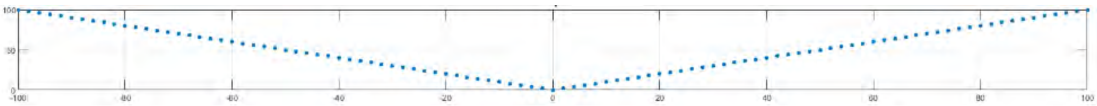


Fig. 4 Eigenvalues from Example 2 a – Product of the absolute values of the eigenvalues; b – Position of eigenvalues in the Gaussian complex plane, corresponding eigenvalues are connected in a triangle; c – Position of eigenvalues in the Gaussian complex plane

5.2. Results for Higher Degrees

In Figs. 5 and 6 we can see the results for fourth-order and fifth-order HLDE.



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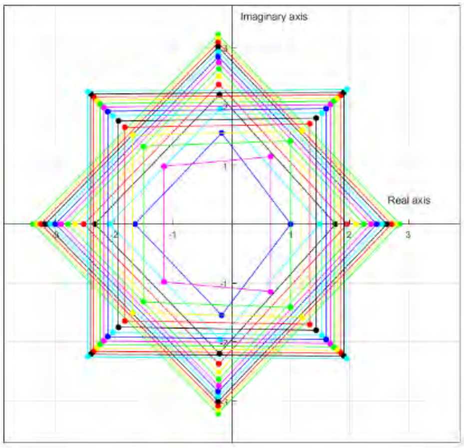
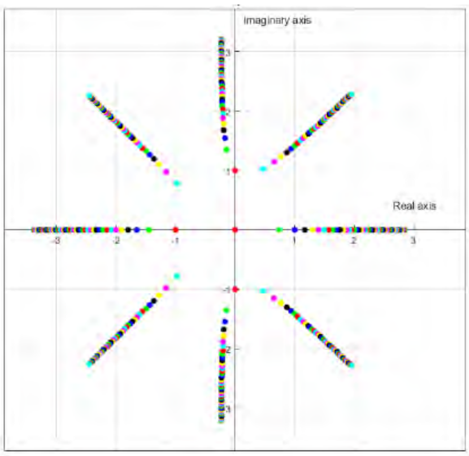
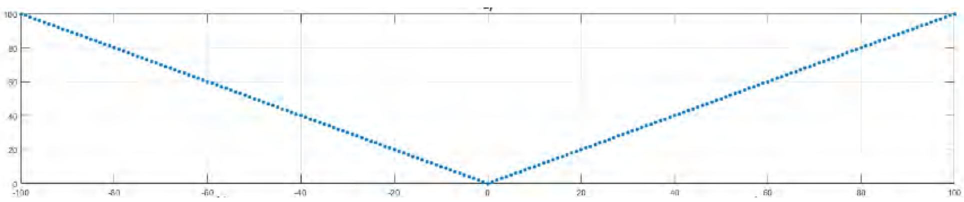




b c

Fig. 5 Eigenvalues from Example 4: a – Product of the absolute values of the eigenvalues; b – Position of eigenvalues in the Gaussian complex plane, corresponding eigenvalues are connected in a quadrilateral; c – Position of eigenvalues in the Gaussian complex plane



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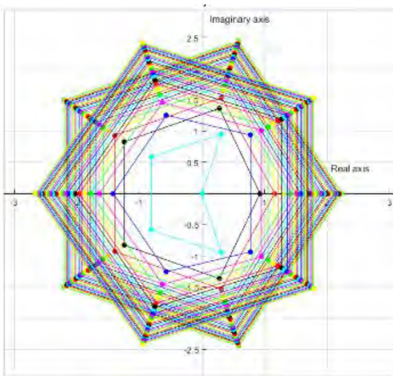
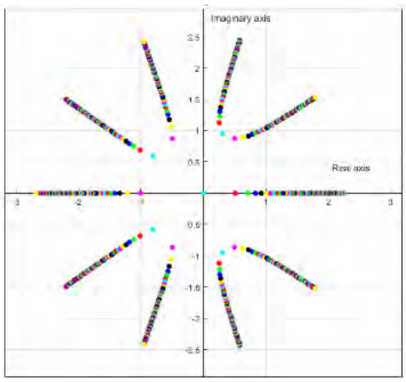


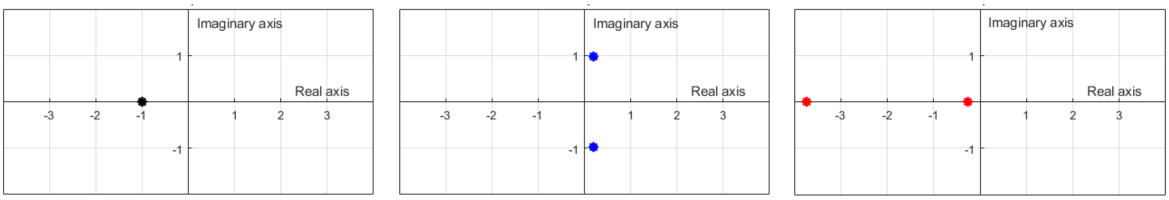


b c

Fig. 6 Eigenvalues from Example 5: a – Product of the absolute values of the eigenvalues; b – Position of eigenvalues in the Gaussian complex plane, corresponding eigenvalues are connected in a pentagon; c – Position of eigenvalues in the Gaussian complex plane

6. Discussion

If, for parameters m, k, and b, it holds that $b = \pm 2\sqrt{mk}$, we will always get one double eigenvalue which lies at the intersection of the real axis and the reference circle of the circular inversion. This case corresponds to a system with critical damping, where the system does not oscillate and is only damped. One double eigenvalue is in the position shown in Fig. 7, a. If, for parameters m, k, and b, it holds that $b \in \left(-2\sqrt{mk}\,;2\sqrt{mk}\right)$, we always get two complex conjugate eigenvalues which lie on the reference circle of the circular inversion, and they are self-conjugate points. This case corresponds to a damped system, where the system oscillates with a decreasing amplitude. A special case occurs when the damping coefficient is equal to zero, then the oscillation is not damped and the amplitude remains the same. The eigenvalues are in the position shown in Fig. 7, b. If it holds that $c \in \left(-\infty; 2\sqrt{mk}\right) \cup \left(2\sqrt{mk}; +\infty\right)$, we will always get two real different eigenvalues which lie on the real axis and each is the image of the other in circular inversion with a reference circle having its center at the origin and radius equal to the square root of the natural frequency of the system $\omega_0^2 = \frac{k}{m}$. This case corresponds to an overdamped system that does not oscillate and the amplitude decreases exponentially. The eigenvalues are in the position shown in Fig. 7, c.



a b c

Fig. 7 Position of eigenvalues for second-order linear homogenous differential equation in three basic cases

In the case of third-order HLDE, the corresponding eigenvalues are always one real and two complexly conjugate numbers, they form an equilateral triangle in the Gaussian plane of complex numbers and the vertices of the triangle move along lines or parabolas. Regarding HLDE of higher orders, the eigenvalues always form vertices of an n-gon.

7. Conclusions

Based on numerical analysis, we expressed and proved the hypothesis that in a mechanical mass-damper-spring system, which is a single-degree-of-freedom dynamical system corresponding to the solution of a second-order HLDE with constant coefficients, the following statement holds. The product of the distances of the corresponding eigenvalues from the origin is constant and equal to the square of the natural circular frequency of the system. The eigenvalues satisfy the conditions of a circular inversion with respect to a reference circle with its center at the origin and radius equal to the natural frequency of the system. A similar property for eigenvalues was proved for the third-order HLDE equation with constant coefficients, and it was additionally shown that the same property applies to eigenvalues for corresponding higher-order HLDE. Finally, a further direction of research on this issue was suggested.

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