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PREFACE

25th international scientific conference TRANSPORT MEANS 2021 due to the COVID-19 pandemic in the world, for the second time was organized as a virtual event on 06-08 October, 2021. It continues long tradition and reflects the most relevant scientific and practical problems of transport engineering.

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

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

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

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

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

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

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

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

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Proceedings of 25th International Scientific Conference. Transport Means 2021.

Section of Double-Tracked Railway Line with Switch Point Area in the Middle: a Simulation Capacity Assessment

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Abstract

There is a number of double-tracked railway lines in operation in practice. The paper is focused on line sections that are divided by crossover, i.e. by switches allowing movement of a train from one line track to another. These switches can be possibly applied for overtaking another train and for improvement of line capacity. The research is focused on the relation between traffic volume, line capacity and timetable stability. The role of crossover is the subject of research for regular as well as irregular operating conditions. Irregular conditions are usually related to track closures.
KEY WORDS: *crossover; double-tracked railway line; model; OpenTrack; simulation*

1. Introduction

Crossover is one of the possible measures for the improvement of the capacity of double-tracked railway lines. A crossover is a switch area located almost in the middle of the line section between stations. Movement of trains from one track to another is possible at crossover. Application of crossovers can be simplified in the case of remote way of traffic control with no need to have staff at the place. It can be beneficial also by the closure of one track. The length of the restricted segment can be shortened in this way.

Evaluation of the following four linked hypotheses is a base for this research:

H1: Shortening headway (time gap) between trains increases utilization of crossover.

H2: Heterogeneity of timetable has an impact on utilization of crossover.

H3: Trains running in the reverse direction can reduce utilization of crossover (caused by trains in basic direction).

H4 (supplementary): Crossover is beneficial in the case of closure of one line track.

The conducted research is divided into three stages. Stage A is focused on selected features on the interface between timetable and utilization rate of crossover. Specific testing conditions with no regular operation on the second track (in the reverse direction) are applied. This allows paying attention to interactions between successive trains. Stage B is dedicated to the standard bidirectional operation of traffic (using both tracks in a standard way). Interactions with trains in the reverse direction are considered. Finally, the last stage C is focused on closure of one from two line tracks. This stage C plays a supplementary role in the research only.

The microscopic stochastic simulation model developed in the OpenTrack software is applied. A number of trains using second line track in an irregular direction (for overtaking) is applied as the main indicator in stages A and B. Increment of delay of trains at the assessed line segment is applied in stage C. The research is based on the presumption that capacity is connected to the quality of operation. Insufficient capacity can lead to delays caused by waiting in front of infrastructure devices (railway line segment).

The aim of this research is to investigate operational effects influencing railway line capacity and other operational features. There is an effort to define principles and starting points, how to assess crossovers as a possible measure for improvement capacity as well as operational stability.

2. State-of-Art Knowledge in the Field

The field of capacity assessment of railway infrastructure is relatively extended. The paper [1] is focused on the assessment of railway line capacity by using different interlocking (blocking) systems.

Operational irregularities in railway transport are a relatively common issue of research based on modelling. Blockages of a part of the railway line are the scope of the paper [2]. Mixed integer linear model is applied for scheduling of trains turning in front of the blocked sections with an effort to ensure traffic inline sections is in operation.

Technical efficiency and service effectiveness of railway stations (considered as a potential bottleneck of railway transport system) is assessed using model based data envelopment analysis in the paper [3]. Relation between capacity utilization (number of trains) and punctuality of operation creates a scope of the paper [4]. The analysis is focused on railway stations and junctions. Despite the fact that the papers [3, 4] are focused on stations, it is evidence that the relation between capacity utilisation and operation stability is important.

A topic close to our research is presented by the paper [5]. It is focused on the application of the UIC 406 methodology for railway infrastructure capacity assessment and its modification.

Train platforming problem at the complex railway stations is the main issue of the paper [6]. The solution is based on mixed-integer linear programming. Inspiring is the incremental method based on a sliding-window algorithm. Track assignment takes a part of the paper [7] as well. That research topic is focused on optimization in freight traffic.

There is proposed a methodology for rescheduling of timetable based on simulation and on multi-criteria decision making in the paper [8]. It represents a complex approach to organisation of railway operations as well on the operative level.

The effort to design a punctual and reliable timetable is presented by the paper [9]. Simulation of effects influencing railway punctuality is applied.

Economic and organisation points of view on allocation of railway capacity in the case of railway sidings are the scope of the paper [10].

The paper [11] deals with critical elements in railway infrastructure. This provides one of the fundamental ideas for our research as well. Aspects or effects influencing capacity and operation quality can be considered also individually as such elements that determine final operational features.

This brief overview characterizes the situation in the field of railway infrastructure capacity and some of the possibilities and principles applicable in the field of simulation and optimization.

3. Research

There is a fundamental question – if the crossover interconnecting line tracks of double-tracked line located almost in the middle of the section between stations is effective or not. A universal solution to this simple question does not exist, because it depends on many factors. Length of a line segment, travel and track occupation times, number of trains, the composition of timetable, punctuality of operation on arrival to modelled area, way of traffic control, way of interlocking and volume of needed investments are main examples of these factors. The second point of view is that these factors are interconnected.

Research is based on the fact that these main factors should be researched individually to define their meaning and impact. Finally, it can lead to the possibility to estimate capacity by a specific set of factors that occurred on the assessed line.

A set of timetable variants (for 6 hours long time frame) has been prepared for this research. Each of these variants is focused on different conditions for operation. Some features, e.g. headway (time gap) between individual trains, can be applied in the different forms by different trains. This creates an opportunity to evaluate more variants within one simulation scenario. The relatively long length of simulated time frame (6 hours) supports this approach. The impact of assessed aspects is possible to be researched by comparison of output and input values for individual trains and by comparison of individual simulation scenarios (timetable variants) as well.

A double-tracked railway line with a total length of 50 km was applied as testing infrastructure within this simulation model. The line consists of 6 stations (named by letters A – F) so that there are 5 line sections. The distance between stations is 10 km in all cases. All these sections are divided by crossover in the middle. The line is equipped with the interlocking plant using so called automatic block. Block signals are placed with a distance of 1 km so that there can be more trains at one track between neighboring stations (maximally one between 2 block signals). The switch area of crossover is an exception with different distances (but not shorter than the braking distance needed to stop the train). Comparison of values for individual sections can be also applied for generalization in some cases.

All simulation scenarios (timetable variants) are designed as conflict-less in the case of deterministic operation (with no train delay). Simulation scenario 4 is an exception due to the assessment of track closure. For the better possibility to investigate the role of crossovers in stochastic conditions, each train is scheduled to occupy a track used for given direction regularly. The need to switch to another track can occur only in the case when the line track is occupied by some of the previous trains (e.g. due to delay). The list of simulation scenarios with description assessed effects is in Table 1.

Table 1

Simulation scenarios (timetable variants)

Scenario (variant)	Research stage	Train types	Considered sequence of trains	Travel time of fast trainper section	Related hypothesis and assessed effects
1	A	homogeneous	fast > fast	7 min	/H1/ Different scheduled headways (time gaps) between the same trains (7 – 12 and 15 min)
2a		heterogeneous	slow > fast		/H2/ Different scheduled travel times of slow trains (7 – 12 min)
2b			fast > slow		
3	B	homogeneous	fast > fast		/H3/ Interaction with trains in reverse direction
4	C				/H4/ Effect of the closure of one line track in half of the section C – D

All 200 stochastic replications in all simulation scenarios are realized by the same probability distribution of input delay so the results are comparable. The mean value of this delay is set as 2.83 min.

4. Simulation Results in Stage A – Interaction Between Successive Trains

Scenario 1 is focused on the fact how headway (time gap) between trains can influence the number of cases when the second line track (of irregular direction) is applied for overtaking of another (delayed) train as is stated by the hypothesis H1.

Fig. 1 shows the relation between scheduled headway (time gap) before a train and the probability that this train (the second in sequence) will overtake the first one by driving on an irregular train in any of the line sections. Each train (point in the graph) is based on 200 stochastic replications in 5 line sections, which means 1000 cases in total.

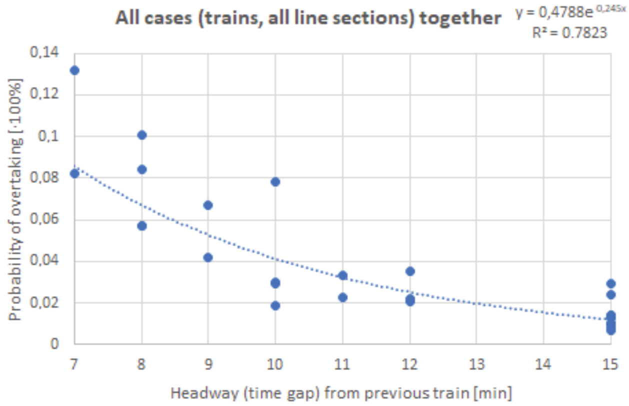

Fig. 1 Overtaking probability in total

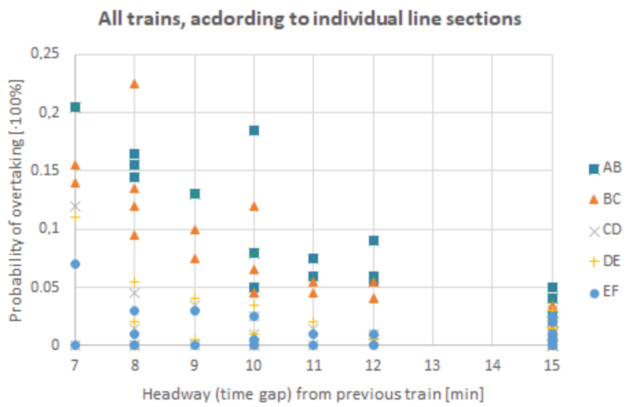

Fig. 2 Overtaking probability according to line section

Fig. 2 represents similar data with the resolution of each individual line section. The general result is that the probability of overtaking (by using of the irregular track) decreases in an exponential way by rising of headway (time gap) between trains. Fig. 2 shows that the probability of overtaking decreases by rising distance from the origin station of A where both trains are coming into interaction (trains are homogeneous – with same travel time and with same operating features). When this factor is individually assessed (like in Figs. 1 and 2) the hypothesis H1 cannot be rejected. Implementing crossover can be effective inline sections close to the station where successive trains come into interaction (they meet for the first time or as close one to another in time). On the other hand, this can be influenced by the number of local operative conditions and constraints like the mean value of delay by each train etc.

Scenario 2 is focused on interaction in couples of trains when both have different travel times. It can be practically expressed as a couple of fast long-distance and the slower regional trains. The travel time of fast trains is 7 min in each line section. Travel time of slow trains ranges from 7 to 12 min with 1 min increments. This interaction is evaluated in 2 ways. Scenario 2a is dedicated to a sequence of the slow and fast trains in order; scenario 2b is for a sequence of the fast and slow trains.

Fig. 3 shows the decreasing probability of overtaking related to the rising travel times of the slower trains. It can be seen that a higher probability of overtaking is recorded by fast trains going as the second train in order (scenario 2a) than by slower train going as the second (scenario 2b). On the other hand, the probability that a slower trains will overtake the faster one is increased by dispatching rules in the model as well. In fact, the slower train will not overtake the faster one, but it can continue without waiting on clearing of line track after the faster train.

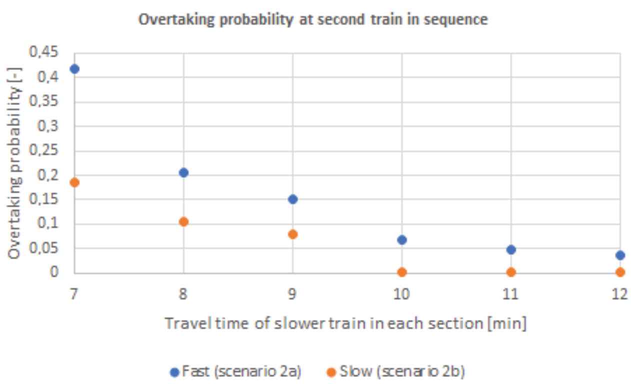

Fig. 3 Overtaking probability in sequence of trains

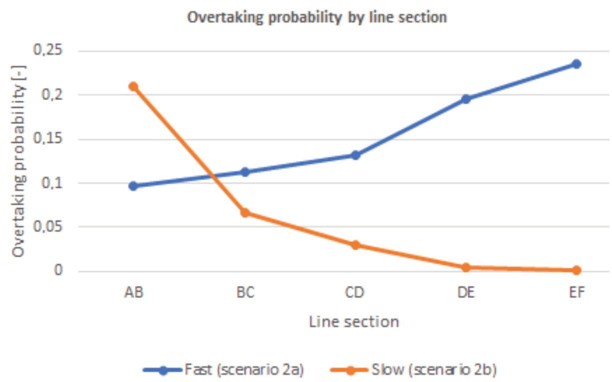

Fig. 4 Using of line sections for overtaking

The shortest headway (time gap) between slow and fast trains is 4 min on arrival at the final station F within scenario 2a. Scenario 2b is focused on different situations. Slow trains depart 4 min after faster trains from the origin station A. Crossover is more frequently utilized when train routes are closer one to another in the timetable. This simple presumption is confirmed by Fig. 4 in complex context – what is the probability of using crossover (overtaking probability) in each line section.

The hypothesis H2 that timetable heterogeneity has impact on utilization of crossover cannot be rejected as well. This idea can be stated in relation to Fig. 3. Rising headway (time gap) due to heterogeneity between the trains decreases the probability of overtaking.

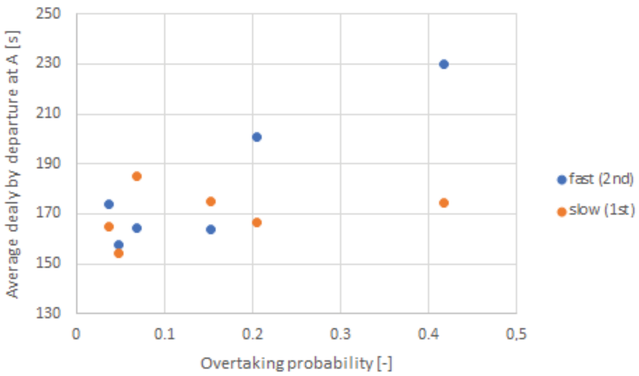

Fig. 5 Relation between overtaking probability by train and delay values, scenario 2a

Fig. 5 shows the relation between overtaking probability (according to fast trains) and average value of delay of overtaking fast train (blue points) as well as the average delay value of previous slower train (brown points). Each couple of nodes aligned in a vertical way represents one situation related to one fast train and to its probability to overtake a slower train. There is no strict relation between these factors as follows from Fig. 5. The Figure is based on 200 replications managed within simulation scenario 2a.

5. Simulation Results in Stage B – Interaction with Trains in the Reverse Direction

Stage B of the research is dedicated to hypothesis H3 that interaction with the trains in the reverse direction using second line track reduces overtaking probability or utilization rate of crossover in another expression. This is a simple presumption, but the issue is how serious is this impact. Simulation scenario marked as 3 is introduced for this stage.

This scenario 3 is based on alternating of 2 one-hour long periods of the timetable (peak and off-peak). The operation consists of 6 homogeneous trains going in two bundles (with headways 7-7-15-7-7-15 min) in the peak period. There are 4 homogeneous trains going regularly (15-15-15-15 min) in the off-peak one. These two ways of operation alternate during all assessed periods (6 hours). A total number of evaluated trains is 40 (20 in each direction).

Table 2

Overtaking probability – scenario 3

		Line section:	AB	BC	CD	DE	EF
Peak periods	1st bundle	1st train	0.08	0.04	0.01	0.00	0.00
		2nd train	0.16	0.14	0.05	0.03	0.03
		3rd train	0.16	0.12	0.08	0.11	0.08
	2nd bundle	1st train	0.02	0.01	0.01	0.01	0.01
		2nd train	0.13	0.11	0.01	0.01	0.04
		3rd train	0.18	0.14	0.11	0.08	0.07
Off-peak periods		1st train	0.04	0.03	0.02	0.01	0.01
		2nd train	0.01	0.00	0.01	0.00	0.00
		3rd train	0.01	0.01	0.00	0.01	0.00
		4th train	0.01	0.01	0.00	0.00	0.00

As follows from Table 2 elaborated for trains in so called basic direction from A to E, the main reasons determining the overtaking probability are bundling of trains and scheduled headway (time gap) between trains. Reached values of overtaking probability are similar to scenario 1 with homogeneous trains (about 4% in both cases), so the hypothesis H3 is not possible to be rejected. The reason is that this is closely related to timetable composition. On the other hand, the rate of validity is also an issue. It depends on multiple conditions.

6. Simulation Results in Stage C – Closure of One Line Track with Crossover

Stage C plays a complementary role in the research. It is a general assumption that crossover will be advantageous in the case of line track closure. One of the tracks may be closed in half of a section only. A higher stability level of operation can be expected. Supplementary hypothesis H4 is not too much specific, because only initial research was conducted in this point of view. The hypothesis states that crossover is beneficial by the closure of one line track.

Scenario 4 is based on the same timetable as scenario 3, but the track for direction A – F cannot be used in the middle section C – D in full length. The closed part is between the crossover and station D. This is the reason, why the timetable for this simulation scenario is not conflict-less in deterministic conditions with no delay. It is such a case of an irregular situation.

Simulation results are compared for both scenarios (3 and 4) and for direction A – F noted as basic within this study. Delay increment is applied as an indicator for evaluation. The reason is that closure can affect the stability of operation. The same simulation seed was applied for both scenarios (3 and 4) so that the results are comparable also in stochastic conditions. This evaluation is based also on 200 stochastic replications.

The results were measured at station D behind the line section with closure in a basic direction. The simulation shows that crossover is not the only one effect determining operational stability. It also depends on operative dispatching of traffic. There are 23.2% trains in average with the same delay as without closure in scenario 4. The closure causes an increment of delay by 36.1% of trains on average and reduction of delay by 40.7% of trains. Fig. 6 shows a more detailed overview for each train in basic direction A – F.

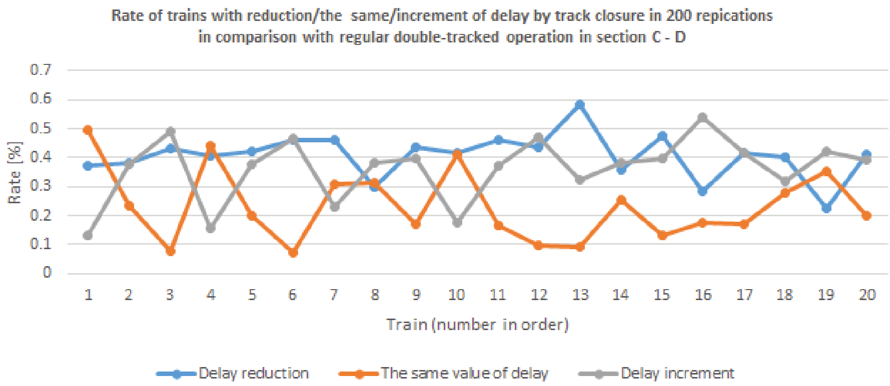

Fig. 6 Impact of line track closure on operation stability in section C – D

The average delay increment is 266 seconds, when the train is stopped (or affected) due to closure. There are average values from 156 to 525 seconds recorded by individual trains (each of them is averaged over 200 replications). These values occur in comparison with the standard double-tracked operations (scenario 3).

On the other hand, reduction of delay occurs also by some trains (in comparison with standard operation according to scenario 3). The total average change of delay is -0.99 seconds by all trains together (trains with the same value of delay and with reduction of delay are also included). This can be interpreted that crossover can allow flexible organisation of closure, but it also depends on dispatching rules next to a number of trains, timetable, specifically generated input delays etc.

The result is that there is no reason for rejection of hypothesis H4 that crossover is beneficial. On the other hand, the simulation results show that the positive impact should be significantly limited and that the situation must be considered carefully, in a more complex way and with regard to other influences as well.

7. Conclusions

This chapter is dedicated to discussion, further research and conclusions together. There are presented some important results of our research in this paper. The general aim of this research and project (mentioned in acknowledgement part) is to identify and assess some aspects influencing the stability of operation based on OpenTrack microsimulation models. These results can be incorporated in a modified methodology for capacity assessment or railway infrastructure. This paper is dedicated to the part focused on crossovers in the middle of sections located on double tracked lines.

The main feature to be discussed is the fact that capacity assessment is going to be a more complex process. As follows also from the facts mentioned in this paper, there are many features influencing the capacity as well as operational stability. Operation stability is applied as a capacity indicator nowadays. On the other hand, the influence of some aspects can be defined. It is complicated to define a set of universally valid equations like it was within the capacity assessment in the past due to above mentioned facts. It is necessary to define the overall relations between various aspects now. Defined relations can be used by the design of simulation models, but the application of simulation will be still recommended for complex results. The question remains that these simulation results are still of particular nature and that they are valid for each specific situation only. This is seen to be away, how to improve capacity as well as operational assessment of the infrastructure by using pointed and effective design of models.

The results presented in this paper follow this scheme. Not-rejected hypotheses of H1, H2 and H4 will provide a guideline that line track crossovers can be seen as a potential measures for lines with heterogeneous trains, but with similar travel times and with trains going with short headway. Sections with crossovers should be located as close as possible to stations where successive trains became in interaction. Crossovers are suitable also in the case of a track closure. On the other hand, an attempt to consider the hypotheses of H3 as well as H4 shows that final results, including efficiency, depend also on other effects – e.g. on the composition of the timetable. In general, the application of simulation can be recommended to regard the mixture of influencing aspects which can cause the reaching of totally different results from the generally assumed ones. Further research will be focused on other effects influencing the capacity and operational (timetable) stability.

A number of trains using the second line track should be applied as a newly designed indicator for railway line capacity assessment. Its application is assumed by considering crossover as a switch area in the middle of the line section. This measure allows moving a train from one track of double-tracked railway line to another.

The final conclusion is that simulation can be a powerful tool how to make a capacity assessment in a more complex way. Rules for the design of simulation models (extent of operation and infrastructure, set of scenarios, set of assessed results etc.) must take an integral part of the capacity assessment to reach more complex results.

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The Quality of Urban Public Transport Operation in the Conditions of Small Towns in Slovakia

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Abstract

The role of urban transport systems in the cities has an increasing role for a number of reasons. The most important is to restrict the entry of private car transport to the centers, to improve the environment of the cities and to provide more space for pedestrians, cyclists and inhabitants generally. The operation of the urban public transport systems in the biggest cities are operated by transport companies with shares of cities. But there are many small towns in which the urban public transport is operated but the operation is mainly provided by transport companies focused usually mainly on the regional bus transport. The article will deal with the analyses of the operation of urban public transport in the selected towns in Slovakia and with the suggestion for improving the services from the passenger point of view.
KEY WORDS: *urban public transport, timetable*

1. Introduction

The operation of urban public transport is regulated in Slovakia by Act no. 56/2012 The Road Transport Act and also according to Decree 5/2020 certain provisions relating to the ordering of public passenger transport are implemented. For the purposes of this Decree, the standards mean a set of rules that apply to the creation and provision of an adequate range of transport services in public passenger transport in the customer's area of interest, in particular:

- walking distance;
- stop service frequency;
- continuity of connections during the transfer;
- number of transfers;
- time interval between connections [1, 2].

The standards specify the conditions that apply to the national rail transport (hereinafter referred to as "long-distance transport"), regional rail transport, suburban rail transport and suburban bus transport (hereinafter referred to as "suburban transport"), urban bus transport, urban tram transport and trolleybus transport. and urban rail transport (hereinafter "urban transport") and public passenger water transport.

The standards take into account the division of transport services in the territory, as a rule, into main“ lines and service lines.

The number of connections and their capacity are determined on the basis of the results of the analysis of demand and the analysis of the justified requirements of the traveling public so that there is no concurrence and at the same time the minimum transport service is taken into account. The priority of providing transport services for a given catchment area or transport relationship is the type of transport that optimally meets the transport requirements in terms of capacity, cruising speed, economic efficiency, environment and walking distance.

The customer or integrator may exempt designated areas or off-peak times with low traffic flows from the application of the standards [3].

The standards define the offer of connections, in particular their number and the maximum departure interval between connections, ensuring the required capacity of the public passenger transport system, taking into account the time of day, night hours and non-working days.

The general standards are:

- the transfer time, which is:
  1. a maximum of 10 minutes in the case of guaranteed transfers in the direction of the transport stream in which the most passengers are transported at the transfer node;
  2. maximum 30 minutes for other guaranteed transfers;
- the organization of all connections on the line principle with a uniform route or with minimal deviations on the line route;
- the determination of the length of connection departure intervals depending on the intensity of transport flows;
- the traffic on carrier lines at regular intervals;
- the addition of service lines on selected sections [2].

Transfer time according to paragraph 1 letter (a) may be extended accordingly depending on the time of movement due to local conditions, in particular the distance of the platforms.

Special standards for urban transport

Specific standards for urban transport in municipalities with a population of less than 50,000 are the creation of connections, in particular to job centers, schools, medical facilities and public authorities with guaranteed transfers in connection with suburban transport or long-distance transport to those facilities, if such centers are more than 1 500 m or more than a 20-minute walk from a long-distance or suburban bus stop [2].

2. The Operation of Urban Public Transport in Small Towns

Urban public transport is introduced in settlements with a population above 20 000 inhabitants and it is a necessity in cities above 40 000 inhabitants. In addition to the number of inhabitants in the city there are other aspects for creating the urban public transport in the town or city such as the distribution of functions in the city, the nature of the settlement form (area, linear, satellite) but also the size of the catchment area, various social goals, lifestyle, basic functions of the city and others. An important prerequisite for the quality, efficiency and attractiveness of public transport is the solution of the public transport network and good general service in the city [4].

In Slovakia there are many small towns in which urban public transport is operated. Usually the operation of the urban public transport in the small towns is provided by the transporters who provide mainly the regional bus transport services in the region or long distance bus transport services. This is why usually there are some main differences between the operations of urban public transport in the bigger cities where the operation is provided by the transport company.

Therefore there are some basic differences:

– the regional bus transport operators usually use the planning software for regional bus services;

– the timetables are often not clear for passengers with many different routes and notes;

– the possibility to buy the tickets is only from the driver and so there are only the possibility to board the bus only through the first door;

– the range of tickets is not so extensive as in the bigger cities and so not so advantageous.

The case study of one small city will be used as an example of all these issues which can make urban public transport not so attractive and used in the small towns [5-8].

3. Case Study of Urban Public Transport in Town Handlová

The town Handlová is situated in the Prievidza District, Trenčín Region in the middle of Slovakia. It is made up of the three parts Handlová, Nová Lehota and Morovno. It is mainly the mining town but because of mining decline the number of inhabitants has decreased in last years. Nowadays Handlová has about almost 17 000 inhabitants [10].

Fig. 1 Location of Handlová ton in Slovakia and the area of town where the urban public transport is provided

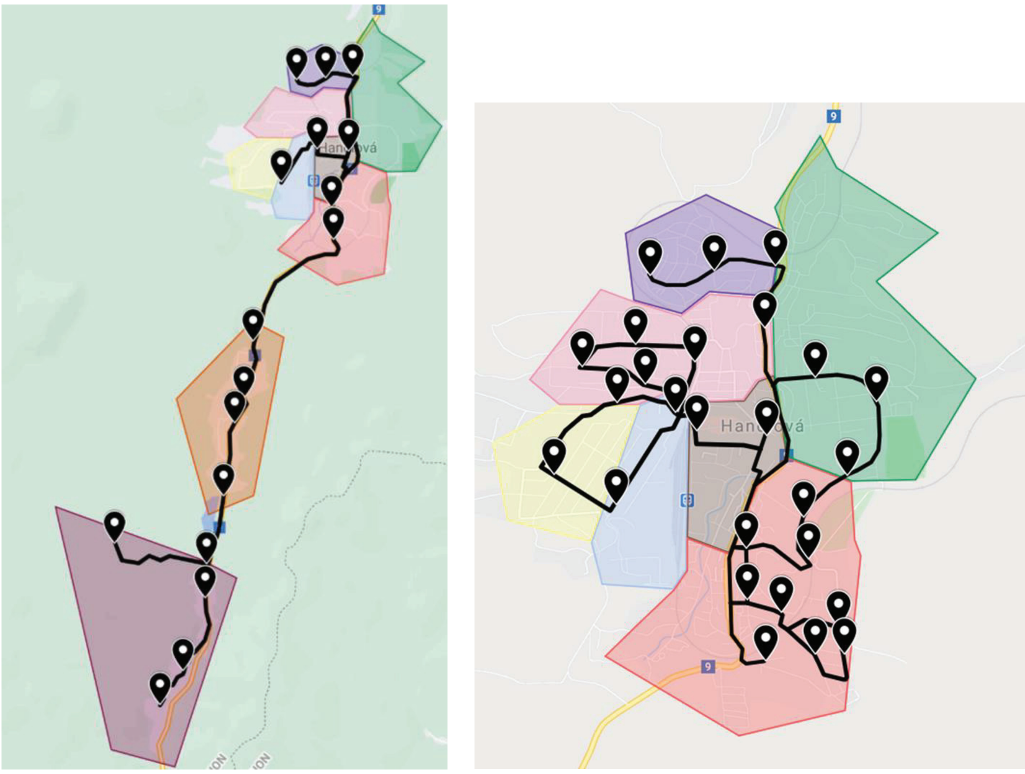
Fig. 1 shows the parts of the town. It can be seen that there are the town parts – former villages – which were connected to the town and to which also the urban public transport has to be provided. This is one of the usual problems of the small cities because these parts are longer distances from the town.

The town of Handlová is served by two lines of public transport, namely the line MHD307201 and the line

MHD307202 (hereinafter only as line no. 1 and line no. 2). These lines are operated by SAD Prievidza, a.s. There are currently 37 stops available for passengers.

Line no. 1 serves 18 stops. Its main goal is to provide transport services in more remote areas of Nová Lehota and the upper end of Handlová. In these two parts there are a total of 9 stops, of which 5 in Nová Lehota and 4 in the upper end of Handlová. In the main part of the city, this line serves 9 stops, important for the inhabitants of suburban areas, such as the center, hospital and industrial part, specifically the Handlová stop, mine. On this line there are 18 connections in the direction of Handlová, a mine to Nova Lehota and 17 connections in the opposite direction.

Line no. 2 serves 26 stops. Its main goal is to serve the main city districts of Handlová and to transport residents from the outskirts to work, school and recreation. Together with line no. 1 it serves the center, hospital and for the most part, as line no. 1, industrial parts and companies offering work. On this line, 33 connections are made in the direction of Handlová, sídl.MC, block F4 to Handlová, Gewis and 27 connections in the opposite direction [9].



a b

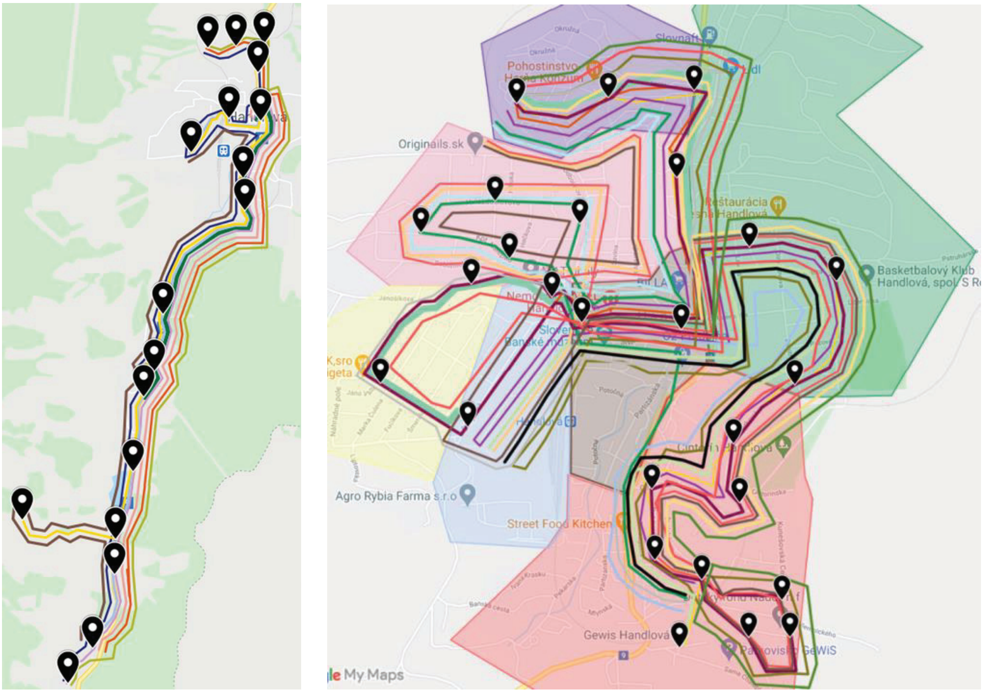
Fig. 2 Two urban public transport lines operated in Handlová: a – line no.1; b – line no. 2

In Fig. 2 we can see that the tracing of the lines is very confusing, because there are a large number of connections with different routes. This lack of clarity can complicate travel for tourists and people who do not use public transport in Handlová. This lack of clarity can also affect the number of passengers, so an effort should be made to simplify line routing, even if it means increasing the number of routes. From the first view of line no. 2 we do not see where it has a beginning and the end and we also do not know the sequence of servicing the parts of the town.

The timetable is also a problem on both routes. Both lines have a timetable created for both suburban bus services. It follows that there are different routes of connections on one line, the connections do not have an interval between them and the timetable is not divided into working days and days off, but above the connection there is a sign that characterizes the connection when it runs.

On line no. 1 we have 5 different route options in the direction of Handlová, mine to Handlová, Nová Lehota, gardens and 9 different route options in the opposite direction. The entire network of connections on line no. 1 can be seen in (Fig. 3, a). The picture shows a total of 9 different routes on this line. By analysis, we found that in the opposite direction, ie Handlová, Nová Lehota, gardens to Handlová, housing estate, MC, block F4 has 4 routes more than the first direction. Five options for tracing connections in the first direction can be found identical to connections that run in the opposite direction.

On line no. 2 we have 13 different routes in the direction of Handlová, part – housing estate called “MC block F4” to Handlová, Gewis and 8 possibilities of routes in the opposite direction. The entire network of all connections on line no. 2 can be seen in (Fig. 3, b). There are a total of 19 different ways of tracing the line in one and the opposite direction on this line.



a b

Fig. 3 Different routes of both lines

MHD307201 Handlová,baňa - Handlová, Nová Lehota,dedina — Platí od 15. 12. 2019 — www.mojbus.sk

Prepravu zabezpečuje:SAD Prievidza a.s., prev. Handlová,Handlová,Prievidzská 33,tel.č.046/5424433

Tč	SAD Prievidza a.s., prev. Handlová		35		1		3	5		7	9		11		31	13		15	17		21		19	23		25	27		33		29
			⚒ [41]		[39]		⚒	⚒										⚒			⚒										
1 od	**Handlová,baňa**	MHD	450	...	505	...	530	640	...	⚒	...	...	...	...	...	...	...	1310	⚒	...	1435	...	...	...	...	[63]	...	...	...	...	⚒
2	Handlová,nem.	MHD	452	...	507	...	533	643	...	[10]	...	...	M42	...	...	...	...	1312	[10]	...	1438	...	⑥+	⚒	...	M42	[63]	...	[63]	...	[22]
3	**Handlová,centrum**	MHD	453	...	508	...	535	645	...	705	735	...	925	...	1145	1245	...	1315	1340	...	1440	...	1440	1535	...	1625	1835	...	2050	...	2230
4	Handlová,Vežička	MHD	455	...	510	...	536	646	...	707	737	...	927	...	1147	1247	...	1316	1342	...	1441	...	1441	1537	...	1627	1837	...	2052	...	2232
5	Handlová,detský domov	MHD	457	...	512	...	537	648	...	708	738	...	928	...	1148	1248	...	1318	1345	...	1443	...	1443	1538	...	1628	1838	...	2053	...	2233
6	Handlová,hor.koniec	MHD	459	...	514	...	540	651	...	711	741	...	931	...	1151	1251	...	1321	1348	...	1446	...	1446	1541	...	1631	1841	...	2056	...	2236
7	Handlová,hor.koniec kostol	MHD	501	...	516	...	542	653	...	713	743	...	933	...	1153	1253	...	1323	1350	...	1447	...	1447	1543	...	1633	1843	...	2058	...	2238
8	Handlová,majer	MHD	503	...	518	...	543	655	...	715	745	...	935	...	1155	1255	...	1325	1354	...	1450	...	1450	1545	...	1635	1845	...	2100	...	2240
18	Handlová,rybník	MHD	504	...	519	...	544	656	...	...	746	...	936	...	1156	1256	...	1326	1355	...	1451	...	1451	1546	...	1636	1846	...	2101	...	2241
9	Handlová,vých.šachta rázc.	MHD	⌇	...	⌇	...	545	⌇	...	...	⌇	...	⌇	...	⌇	⌇	...	1327	⌇	...	⌇	...	⌇	⌇	...	⌇	⌇	...	⌇	...	⌇
10	Handlová,vých.šachta	MHD	⌇	...	⌇	...	550	⌇	...	...	⌇	...	⌇	...	⌇	⌇	...	1330	⌇	...	⌇	...	⌇	⌇	...	⌇	⌇	...	⌇	...	⌇
11	Handlová,Nová Lehota,hostinec	MHD	506	...	521	...	...	657	...	...	748	...	938	...	1158	1258	...	...	1356	...	1453	...	1453	1548	...	1638	1848	...	2103	...	2243
13 ↓	**Handlová,Nová Lehota,dedina**	MHD	510	...	525	...	...	700	...	...	750	...	942	...	1200	1300	...	...	1400	...	1455	...	1455	1550	...	1640	1850	...	2105	...	2245
19 pr	Handlová,Nová Lehota,záhradky	MHD	...	...	...	...	...	...	...	...	...	...	945	...	...	...	...	...	...	...	...	...	...	...	...	1642	...	...	...	...	...

⚒-premáva v pracovné dni
+-premáva v nedeľu a v štátny sviatok
⑥-premáva v sobotu
[10]-nepremáva 23.12.19 -7.1.,3.2.,24.2.-28.2.,9.4.-14.4.,1.7.-31.8.,29.10.-30.10.,23.12.-31.12.20
[22]-nepremáva 31.12.
[39]-premáva 23.12.,27.12.,30.12.,31.12.19, 2.1.-3.1.,7.1.,23.12.,28.12.-31.12.20
[41]-nepremáva 23.12.,27.12.,30.12.,31.12.19, 2.1.-3.1.,7.1.,23.12.,28.12.-31.12.20
[63]-nepremáva 24.12.,31.12.
M42-spoj od 15.4. do 15.10. končí na zastávke Handlová,Nová Lehota,záhradky

opačný smer

Tč	SAD Prievidza a.s., prev. Handlová		2		40	4		6	10		8	12		38	14		32		16	18		20	22		24	26		28	34		30
			⚒⑥		⚒									⑥+ M43	⚒ M43					⚒						[63] M43					⚒
19 od	Handlová,Nová Lehota,záhradky	MHD	[20]	...	[41]	[39]	...	⚒	...	...	⚒	...	...	950	950	...	...	...	...	[10]	...	...	...	...	⚒	1643	...	[63]	[63]	...	[22]
13	**Handlová,Nová Lehota,dedina**	MHD	440	...	515	530	...	555	...	...	710	750	...	952	952	...	1205	...	1305	1400	...	...	1500	...	1550	1645	...	1855	2105	...	2245
11	Handlová,Nová Lehota,hostinec	MHD	443	...	518	533	...	558	...	...	715	753	...	955	955	...	1208	...	1308	1403	...	⚒	1503	...	1553	1648	...	1858	2108	...	2248
10	Handlová,vých.šachta	MHD	⌇	...	⌇	⌇	...	605	...	...	⌇	⌇	...	⌇	⌇	...	⌇	...	⌇	⌇	...	1415	⌇	...	⌇	⌇	...	⌇	⌇	...	⌇
9	Handlová,vých.šachta rázc.	MHD	⌇	...	⌇	⌇	...	607	⚒	...	⌇	⌇	...	⌇	⌇	...	⌇	...	⌇	⌇	...	1416	⌇	...	⌇	⌇	...	⌇	⌇	...	⌇
18	Handlová,rybník	MHD	444	...	519	534	...	608	[10]	...	716	754	...	956	956	...	1208	...	1309	1404	...	1417	1504	...	1554	1649	...	1859	2109	...	2249
8	Handlová,majer	MHD	445	...	520	535	...	609	715	...	717	755	...	957	957	...	1210	...	1310	1405	...	1418	1505	...	1555	1650	...	1900	2110	...	2250
7	Handlová,hor.koniec kostol	MHD	446	...	521	536	...	611	716	...	718	757	...	958	958	...	1211	...	1312	1407	...	1419	1506	...	1556	1651	...	1901	2111	...	2251
6	Handlová,hor.koniec	MHD	447	...	522	537	...	612	717	...	719	758	...	959	959	...	1212	...	1313	1408	...	1420	1507	...	1557	1652	...	1902	2112	...	2252
5	Handlová,detský domov	MHD	450	...	525	540	...	615	721	...	722	802	...	1003	1003	...	1216	...	1317	1412	...	1422	1511	...	1601	1656	...	1906	2116	...	2256
4	Handlová,Vežička	MHD	452	...	526	541	...	618	723	...	724	803	...	1004	1004	...	1217	...	1318	1413	...	1423	1512	...	1602	1657	...	1907	2117	...	2257
3	**Handlová,centrum**	MHD	455	...	527	542	...	620	725	...	726	805	...	1005	1007	...	1220	...	1320	1415	...	1425	1515	...	1605	1700	...	1910	2120	...	2300
2	Handlová,nem.	MHD	457	...	528	543	...	623	...	...	727	⌇	...	...	⌇	...	...	...	1322	1417	...	1428	1517	...	...	...	...	...	...	...	...
1	**Handlová,baňa**	MHD	500	...	530	545	...	625	...	...	730	⌇	...	...	⌇	...	...	...	1325	1420	...	1430	1520	...	...	...	...	...	...	...	...
17 ↓	Handlová,sever	MHD	...	...	...	...	...	...	...	...	735	807	...	...	1009	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
16 pr	Handlová,sídl.MC Barum	MHD	...	...	...	...	...	...	...	...	736	808	...	...	1010	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

⚒-premáva v pracovné dni
+-premáva v nedeľu a v štátny sviatok
⑥-premáva v sobotu
[10]-nepremáva 23.12.19 -7.1.,3.2.,24.2.-28.2.,9.4.-14.4.,1.7.-31.8.,29.10.-30.10.,23.12.-31.12.20
[20]-nepremáva 29.8.,26.12.20
[22]-nepremáva 31.12.
[39]-premáva 23.12.,27.12.,30.12.,31.12.19, 2.1.-3.1.,7.1.,23.12.,28.12.-31.12.20
[41]-nepremáva 23.12.,27.12.,30.12.,31.12.19, 2.1.-3.1.,7.1.,23.12.,28.12.-31.12.20
[63]-nepremáva 24.12.,31.12.
M43-spoj od 15.4.do 15.10. začina na zastávke Handlová,Nová Lehota,záhradky

Fig. 4 Timetable of line no. 1

The different routes have an impact on timetable development. As it can be seen from Fig. 4, the visualization of the timetable looks chaotic. The issue is not only that each of both lines has many different routes (spacial problem) but also there are many notes about each of vehicle journey different time availability. The passengers can have a problem choosing the right connection, it is disarranged and confusing for them. Together with other problems the interest in urban public transport in small towns can decrease on the border of efficiency and the city government can logically approach a negative solution for inhabitants – to minimize the offered urban public transport services to the necessary minimum [1].

4. The Results of the Case Study and Solution Design

The case study of urban public transport in the town Handlová is an example of how urban public transport is operated in many more small towns around Slovakia. As the analyses show it is not a suitable way how to provide attractive urban public transport in small towns. The system is chaotic and non-attractive for inhabitants. The inhabitants will choose rather other possibilities how to get to their destination than the public transport.

If we want to provide quality public transport in small towns on the same quality as in larger towns or cities, the basic rules of system design must be followed. These basic rules are clear and direct line routes, the lines should be radial or diagonal, the network of lines is focused on selected transport tasks, construction of a transfer node in the center to facilitate the interconnection of lines, the urban areas within reach of the lines are covered as much as possible, the operation on the lines is provided periodically in all transport periods of the day, the branches of the lines are designed in such a way that the urban residential areas are served with as few vehicles as possible.

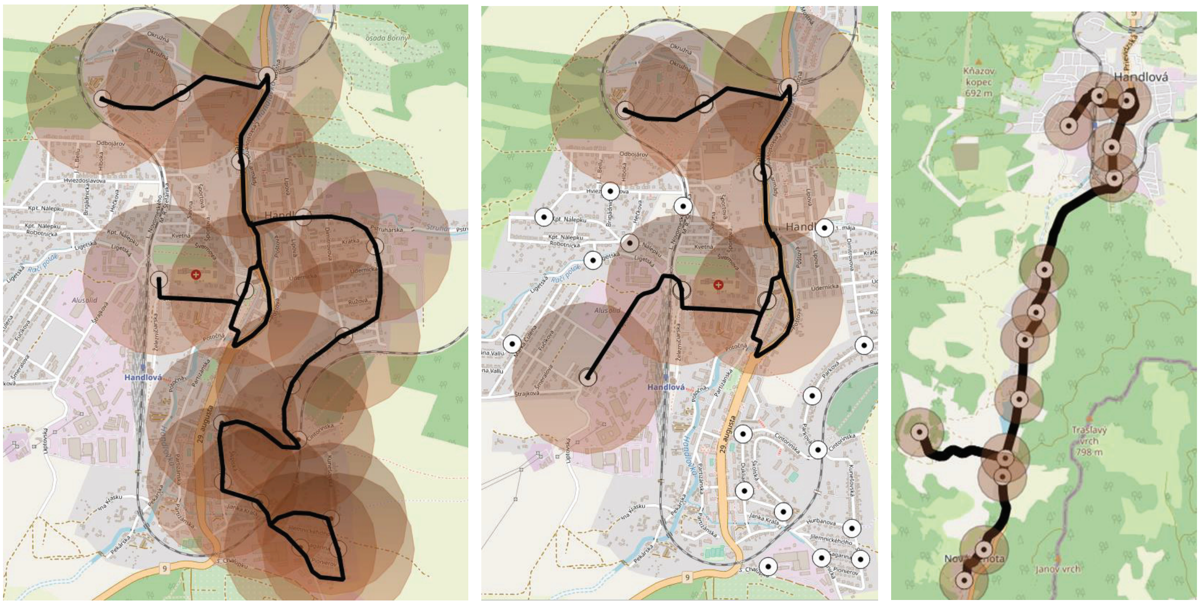


Fig. 5 The proposals of possible new line routes in the Handlová town

Fig. 5 shows the proposals of 3 lines with stable line routes for each vehicle journey in the Handlová town. It also influences the design of the timetable with the division of vehicle journeys only into the work days and weekends. It provides a clear and understandable timetable and the line routes for inhabitants.

5. Conclusions

The standards of quality urban public transport should be provided not only in the public transport systems in the large cities with many lines of different modes but also in the small towns. The key factors for such quality urban public transport even in the small cities are mainly the easy, understandable accessibility, the clear and understandable line routes and regular vehicle journeys for each line. It can be provided on the basis of a thorough analysis of citizens' mobility, their demand for journeys with regard to the destination and time of transport When all these key factors are proposed understandable for passengers, together with attractive tariff system also the urban public system can be attractive and the number of passengers can have the increasing trend.

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Research of the Model of the Life Cycle of Investment Projects of Subway Rolling Stock

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Abstract

The issue of traffic safety in general, in particular the subway, is considered. It is determined that the safety of traffic and passengers depends on many factors, including the technical condition of rolling stock. Keeping subway rolling stock in good technical condition requires a significant increase in investment funds for projects at the current level.
The principles of evaluation of investment projects of rolling stock of both railway and subway, which will allow in the real environment of operation to make optimal decisions on the choice of investors. The factors necessary for making a decision on investing in the project are identified.
The model of the life cycle of investment projects of subway rolling stock is presented, which provides a solution to the problem of high-quality methodological potential for solving new optimization problems of development and implementation of promising investment projects of modern rolling stock.
KEY WORDS: *project, model, investment, evaluation criteria, optimization, methods, rolling stock, subway.*

1. Introduction

From the beginning of investing the project to receiving the results takes some time. When deciding to invest in a project, at least three factors must be taken into account: inflation, risk and uncertainty, and the so-called possibility of today's use of funds. These factors determine the fact that the same amount is characterized by different values over time. The funds we have today are more valuable than the equivalent amount we expect in the future. Thus, the costs and benefits of the project that arise earlier should be given more "weight" than those that will occur later.

Since the safety of trains and passengers is guaranteed by the technical condition of rolling stock. Keeping rolling stock in good technical condition requires a significant increase in investment funds for projects at the current level [1-3].

The main principles of evaluation of investment projects of track economy are: purposefulness, system efficiency, system orientation on high final results of activity, logical-informational and resource realization

The financial and economic analysis of projects uses the same method of bringing current and future events (in their valuation) to a comparable form - discounting.

Discounting in the most general form can be defined as the reduction of financial and economic indicators to a time-comparable form with a discount rate. There are two methods that take into account the time factor - discounting and compounding.

When calculating the future value of the current amount of money, use compounding. The future value of money is the amount of money currently invested, in which they will be converted over a period of time, taking into account a specific interest rate.

2. Research Materials and Results

Determining the future value of funds is associated with the process of increasing this value, which is a constant increase in the amount of the deposit by adding to its original size the amount of interest (interest payments). This amount is calculated at the so-called interest rate [4]. In investment calculations, the interest rate is calculated not only as a tool to increase the value of cash, but also in a broader sense as a measure of the degree of profitability of investment operations [5]. The future value of the current amount of money is calculated by the so-called compound interest formula (compound interest is the amount of profit generated by investing, provided that the amount of accrued simple interest is not paid after each period, but joins the principal deposit and subsequent payment period itself brings profit):

$$FV = PV\left(1+\ldots i\ldots\right)^{n}, \tag{1}$$

where FV – the future value of benefits (costs); PV – current value of benefits (costs); i – interest rate (discount); n – number of time periods (years, months, etc.); $\left(1+\ldots i\ldots\right)^{n}$ - compound interest rate.

When calculating the current value of the future amount of money use their own discounting. The current value of money is the sum of future cash inflows, which are adjusted for a specific interest rate, the so-called "discount rate" for the current period. The process of discounting is an operation, the reverse of the build-up, with a predetermined final amount of cash. In this case, the amount of the discount percentage is deducted from the final amount (future value) of cash. This situation arises in cases where it is necessary to determine how much money needs to be invested today in order to get a previously agreed amount over a period of time [6]. The calculation of the current value of the future amount of cash is determined by the expression:

$$PV = FV\left(1+\ldots i\ldots\right)^{n}, \tag{2}$$

where $1/\left(1+i\right)^{n}$ is the discount rate.

When making financial and economic calculations that involve investing funds, the processes of increasing and discounting the value can be carried out not only at compound interest, as described above, but also at simple interest. For short-term investment, simple interest is usually used. A simple interest is the amount that is accrued on the initial value of the deposit at the end of one payment period due to the terms of investment (month, quarter, etc.). In this case, the future value of funds at a simple interest rate in the process of compounding is calculated by the formula:

$$FV = PV\left(1+ni\right), \tag{3}$$

where $\left(1+ ni\right)$ is the coefficient of increase of simple interest. It must always be greater than 1.

The current value of funds at a simple interest rate in the discounting process is calculated by the formula:

$$PV = FV\left(1+ni\right), \tag{4}$$

where $1/\left(1+ ni\right)$ is the discount rate of simple interest. It must always be less than 1. The main assessment of investment efficiency is the most important stage in the investment decision-making process. The timing of the return on investment depends on how objectively and comprehensively this assessment has been made. This objectivity and comprehensiveness of the evaluation of the effectiveness of investment projects is largely determined by the use of modern methods of such evaluation.

The methods of assessing the effectiveness of capital investments, which are currently used in practice, cannot be considered correct. Both indicators - the coefficient of efficiency (the ratio of the average annual amount of return to the amount of capital investment) and the payback period (the turnover to it) have a number of significant shortcomings that do not allow to assess the effectiveness of real investment.

Consider the methodological approaches used in foreign practice to assess the effectiveness of real investment. One of such principles is the assessment of return on invested capital on the basis of cash flow (cash flow), formed by the amounts of net profit and depreciation in the investment project. In this case, the cash flow ratio can be taken as differentiated for individual years of operation of the investment project or as an annual average.

In this case, it is mandatory to bring to the real value of both investment capital and cash flow. At first glance, it seems that the invested funds are always represented by the real value, as they significantly warn the repayment period in the form of cash flow. In real practice, this is not the case - the investment process in most cases is not carried out simultaneously, but goes through a number of stages. Therefore, with the exception of the first stage, all subsequent invested amounts must be reduced to the actual value (differentiated for each stage of subsequent investment). The amount of cash flow (for individual stages of formation) should also be reduced to the actual value. An important step is to choose a differentiated interest rate (discount rate) in the process of discounting cash flow for different investment projects [7]. As mentioned earlier, the amount of return on investment (in real investment, such income is the cash flow) is formed taking into account the following factors:

- average real deposit rate;
- inflation rate (or inflation premiums);
- risk premiums;

– premiums for low liquidity.

Therefore, when comparing two investment projects with different levels of risk, different interest rates should be used when discounting (a higher interest rate should be used for a project with a higher level of risk). Similarly, when comparing two investment projects with different total investment periods (investment liquidity), a higher interest rate should be used for a project with a longer implementation.

The principle of system orientation on high final results of activity provides formation of properties of ways of the underground and maintenance of their achievement at all stages of a life cycle.

When calculating various indicators of investment efficiency, the following can be used as the interest rate we will receive for discounting: the average deposit or credit rate; individual rate of return on investment, taking into account the level of inflation, the level of risk and the level of liquidity of investments; alternative rate of return on other possible types of investment; rate of return on current economic activity, etc [8].

Taking into account the above principles, consider the method of restraint model for assessing the effectiveness of real investment on the basis of various indicators:

In practice, the criterion for assessing the value of projects such as net present value (value) is widely used in the analysis of projects. It is the difference between the discounted benefits of the project and the discounted costs.

For conditions where the opportunity cost of capital changes over time, the net present value (value) is determined by the expression:

$$NPV = \left[\left((B_1 - C_1)/(1+i_1) + (B_2 - C_2)/(1+i_1)\ *(1+i_2)\right) + \left((B_n - C_n)/(1+i_1)\ *(1+i_n)\right)\right], \tag{5}$$

where $B_1, B_2, ..., B_n$ − benefits respectively $1, 2, \ldots, t, \ldots, n$ years; $C_1, C_2, \ldots, C_n$ − costs, respectively, $1, 2, \ldots, t, \ldots, n$ years; $i_1, i_2, \ldots, i_n$ − discount rates of $1, 2, \ldots, t, \ldots, n$ years, respectively.

In the case of $i = const$ in time Eq. (5) can be written:

$$NPV = \sum_{t=1(0)}^{n(n-1)} \left(B_t / (1+i)^t\right) - \sum_{t=1(0)}^{n(n-1)} \left(C_t / (1+i)^t\right). \tag{6}$$

Thus $t = 1(0)$ indicates that, when carrying out calculation, it is necessary to specify the year of the beginning of life of the project (as zero or as the first).

Eq. (6) allows us to take into account the possible difference in discounting the benefits and costs associated with the project. When this difference does not exist, Eq. (6) should be represented as:

$$NPV = \sum_{t=(0)}^{n(n-1)} \left(B_t - C_t / (1+i)^t\right), \tag{7}$$

if $B_t - C_t = const\,t$ for n years, then:

$$NPV = (B-C)/i(1-1)/(1+i)^n, \tag{8}$$

under conditions when n is large enough:

$$NPV = (B-C)/i. \tag{9}$$

The use of *NPV* as a criterion means that a project independent of other projects is implemented if its *NPV* is greater than or equal to zero. When choosing between several projects, preference should be given to a project with a larger, usually positive, *NPV* value.

The internal rate of return (profitability) is the discount rate at which the benefits are equal to the reduced costs, ie the discount rate at which the net present value (value) of the project is zero.

In fact, the internal rate of return (profitability) is equal to the maximum interest on loans that project investors can pay for the necessary financial resources, provided that it remains self-sustaining:

$$\sum_{t=1(0)}^{n(n-1)} \left(B_t - C_t / (1+i)^t\right) = 0\,. \tag{10}$$

The domestic discount rate serves as a benchmark for investors when compared to the opportunity cost of capital. The *IRR* selection criterion implies the acceptance of a project with a higher *IRR* value, which at that time must exceed the opportunity cost of capital.

Some properties of *IRR* limit its use. First, there may not be a single *IRR* value at which $NPV = 0$, ie the decision is relative and in some cases, when the annual net benefits in the project change sign over time more than once, can lead to multiple decisions. Second, the use of a single *IRR* value assumes that the interest rate is constant throughout the life of the project [9]. For projects with a deep time horizon, it is difficult to agree with this assumption, given the high level of uncertainty in more different years. Third, the *IRR* selection criterion may set priorities different from other criteria used in project analysis, in particular *NPV*.

Despite these shortcomings, *IRR* is widely used in project analysis. Most investors view the *IRR* as an indicator of what the return on equity will be, and decide to invest depending on the level of the. Modern analysis is based on the integrated use of and *IRR*.

IRR is calculated by trial and error, successive approximations, in the process of which the value of the net present value (*NPV*) is determined by the discount rates.

If you find that the net present benefits of a project change sign only once during its life cycle, then the *IRR* can be calculated using the equation:

$$IRR = i_1 + (i_1 + i_2)\left(|NPV_1| / |NPV_1| + |NPV_2|\right), \tag{11}$$

where i_1 – the discount rate at which $NPV = NPV_1\left(NPV_1 > 0\right)$; i_2 – the discount rate at which $NPV = NPV_2\left(NPV_2 < 0\right)$ The index of profitability (profitability) in methodological terms resembles the assessment of the previously used indicator "efficiency ratio of capital investments".

However, in economic terms, this is a completely different indicator, as the return on investment is not net income, but cash flow. In addition, future return on investment (cash flow) is reduced in the valuation process to value at present. The calculation of the yield index is carried out according to the formula:

$$PI = \sum_{t=1(0)}^{n(n-1)} \left(B_t - C_t / (1+i)^t\right) / \sum_{t=1(0)}^{n(n-1)} \left(I_t / (1+i)^t\right), \tag{12}$$

where I_t – investment costs per year.

The indicator "profitability index" can also be used not only to compare the assessment, but also as a criterion for accepting an investment project for implementation. If the value of the yield index is less than or equal to one, the project will not be implemented due to the fact that it will not bring additional income to the investor. In other words, investment projects can be accepted for implementation only with the value of the rate of return above one. Comparing the indicators "profitability index" and "net present value (value)", it should be noted that the results of the assessment of their efficiency of investment is directly dependent: with increasing absolute value of net present value (value) increases the value of the profitability index and vice versa. Moreover, at zero value of net present value (value) the profitability index will always be equal to one, which means that only one (any) of them can be used as a criterion for the feasibility of the investment project. With regard to the comparative assessment, in this case, both indicators should be considered, as they will allow the investor from different angles to assess the effectiveness of the investment [10].

The payback period is one of the most common and understandable indicators for assessing the effectiveness of investments. In comparison with the indicator "payback period of capital investments" used in our practice, it is also based not on profit, but on cash flow with the reduction of invested funds and the amount of cash flow to the actual value. The calculation of this indicator is carried out according to the formula:

$$\sum_{t=1(0)}^{n(n-1)} \left(B_t / (1+i)^t\right) > -\sum_{t=1(0)}^{n(n-1)} \left(C_t / (1+i)^t\right). \tag{13}$$

Characterized by the indicator "payback period", it should be noted that it can be used to assess not only the effectiveness of investment, but also the level of investment risks associated with liquidity (previously noted that the longer the project period to full its essence, the higher the level of investment risks). The disadvantage of this indicator is that it does not take into account the cash flows that are formed after the payback period. Thus, for investment projects with a long service life after the payback period can be obtained a much larger amount of net present value than for investment projects with a short service life (with a similar and faster payback period).

The cost-benefit ratio is defined as the ratio of discounted benefits to discounted costs:

$$B / C = \sum_{t=1(0)}^{n(n-1)} \left(B_t / (1+i)\right)^t / \sum_{t=1(0)}^{n(n-1)} \left(C_t / (1+i)^t\right). \tag{14}$$

There are several variants of this relationship. Most often in practice, the ratio is calculated by Eq. (14).

If $B / C > 1$, then the project deserves attention because it means that $NPV > 0$. Projects that are characterized by a higher value of the "cost-benefit" ratio are more profitable.

There are other cases of application of this criterion in practice. For example, in public transport projects, the project analyst may need to set a payback level for the fare, ie the minimum price at which the system will pay off financially. Comparing the payback price with the existing tariffs or with the actual production costs, the analyst will determine whether the subsidy and its size are needed.

The task of payback point analysis is to establish the following values of B_{jt} or C_{jt}, at which:

$$\sum_{t=1(0)}^{n(n-1)} \left(B_t - C_t \,/ \left(1+i\right)^t \right) = 0, \tag{15}$$

where $B_t = b_{1t} + b_{2t} + ... + b_{mt}$; $C_t = c_{1t} + c_{2t} + ... + c_{kt}$; $b_{1t} + b_{2t} + ... + b_{mt}$ − individual benefits per year *t*; $c_{1t} + c_{2t} + ... + c_{kt}$ – individual benefits per year *t*.

The payback selection criterion indicates that the project should be selected if the payback price is satisfactory in terms of the purpose of the company or private owner [11].

In investment practice, we constantly have to take into account the inflation factor, which over time depreciates the value of money. This is due to the fact that rising inflation causes a corresponding decrease in the purchasing power of money. When calculating the adjustment of cash flows in the process of investing for inflation, it is customary to use two basic concepts - nominal and real amount of money.

The nominal amount of cash is an estimate of its value without taking into account changes in the purchasing power of money.

The real amount of money is an estimate of its value, taking into account changes in the purchasing power of money due to inflation.

The principle of system efficiency determines the implementation of such track repair projects, which provide high quality and efficiency of their intended use.

3. Conclusions

It is determined in the work that for the decision of new optimization tasks of development and realization of perspective investment projects of a rolling stock creation of qualitative methodological potential is necessary.

The principles of evaluation of investment projects of metro rolling stock functioning are formulated, which will allow to make optimal decisions on the choice of investors in the real environment of functioning.

Possible options for ensuring the efficiency of investments in various areas in rolling stock projects are shown.

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A Practical Way to Determine Slippage and Lead in the Front Wheels of the BELARUS 112H Mini-Tractor

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Abstract

Various mini-machines are used on small farms to carry out various field works, with vehicle types including mini-tractors. Tractor wheels have a powerful effect on the soil while they are being subjected to loads, severely compressing the soil in the process and leaving deep tracks in it due to slippage and skidding. This article reviews slippage and front wheel lead in the wheels of a mini-tractor, the methods which can be used to determine such slippage, and methods which can be used in improving the economic efficiency of a mini-tractor. In order to increase the economic efficiency and performance of such mini-tractors, it is apparent that there is a requirement to increase the load and adaptation of the mini-tractor so that it can better handle various agricultural jobs. The starting point is to properly determine front wheel lead and slippage in the wheels of the mini-tractor, as this has the greatest level of impact on fuel consumption and the mini-tractor's performance levels. Wheels which are unnecessarily slipping extend the time taken to complete tasks while also increasing fuel consumption.
KEY WORDS: *mini-tractor, front wheel lead, slippage*

1. Introduction

A mini-tractor with pneumatic tyres is usually one of the most widely used main tools where agricultural machinery is concerned. When operating a mini-tractor and working with an engaged front axle (a 4x4), various tyre pressures, various levels of tyre tread wear, or uneven wear in other areas, a kinematic mismatch occurs between the front and rear wheels. This mismatch increases engine load and fuel consumption. This article provides a way of being able to determine slippage and front wheel lead in the mini-tractor's tyres. This often happens when the tractor's front and rear axles are engaged. Due to the kinematic mismatch between the theoretical speeds of the front and rear wheels (even when driving on a straight smooth road), the front or rear wheels start to skid. Consequently, the steering wheels start to lose firm adhesion to the surface, the lateral force which is required to turn the tractor is not generated, and the tractor's steering ability deteriorates. When the front wheels skid due to a kinematic mismatch while the tractor is engaged in agricultural work, the tyres heat up, their levels of durability are compromised, and the soil's surface is damaged. A mini-tractor wheel will slip or skid when the force which is acting parallel to the road's surface is greater than the force of the tractor wheel's adhesion to the road. The wheels of a mini-tractor are subject to different levels of ground adhesion due to the differing potential loads, which can result in unequal slippage meaning that, whatever the kinematic relationship of the drive axles may be, their vertical load is usually not the same, so the torques are not evenly distributed on both axles. The greater the difference in kinematic mismatch between the front and rear wheels, the more different are the theoretical speeds of the front and rear wheels in all conditions, especially if the mini-tractor's wheels are not of the same dimensions. When these theoretical speeds are unequal, the actual speeds of the front and rear axles can only be matched if any slippage in their wheels is unequal. Knowing the front wheel lead and slippage of a mini-tractor's tyres can reduce the impact of kinematic mismatch on engine load and fuel consumption.

The aim of the article is to provide the reader with a practical way of being able to determine the lead and slippage of the front wheels on the Belarus 112H mini-tractor.

The objective of the research is to calculate the lead and slippage of the front wheels on the Belarus 112H mini-tractor.

In view of the above, there is a need to determine lead and slippage values for the front wheels of the mini-tractor and, once these have been determined, to decide upon what can be done to change those values for slippage and front wheel lead in terms of the mini-tractor's wheels to achieve values which fall between an acceptable range.

2. The Need to Reduce Slippage on the Drive Wheels and the Lead on the Front Wheels of the Mini-Tractor

The front and rear wheels are loaded differently during operation of the mini-tractor, resulting in uneven deformation, while a kinematic wheel mismatch can occur when the front wheels run on uncompressed soil; they deform the soil and the tyres themselves and the rear wheels ride in the tracks which have been formed by the front wheels, while also deforming differently from the front tyres. Due to the aforementioned kinematic mismatch, the wheel, and even the tractor itself, can skid both in the longitudinal and transverse directions [1].

Rapid wear on a tyre reduces its actual (kinematic) rolling radius. The radius can also become uneven due to differences in tyre pressures. If the radii of the left and right wheels are different, the wheels skid while they roll, and the torque which is transmitted by the engine is distributed differently between them. Not only that, but the circulation of parasitic power in the transmission increases, the tyres wear even more intensively, and the soil surface is torn up. Due to the different loads being placed on the front and rear wheels, their deformations also differ [2].

If the traction force on the drive wheels of the mini-tractor is greater than the force of adhesion to the road, the wheels will start slipping. Slippage in the mini-tractor's wheels is a necessary phenomenon to protect the mini-tractor's transmission from mechanical damage and excessive wear of the mini-tractor's transmission units.

In the available literature, authors indicate different values for permissible slippage limits in the tractor wheels, which should be within the range of 8-15%. The recommended limit for a tractor with two drive wheels is between 10-15%, and for a tractor with all four drive wheels the range is smaller: between 8-10%. If slippage is lower than indicated in the available literature, this figure can be classed as being incorrect because the tractor's tractive potential is not fully being used, the drive wheels have to handle too much gravity, and energy is wasted in terms of having to move the excess weight, while at the same time compressing the soil. In this case, fuel consumption can increase by as much as 15%. The optimal slippage value for tractors with all-wheel drive is between 6-8% [2-4].

Modern mini-tractors with 4WD drive often have a rigid connection between the front and rear axles; the drives on agricultural machines usually do not have any mechanical ability to be able to compensate for the change in wheel diameter, depending upon load, tyre elasticity, air pressure, or tyre type or wear [5-7].

In tractors, the tyre diameters must be chosen in such a way that the rear and front axles are able to generate the same speeds in relation to the ground's surface. The rear wheels are larger than the front wheels, so the front wheels must rotate faster because the linear speed must coincide with the rotation of the rear wheels, or they should at least be close to each other. The front wheels are usually adjusted to rotate faster than the most suitable speed for all wheels, depending upon the transmission ratio for the rear and front axles. Lead in the front wheels is performed in order to obtain the most suitable rotational speed between the rear and front wheels in relation to the ground. One of the drive axles in the transmission of agricultural machinery has a lead ratio. The front wheels on most agricultural machines are the leading ones, i.e. they rotate faster. The lead ratio is determined as follows [5]:

$$S_p = \frac{v_p - v_g}{v_t} , \qquad (1)$$

where v_p is the theoretical speed of the front wheels, m/s; and v_g is the theoretical speed of the rear wheels m/s.

The lead of the front wheels on agricultural tractors is about 2-3%. This means that the front wheels rotate 2-3% faster than the rear wheels [5-6]. This ratio between the front and rear axles is not standard on all tractors with a 4x4 drive, as it varies depending upon the size of the tyres being used and on the various tractor models. In tractors, front wheel lead is usually rated at between 1.5% and 4%, as studies have shown that a front wheel lead of between 1-5% is appropriate when working in the soil [7]. The positive lead of the front wheels should never be less than 1% and no more than 5%, as exceeding these limits significantly increases the deformation of the tyres and the tyres then wear faster [6]. When a tractor with a 4x4 drive is working with an incorrect front wheel lead (lead is too fast), it will often jump and vibrate during operation due to excessive speed differences and the fact that the wheels will skid on the surface not at the same time. This usually happens when working on a hard surface [6, 7].

Accurate measurements are required to determine whether lead is not excessive. The front wheels will no longer do their job if their lead is too slow. This is easiest to determine during towing when working in soft ground, by switching the tractor to two-wheel drive mode. Switching to 2x4 mode did not significantly increase wheel skid, so it can be concluded that the lead of the front wheels is too slow. Power circulation occurs when the rear wheels try to push the front wheels. This can lead to transmission failures, faster tyre wear, rough driving, increased turning radius, and higher fuel consumption [6-9].

This reduces the efficiency of the tractor, increases tyre wear, and also increase wear in the transmission units. The transmission creates unwanted power circulation and system losses. Damage is caused by power circulating not only between the axles but also between the front wheel and the rear wheel surfaces. Therefore the tractor needs more force to compensate for the resulting circulation losses. Excessive lead of the front wheels can cause the front wheels to jump, the front wheels will wear faster, and the ground will be crushed under the front wheels as they will be pushed through the ground's surface. This is most commonly observed when working on hard surfaces [6, 10].

Most tractors come with different tyre sizes on the front and rear axles. Most of them are also built so that the front axle is loaded with between 50% and 65% of the tractor's mass when standing. Studies and tests have recommended that this vertical wheel load ratio be maintained during operation [11-14].

Agricultural machinery uses a variety of implements, so it is natural that the load on the wheels is constantly changing. For this reason, when using ballast weights, it is recommended that the vertical wheel load between the front and rear axles does not differ by more than 10% [10-13].

3. Determining Drive Wheel Slippage on the Mini-Tractor

In most cases, mini-tractors do not have an automatic wheel slippage control system, which makes it necessary to calculate the lead and slippage of the front wheels on a mini-tractor. Determining wheel slippage is not a difficult process.

It can be done in a simple, practical way by calculating the number of revolutions of the tractor drive wheels on a given section of soil: first the figure for the fully unloaded mini-tractor, n_t, is calculated and then, when working with a loaded mini-tractor (after attaching an agricultural implement, additional ballasting, etc.), the drive wheel revolutions, n_f, are calculated. Following those calculations, drive wheel slippage is calculated:

$$\delta = \frac{n_t - n_f}{n_t}, \tag{2}$$

where n_t is the number of revolutions in the wheels of a fully unloaded mini-tractor; and n_f is the number of revolutions in the drive wheels of the loaded mini-tractor.

A general algorithm for determining tyre slippage using a practical method is presented below:

1. Check whether all tyres on the mini-tractor are of the same size. Check the air pressure in the tyres and inflate them to 0.1MPa; use an air gun for this work (when the accuracy of the scale interval does not exceed 10 kPa). Check the air pressure in the mini-tractor's tyres and inflate them when they are cold.
2. While driving, lower the implements to the ground and stop.
3. Mark the index points of the mini-tractor's front and rear wheels using a chalk stick as shown in Fig. 1.

Fig. 1 Marking the index points of the mini-tractor's wheel

4. Place the markers on the ground next to where the mini-tractor's tyre touches the ground. The marker must be inserted in such a way that it is not interfered with mounted implements. When marking out, make sure that the assistant does not enter the movement area of the mini-tractor's mounted implements.
5. When moving around the mini-tractor, the assistant must count ten revolutions of the mini-tractor's rear wheel and insert then the second marker. Lead on the mini-tractor's front wheels can be determined using the information in Table 1. Knowing that the mini-tractor's rear wheel has made ten revolutions, as well as the number of revolutions which are made by the mini-tractor's front wheel, we can determine the lead of the mini-tractor's front wheels using the information provided in Table 1, which must be positive.

Table 1

Determining front wheel lead on the mini-tractor

Front wheel revolutions	11	10.75	10.5	10.25	10	9.75	9.5	9.25	9
Rear wheel revolutions	10	10	10	10	10	10	10	10	10
Lead %	10	7.5	5	2.5	0	2.5	5	7.5	10

In the case of needing to determine the lead of the mini-tractor's front wheels and when a negative result is obtained, it is necessary to measure the air pressure in the tyres with a manometer which has a scale interval of no more than 10kPa. If the air pressure reading has not decreased, the air pressure in the rear tyres must be reduced to 90kPa.

6. Raise the mounted implements from the ground, return the mini-tractor to the starting position, where the first marker has been inserted and, after erasing the original marking out, mark out once again as shown in Figure 1, so that the mini-tractor's wheel is marked out at the first marker.
7. Drive from the first marker to the second with the implements raised (Fig. 2), and calculate the revolutions of the mini-tractor's rear wheel. Because the mini-tractor's wheels will slip less, the tyre will need to complete fewer revolutions in order to cover the distance between the two markers.
8. The easiest way to determine the wheel slippage on a mini-tractor's tyres is to calculate the lost road distance between the first and second driving points, depending upon the wheel speed of the mini-tractor based on the information in Table 2.
9. If slippage on the mini-tractor's tyres is too high or too low, a decision must be made to ballast the tractor or to change the tyre pressure. Reduce air pressure below 80 kPa is not allowed as well as it is not allowed to increase the maximum axle load on the mini-tractor above 420 kg.

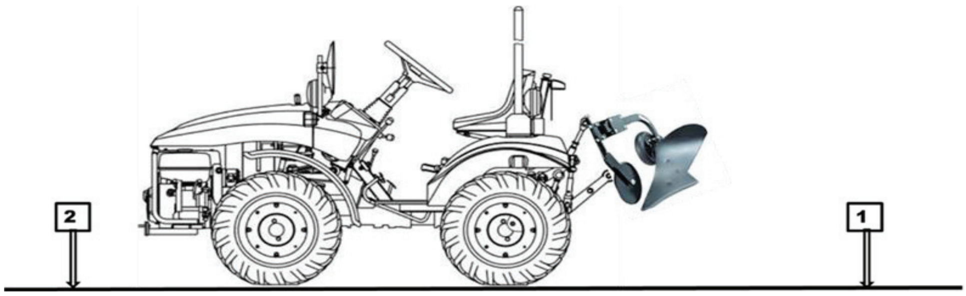

Fig. 2 Diagram showing the determination of wheel slippage on the mini-tractor

Table 2

Determining wheel slipping on a mini-tractor

Front wheel revolutions	10	$9\frac{3}{4}$	$9\frac{2}{4}$	$9\frac{1}{4}$	9	$8\frac{3}{4}$	$8\frac{2}{4}$	$8\frac{1}{4}$	8	$7\frac{3}{4}$	$7\frac{2}{4}$	$7\frac{1}{4}$	7	$6\frac{3}{4}$	$6\frac{2}{4}$	$6\frac{1}{4}$	6
Rear wheel revolutions	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Lead %	0	2.5	5	7.5	10	12.5	15	17.5	20	22.5	25	27.5	30	32.5	35	37.5	40

4. Basic Rules for Ballasting Mini-Tractors

When using fluid as an additional weight, one of the mini-tractor's axles must be filled in equal parts for each tyre. The load must be increased gradually, starting from the minimum mass values. The same principle must be used for metal wheels as for additional weights or other suspended weights. When using a mini-tractor for light work, the distribution of tractor weight between the axles tends not to be significant enough. At high loads, it is recommended that the weight distribution on the mini-tractor between the axles should be 50/50, and the tyre pressure should not be less than 0.80 MPa.

Four-wheel drive mini-tractors are operated under different conditions and are used for different jobs. Therefore maximum efficiency has to be ensured by the tractor's driver. The tractor is equipped with implements with a basic working speed of about 5 km/h, at which there is a higher level of performance and a low probability of mechanical failure. Tractor performance depends upon many factors, such as the load amount, slippage of the wheels, the rolling resistance of the wheels, and operating mass and its distribution between the mini-tractor's axles. Operating the mini-tractor with high loads in terms of suspended implements is something that is not allowed; the purpose of the mini-tractor is to carry out field agricultural work. Prolonged operation of a mini-tractor with a heavy load will result in a transmission failure in the mini-tractor and will shorten the service life of the tyres.

The best levels of traction are achieved when the rate of the mini-tractor's wheel slippage falls between the range of 8-15% for towing work and 13%-15% for agricultural work with implements which are equipped with a three-point suspension system. If possible, the mini-tractor's ballast should be reduced when loads are light. The best indicator to use when ballasting a mini-tractor is to prevent the tractor from operating under a load which produces a wheel slippage of at least 12%. Lead in the mini-tractor's front wheels must be positive (within the range of between 1% and 5%), as this is when the mini-tractor's maximum traction is developed. From an economic point of view, the best value for lead in the mini-tractor's front wheels is at about 1-2%.

5. Conclusions

This article presents an algorithm which can be used to determine tyre slippage and front axle lead on a mini-tractor without an integrated automatic wheel slippage control system, which makes it possible to determine the value using a simple, practical method. If the values for front wheel lead in the mini-tractor are higher than the recommended value (the best value for the lead of the front tractor wheels is about 1-2%, while for slippage in the mini-tractor's wheels falls between 8-15%), then steps must be taken to adjust the wheels.

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Method for Determining the Linear Velocity of a Locomotive Development

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Abstract

The article discusses a method for determining the linear velocity of a locomotive based on the use and conversion of automatic locomotive signals, taking into account the shortcomings of existing systems using a distance sensor, velocity sensor and GPS.
KEY WORDS: *locomotive, locomotive signaling, linear velocity, slipping, distance, distance sensor, velocity*

1. Introduction

Ukraine has got one of the largest railway networks in Europe, which handles a significant part of freight and passenger flows, and the favorable geographical location of Ukraine in the center of Europe creates a transport corridor between the countries of Europe and Asia, which is developing at a very fast pace.

Railway transport takes a leading place in the general transport system of Ukraine. Increasing the efficiency of railway transport is closely related to solving the problem of increasing speeds and safety in freight and especially in passenger traffic. Increasing train speeds is one of the most important tasks in improving operational work and developing railway transport in all industrialized countries of the world and in Ukraine in particular. The high-speed movement of passenger trains allows to reduce the time spent by passengers on the trip and thereby improve the quality of transport services. Thanks to these and other advantages over other modes of transport, high-speed communication is becoming an economic and environmentally friendly part of the global transport system.

To ensure the safety of train traffic and assess the work of the driver along the route, it is necessary to determine the linear velocity of the locomotive as accurately as possible. The high accuracy of measuring the linear velocity allows to correctly calculate the braking distance, the length of which depends on the square of the velocity, to determine the current coordinate or the distance traveled, which is especially important when the train is running within the station, including when it stops on a limited section. Having information about the linear velocity of the locomotive, it is possible to reliably identify the skidding and skid modes, which will allow to quickly perform actions that prevent the occurrence of these actions.

2. Research Results

Currently wheel track and velocity sensors (TVS) are mainly installed on locomotives to measure velocity and distance. They are attached to the wheel axle of the locomotive, and a certain number of pulses in the output bus of the sensor correspond to one turn of the wheel. Since the wheel is in contact with the rail, factors such as slippage and skidding of the locomotive wheels have unpredictable effect on the accuracy of the sensor readings. The quality of measurements and errors in determining the diameter of the bandage (part of the wheel in contact with the rail) due to its decrease because of wear during operation, etc., affect the quality of measurements. As a result of all these shortcomings, today when using such sensors, the error is up to 50-70 m per kilometer of track [1].

The new navigation systems installed on Russian Railways, namely the GLONASS/GPS satellite navigation systems, although they are advanced technologies, have a number of disadvantages, since the errors of measurements carried out with their help depend on many factors: the influence of the Earth's ionosphere, cloudiness, reflection of signals from surrounding objects and surfaces, the geometry of the location of satellites, etc. Errors in determining the coordinates of the user using these navigation aids on moving objects can reach 15 m and more [2].

One of the ways to determine the linear velocity of a locomotive to avoid the negative impact of the above factors is to use automatic locomotive signaling (ALS) signals.

Automatic locomotive signaling (ALS), is a set of devices that automatically repeat in the driver's cab the indications of the track lights that the train is approaching, regardless of the track profile and weather conditions, and also provides the locomotive driver with information about the train situation, controls velocity, wakefulness and vigilance, generates a signal for registration on the belt of the locomotive velocity meter. At the same time, only three active signals are used to transmit information to the locomotive, and the element base - electromagnetic relays, requires large operating costs and does not significantly increase the reliability of the equipment and expand its functionality.

On periodic basis alternating current electrical signal (code) is sent to the track circuit with a certain number of pulses and the duration of the pause between pulses and pulse trains, which corresponds to a certain color of the traffic light (Fig. 1) [3, 4].

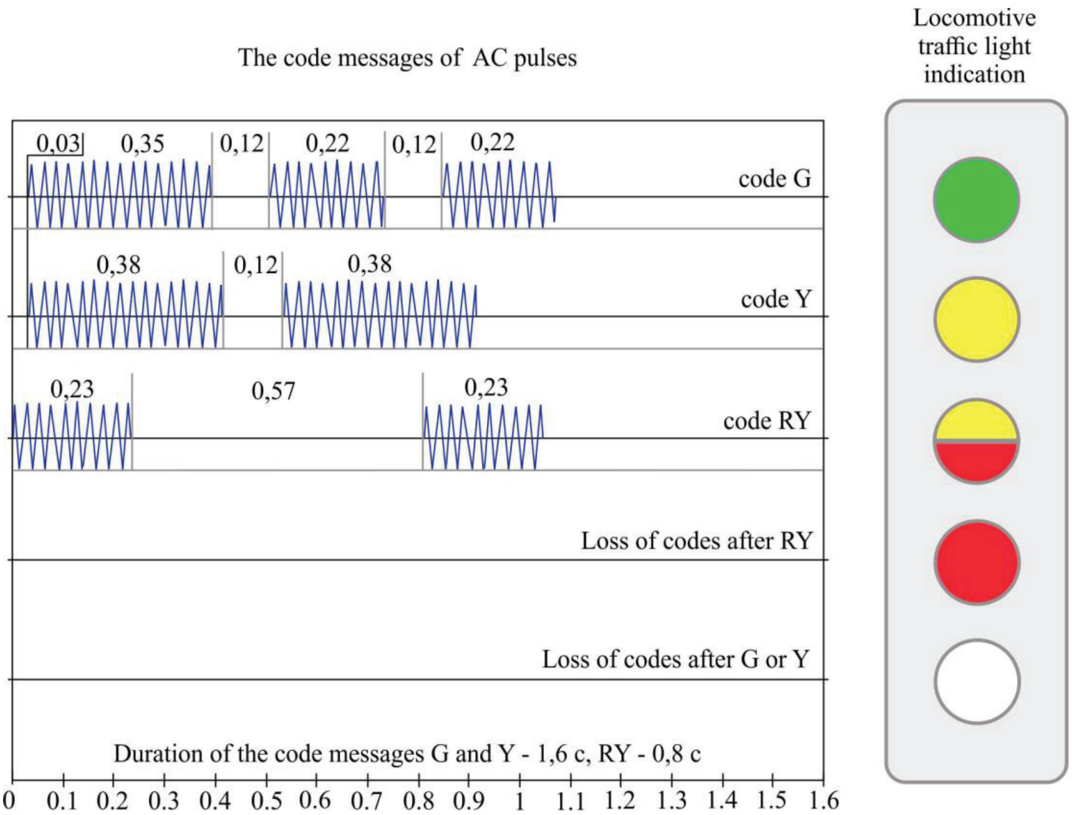

Fig. 1 Transmission of ALS codes

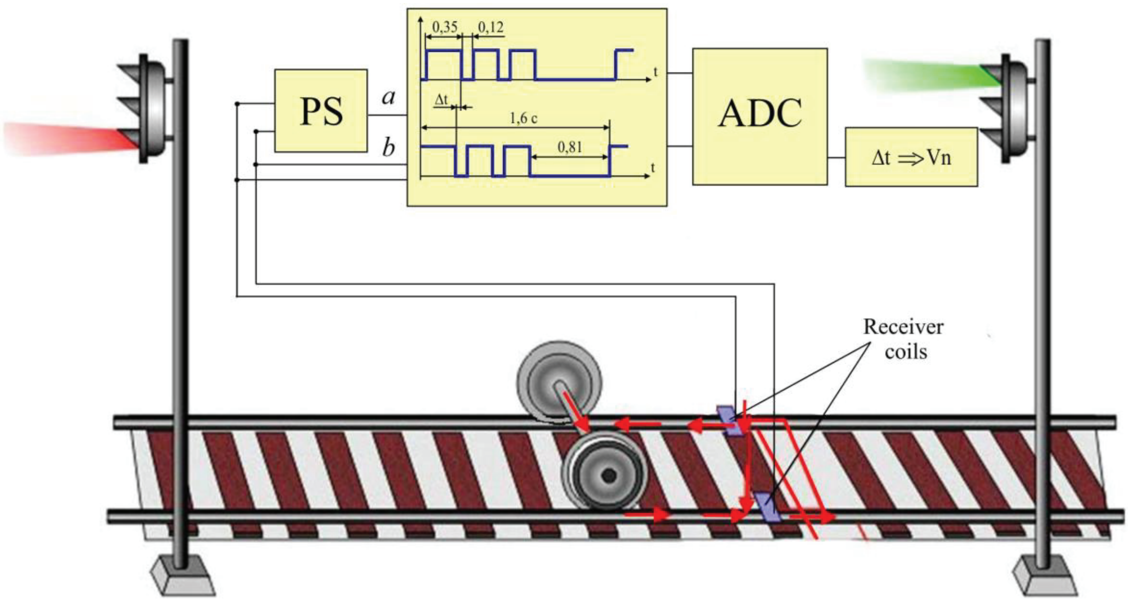

Fig. 2 Diagram of a device for determining the linear velocity of a locomotive

The measurement of the linear velocity of the locomotive is carried out by registering the phase shift of the traffic signal. A diagram of a device for determining the linear velocity of a locomotive is shown in Fig. 2. So, while the locomotive is parked, the original code message of impulses of a certain traffic light is recorded and later compared with the same message of impulses in motion (Fig. 3, a). Further, during the acceleration of the locomotive, a phase shift is formed by the value *Δt* (Fig. 3), which will correspond to the value of the velocity (Fig. 3, b). The subsequent increase in velocity will be compared with the previous one and added up. During braking, the shift will have a negative sign (Fig. 3, c) [5-7].

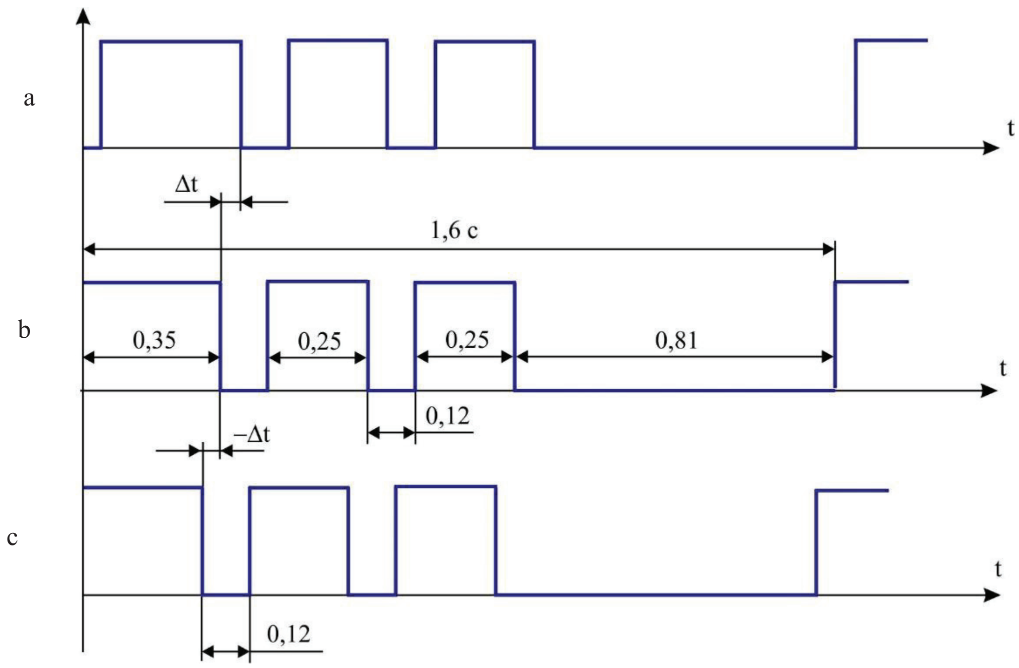

Fig. 3 Phase shift of the combination generated by the ADC-5 green traffic light: a − the reference signal; b − compared signal when moving forward; c − compared signal when moving back

The PS unit, connected to a traction electric motor (TEM), controls the torque and protects the locomotive from skidding during braking. The main advantages of the proposed method in comparison with the existing ones are:

– determination of the linear velocity of the locomotive without taking into account slip, which varies in the range from 1-20% [8, 10];

– high accuracy of measuring the linear velocity of the locomotive due to the use of a stable electrical signal of the automatic locomotive signaling [9].

The novelty and originality of the proposed method for determining the linear velocity of a locomotive is confirmed by the obtained patent of Ukraine for a utility model № 82737 [9].

3. Conclusions

The method for determining the linear velocity of a locomotive, that allows avoiding the negative influence of factors present in existing systems is proposed, it consists in using and converting signals from automatic locomotive signaling. Using the existing ALS system according to the proposed method, it is possible to determine the value of the linear velocity of the locomotive, which will not be influenced by various operational factors (change in the tire diameter, wheel slip of the locomotive, etc.). This device can be used in locomotive traffic control devices and ensuring the safety of traction rolling stock, as well as in anti-blocking and anti-skidding devices of locomotives to measure movement parameters, in particular, linear velocity.

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Electromobility from an Economic Point View

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Abstract

The article focuses on the issue of electromobility on two levels. The first set of problems is based on economic theory and brings broader aspects in terms of introducing innovations. The second set of problems is focused on the corporate perspective, especially on the economic efficiency of the use of electric cars in various modes of transport. The evaluation is performed on the basis of a methodology based on cost calculation in transportation. This methodology is described in the article and given on a specific example.
KEY WORDS: *electromobility, economic, transportation, cost calculation, economic efficiency*

1. Theoretical-Economic View on the Adoption of Electromobility

Problems with replacing petroleum fuels in transport are designed mainly for energy and environmental reasons. Alternative fuels or drives themselves must then meet the requirements, which can be divided into four sets of problems:

- **Economic -** price comparability with conventional fuels;
- **Ecological -** comparability of environmental impacts with conventional fuels;
- **Energy** - in particular, the ratio between energy obtained and input;
- **Technical** - means of transport must be adapted to fuels or drives and infrastructure must be created for their distribution and sale.

By alternative fuel we understand a fuel that is able to replace petroleum products while having significantly less impact on the environment. Such fuels exist, but their use encounters economic, energy and technical problems. One of the properties of an alternative fuel should be its renewability. In general, energy density can be considered a significant problem for alternative fuels. In this respect, of course, conventional fuels dominate, of which we say that they are a concentrated form of solar energy (a small volume contains a large amount of energy compared to alternative fuels). From an ecological point of view, paradoxically, the emphasis here is on carbon dioxide emissions, the impact of which on climate change has not yet been proven. It is also important to perceive the local impacts of transport in terms of air, and in particular emissions of nitrogen oxides, carbon monoxide or hydrocarbons.

In all considerations about the introduction of alternative fuels in transport (particularly in freight) it is necessary to perceive the importance of transport in the socio-economic system of society, as described for example by Duchoň [1]: „ ...accessibility and mobility as an essential condition of the national economic system. Accessibility must be understood as the accessibility of the population to a range of activities, and this can be done by accessibility to transport. Mobility is to be understood as the ability to move through the transport system. Mobility can have a number of limitations (delays caused by traffic congestion, high transport costs or low revenues of the transport company, etc.)".

Transport as a national economic sector contributes to the formation of national economic output, but at the same time it is a production factor that creates positive externalities. Historically, for example, it is very easy to show how new transport technologies have contributed to the growth of the economic level, as they have enabled other areas to engage in trade.

Duchoň [1] states the importance of transport for economic development due to the following factors:

- contribution to GDP creation;
- employment support (production of means of transport, construction, maintenance and reconstruction of transport infrastructure, petrochemical industry and link to other business activities);
- trade promotion;
- establishment of transport companies (transport market;)
- transport (technological output in the form of transfer of persons and goods);
- prices as an indicator for assessing the profitability of individual modes of transport;
- contribution to the state budget (tax system and wide range of taxes).

Within the field of economics, the question of the relation of human activity to the environment has been solved from around the middle of the 20th century and is connected mainly with the economist Arthur Cecil Pigou. He defined as the first so-called social costs, i.e. externalities, or external costs that are not paid by their originator. Pigou suggested that externalities should be solved by taxation (i.e. by adding external costs to the internal costs of the originators of externalities), but the issue itself is not so trivial. The pitfalls can be summarized in the following points [2]:

- internalisation of externalities can bring so-called opportunity costs, i.e. lost income from activities that will not be realized due to higher taxation;

- the effectiveness of the internalisation of externalities when using the so-called Pigouvian taxes depends significantly on the elasticity of demand (e.g. for individual transport) and if the demand is inelastic, the effect of internalisation will be weak;
- internalisation can reduce the competitiveness of the economy and undercut economic growth and, as a result, paradoxically reduce state budget revenues;
- an essential factor in the internalisation of externalities is the transaction costs, which in the case of transport lead to the internalisation solved by state intervention, but this also forms additional transaction costs.

In terms of dealing with external costs, two factors are important - the first is a clear definition of proprietary rights, the second is the size of transaction costs associated with the solution. A necessary part of proprietary rights is the ability to freely handle one's property and the ability to enforce the rights that come with ownership. Transaction costs can be defined as the costs of the price system or costs related to the change of ownership rights. The theory of transaction costs is often neglected, but it is crucial for the understanding of economic processes. It can be stated that if we proceed from an unrealistic assumption of zero transaction costs, the market system would allocate resources with maximum efficiency. However, due to the existence of transaction costs, many transactions (exchanges) will not occur because in some cases the costs of locating a counterparty of the given exchange will be too high [3].

The dominant element that should reduce the impact of the transport system on the environment is technological innovation. Economic science often mentions the influence of innovations and their benefits, when the whole issue can be supplemented with the following remarks:

- the holder of innovation is the entrepreneur, not the state, not any central unit or group of people superior to any business environment;
- if the holder of innovation is the state, it is necessary to accept the distortions that will arise in market relations as a result,
- proprietary rights are a fundamental pillar of a healthy economy and any restriction of them can lead to inefficiencies that often cannot be estimated and quantified in advance;
- the freedom of the individual must be respected in all the measures introduced and careful consideration should be given to regulations that affect this freedom and which may restrict it;
- in transport (particularly in road freight transport) we meet a very tough competitive environment, where even a small price increase can mean a loss of customer;
- for individual modes of transport, it is necessary to consider not only negative externalities, but also positive ones, where the most significant is securing trade as one of the sources of "wealth" (comparative advantages);
- the question is how much influence externalities have on the economic system or society, and whether this influence is not overestimated by current science;
- new technologies (sharing, autonomous vehicles, alternative propulsions, etc.) must come to an evolutionary principle while maintaining basic market principles, legislation must respond to these technologies so as not to hinder their emergence;
- from an ecological point of view, is very problematic the extraction of raw materials, which, with the emergence of particularly electromobility, will be in demand, in particular lithium, nickel, copper or cobalt;
- the level of transport technologies in the future over decades cannot be estimated;
- last but not least, we can mention the concept of diffuse knowledge, introduced into economic science by Frederick August Hayek in 1945. This is specific knowledge that millions of people around the world have. This knowledge can then be optimally integrated through a market system, not through a centrally planned or centrally administered economy [4].

From the mentioned Hayek's article it is possible to quote directly:

“The peculiar character of the problem of a rational economic order is determined precisely by the fact that the knowledge of the circumstances of which we must make use never exists in concentrated or integrated form but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess. The economic problem of society is thus not merely a problem of how to allocate "given" resources — if "given" is taken to mean given to a single mind which deliberately solves the problem set by these "data." It is rather a problem of how to secure the best use of resources known to any of the members of society, for ends whose relative importance only these individuals know. Or, to put it briefly, it is a problem of the utilization of knowledge which is not given to anyone in its totality.” [4].

2. Economic and Operational View

The transport sector can be described as an environment of high competition and pressure to reduce costs and maximize the quality of service offered. In this respect, the introduction of electromobility (but also other alternative drives) is a very risky process.

From a cost perspective, can be mentioned the approach of comparing cost items that will change due to the change in drive. These are acquisition costs, energy costs (diesel vs electricity), maintenance and repair costs, or other costs associated with the construction of charging infrastructure [5]. We do not consider other costs (e.g. wages) because the introduction of alternative fuel will not change them. In the calculation we then look for a price of alternative fuel (at a given diesel price) at which the total cost of the vehicle with alternative propulsion is equal to or lower than the cost of the diesel vehicle [6]:

$$n_D = n_{EL}; \tag{1}$$

$$C_D \cdot S_D + n_p^D + \frac{N_a^D}{T_L^D \cdot L_D} = C_{EL} \cdot S_{EL} + n_p^{EL} + \frac{N_a^{EL}}{T_L^{EL} \cdot L_{EL}}\ , \tag{2}$$

where n_D – unit cost of operating a diesel vehicle (monetary units/km); n_{EL} – unit cost of operating an electric vehicle (m.u./km); C_D – price of diesel (m.u./l); S_D – consumption of diesel (l/km); 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_D – how much the diesel vehicle will travel (km/year); L_{EL} – how much the electric vehicle will travel (km/year); C_{EL} – price of electricity (m.u./kWh); S_{EL} – electricity consumption (kWh/km); 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); N_L^{EL} – the lifetime period of an electric vehicle (years/ vehicle).

$$C_D \cdot S_D - C_{EL} \cdot S_{EL} = n_p^{EL} - n_p^D + \frac{N_a^{EL}}{T_L^{EL} \cdot L_{EL}} - \frac{N_a^D}{T_L^D \cdot L_D}\ ; \tag{3}$$

$$d_P = n_p^{EL} - n_p^D\ ; \tag{4}$$

$$d_{ODP} = \frac{N_a^{EL}}{T_L^{EL} \cdot L_{EL}} - \frac{N_a^D}{T_L^D \cdot L_D}\ . \tag{5}$$

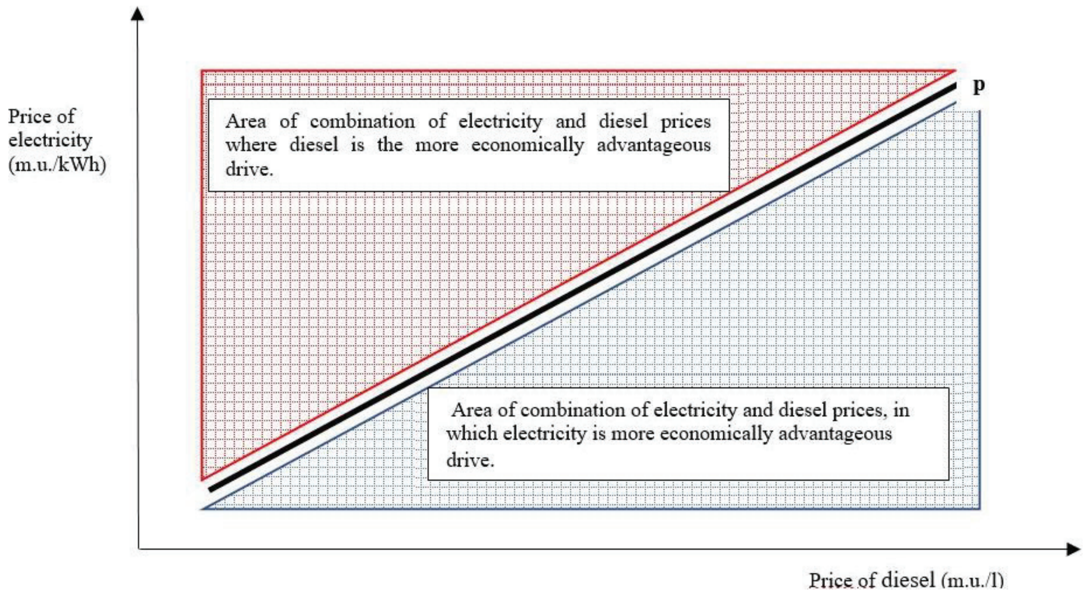

Fig. 1 Principle of graphical expression of cost equality of conventional and alternative fuel

For some simplification, we introduce the following terms: d_P – operating cost differential (CZK/km); d_{ODP} – acquisition cost differential (CZK/km).

$$C_D \cdot S_D - C_{EL} \cdot S_{EL} = d_P + d_{ODP}\ ; \tag{6}$$

$$C_{EL} \cdot = \frac{C_D \cdot S_D - \left(d_P + d_{ODP}\right)}{S_{EL}}\ . \tag{7}$$

The result is a graph, showing various combinations of alternative fuel and diesel prices, for which will hold true that the total cost (f.u./km) of using alternative fuel are equal to the cost of using petrol or diesel via the p line (Fig. 1).

3. Practical Example

A practical example is the cost comparison of utility vans Wolksvagen Crafter in electric and diesel versions. It should be noted that the electric version of this car is in its use limited by the range of one battery charge, which is 173 km. Therefore, it can be used for purely delivery urban operations. In terms of costs, greatly limiting factor is then the purchase price, which is significantly higher for the electric version. The maintenance and repair costs can be expected to be lower (by about 30%) for the electric version. The cost comparison is then based on the parameters in Table 1.

Table 1

Parameters of commercial vehicles for cost comparison
(data sources: e-Crafter | Volkswagen Užitkové vozy (vw-uzitkove.cz))

Volkswagen Crafter	Unit	
Operating costs diesel	CZK/Km	0,5
Saving the operating costs of an electric car compared to a diesel drive	saving in % compared to a diesel van	30,00%
Battery capacity	kWh	35,8
Range	km on a fully charged battery	173
Price of diesel van	CZK without VAT	585000
Price of electric car	CZK without VAT	1645000
Service life	the number of years the vehicle in operation	5
Mileage	number of kilometres driven per year	50000

If we theoretically consider different diesel prices in the range of 25 - 30 CZK/l, we can according to relationship (7) calculate electricity prices at which the total unit cost for both options (diesel and electric) will be the same. We proceed from the fuel consumption 9.3 l/100km of the diesel variant and the 21.3 kWh/km of the electric variant. We assume 30% lower maintenance and repair costs and depreciation expense based on purchase prices and the theoretical assumption that the electric version of the commercial vehicle will be able to achieve the same annual mileage as diesel. Another assumption is that it will not be necessary to purchase new batteries for an electric utility vehicle during its lifetime. Electricity prices for such cost equality are then shown in Table 2.

Table 2

Electricity prices at different diesel prices to meet the cost equality

Price of diesel c_D (CZK/l)	Price of electricity c_E (CZK/kWh)	Consumption of diesel (l/km)	Consumption of electricity (kWh/km)	Operating cost differential (CZK/km)	Acquisition cost differential (CZK/km)
30	-1,401396648	0,12	0,20694	-0,35	4,24
25	-4,300837989	0,12	0,20694	-0,35	4,24
20	-7,20027933	0,12	0,20694	-0,35	4,24
15	-10,09972067	0,12	0,20694	-0,35	4,24
10	-12,99916201	0,12	0,20694	-0,35	4,24
5	-15,89860335	0,12	0,20694	-0,35	4,24

We can also graphically represent these values (Fig. 2) (according to Fig. 1).

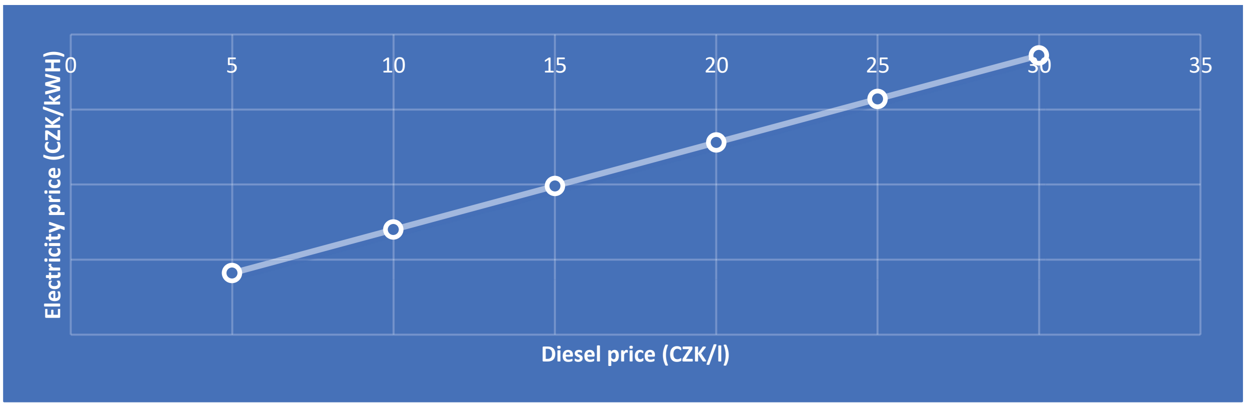

Fig. 2 Electricity prices at different diesel prices to meet the cost equality – graphic expression

For this case it is evident that the Volkswagen e-Crafter electric utility vehicle is economically inefficient compared to a diesel-powered vehicle of the same parameters. Electricity prices would have to be very low or even negative, even at diesel prices around 25-30 CZK/l. As mentioned above, we do not take into account the operating conditions, in particular the limited range per single charge, which very much determines the use of the vehicle essentially only for transport in smaller towns.

4. Conclusions

Electromobility is currently economically disadvantageous for carriers compared to conventional fuels at current oil prices (or other fuels) and this is very unlikely to change in the foreseeable future. At the same time, due to the operating conditions (lower range, long charging times) it is limited only for a very small segment of the transport market - in road freight transport it is essentially just a clearly defined narrow segment of city logistics (in larger cities, for example, it is not possible to go to logistics centres located on the outskirts of cities) [7].

Of course, subsidies or other regulations (additional taxation of conventional fuels, banning diesel cars from entering cities) can solve the situation in terms of costs, but this will only lead to further market distortions and distortions in society in general (especially in areas with lower population density, where life without a car is essentially impossible). In freight transport, the principle should be that, from a national-economic point of view, switching to alternative energy sources should not result in restrictions on mobility and mutual trade. It is crucial that the emergence of alternative fuels is dominated by market principles.

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Evaluation of Rollover Crash Test CDR Data

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Abstract

Currently manufactured vehicles are equipped with various sensors and electronic systems. For forensic purposes are interesting only those sensors and devices could provide valuable information necessary for accidents investigation. However, EDR (Event Data Recorder) is capable to record certain dynamic vehicle parameters, its accuracy and accessibility does not often meet required level. The key point of the article is to verify the reliability of the EDR data by comparing it with an independent measuring system. For EDR data reading was used special device - BOSCH CDR Kit, on the other hand, independent reference measuring system consists of a the DEWESoft Krypton measuring station, accelerometers, potentiometers, a safety belt dynamometer and a specially prepared measuring computer. To obtain such comparison data, a road accident simulation was executed. A specially modified vehicle Toyota RAV4 has been towed and driven to the ditch. The result of the test is actual data comparison obtained with CDR kit and data from the reference system. These valuable findings regarding the accuracy and reliability of the EDR system could lead to improved accident investigation and thus also identification of road traffic accidents offences.
KEY WORDS: *accident, rollover, Event data recorder, CDR kit*

1. Introduction

The modern era has brought a number of new options and sources for the analysis of traffic accidents. Despite the rapidly growing composite automotive system, global vehicle models, sensors and software companies are focusing on the development of automated vehicles due to high and fast data production [3]. Data generated in the vehicle are key to the analysis of accidents. These are usually vehicles that include EDR (Event Data Recorder) data processing equipment. This system, also called a "black box", was used in selected vehicles for the first time in 1974 by Generals Motors (GM) [1, 4]. 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 [5-7].

Other data acquisition devices include, for example, an airbag control module (ACM), which stores certain data on vehicle parameters at the time of a specific event (eg accidents). This data is not stored elsewhere in the electronics and vehicle control systems. Although the vehicle's main control unit stores FreezeFrame (recording of the vehicle's status data in the event of a fault in some systems), the information about the vehicle's status during the event is not so detailed.

This function, however, is not the main function of the airbag control unit, which is to evaluate the input data from the vehicle's sensors (including sudden changes in the speed and rotation of the vehicle) and use it to decide whether the limit values have been exceeded and the airbag should be activated. These sensor data are then stored using the EDR function and can be read using other devices. It stores dynamic vehicle data such as speed, braking, steering angle, always before and after the event, as well as the sequence of impacts, the presence of passengers on the seats, the use of safety belts etc. The EDR system can also directly record and provide a unique overview of driver behavior before a collision [5]. Devices that can read accident data include the CDR system from BOSCH. The purpose of the crash tests, whose results are the core of the paper, was to verify the reliability of the read data by comparing it with an independent measuring system.

2. EDR Data vs. Data from Vehicle Control Units and CDR System

Current available diagnostic tools, e.g. BOSCH KTS 590, Superwag, Gittool, TEXA, allow only access to read the memory of the control unit's faults and then testing to detect the exact fault. Common diagnostic tools are unable to read EDR data or FreezeFrame. There are also diagnostic tools on the market with the ability to read deeper data and change the properties of vehicle control units, but these tools are not suitable due to their unauthorized access. No independent authority is able to validate or verify the accuracy of such retrieved data. Therefore, these devices cannot be used to reconstruct the course of a traffic accident. The EDR data can currently be retrieved only with a special tool. The most common tool is BOSCH CDR Kit (Fig. 1), which can read the EDR data of most carmakers (about 87% of carmakers). Another example is a tool from GIT (Global Information Technology) used to read Hyundai and KIA data.The CDR System (Crash Data Retrieval) is a system developed by BOSCH, which retrieves data that is stored in the airbag control unit. The CDR system can be used to retrieve accident data from the control unit in several ways. If the vehicle has functional electrical circuits after a traffic accident, the CDR device can be connected to the car via the Diagnostic Link Connector (DLC) used for the On-Board Diagnostics (OBD).

Fig. 1 Bosch CDR Kit (left) and its wiring diagram (right, [1])

Data are retrieved using the Crash Data Retrieval Tool. The user checks the connection of the CDR interface with the vehicle, enters the vehicle's VIN and then selects the module from which data is to be retrieved [2, 8, 11].

3. Reference Measuring Equipment

To verify the reliability of the recorded and read data (especially acceleration), the test vehicles were equipped with an independent measuring system consisting of the DEWESoft Krypton measuring station, Kistler and Measurement Specialties accelerometers, Micro-Epsilon potentiometers, a safety belt dynamometer and a specially prepared measuring computer. This system is hereinafter referred to as the Krypton measuring system. The second collision partner was always equipped with a separate PicDAQ5 device made by DSD.

The measuring computer was designed for use in extreme situations, such as crash tests, so no rotating or loose components are used. To put it simply, it is a motherboard with basic PC components, including a network card and a WiFi module that is built into an aluminium chassis. The communication with this computer, which is used to set up and run the measurement and to whose disk the measured data is stored, takes place via wireless connection and the remote desktop function.

The Krypton station was used in two versions, two 3xSTG and two 6xSTG, allowing for connecting up to 18 channels in total, each able to measure frequency up to 20 kHz. Its design is modular, so it could be split for tests with more than two cars to create two independent reference systems. The communication and data transfer between the station and the computer, and between the modules is based on the EtherCAT protocol and the EtherCAT cable that allows both data and power transfer, and provides faster and safer communication between the devices. Krypton was powered by a 12 V cell battery during the tests.

The Krypton, the measuring computer and the battery were attached to an iron structure that was firmly attached to the car body, as illustrated by Fig. 2 below.

Three-axis MEMS accelerometers were used to measure the acceleration, namely ± 500 g (Measurement Specialties, 1203 model), ± 1000 g (Measurement Specialties, 1203 model and Kistler, M1203A model) and ± 2000 g (Kistler, M0053A model). Their purpose was to measure acceleration not only on the car body, but they were also installed in the dummies representing the crew of the vehicle. They represented an adult driver - 50% man (a dummy corresponding to an average male), a 6-year-old child in a child seat, and a dog in a safety harness.

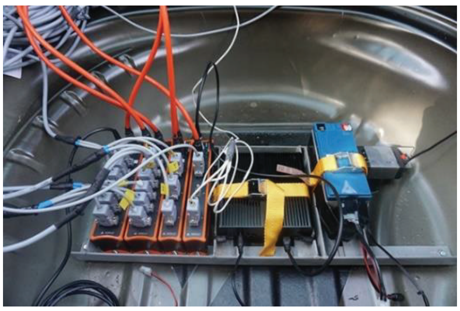

Fig. 2 Illustrative wiring and mounting of the measuring system

In addition to the above, other devices were included in the measuring system to obtain interesting data, including the dynamometer measuring the tension of the safety belt, potentiometers recording the movement of the driver dummy's head and the dog dummy at impact and a trigger determining the moment of impact in the measured data. Finally, yet importantly, the iterior movement was recorded visually using a camera system. The collision partner was always equipped with the PicDAQ5 device to measure impact dynamics. As the system described above, it was firmly attached to the tested car. The output of this device includes data in three axes on acceleration and angular velocity, with frequency up to 1000 Hz [9, 10].

Fig. 3 Test vehicle Toyota RAV 4

Conditions: vehicle as in test, including dummies. Instantaneous weight, including dummies: 1585 kg. In general, CDR of Toyota RAV4 (Fig. 3) provides the following data: records of the last three accidents recorded. It includes information on the order of impact, its type (front/rear, driver side, passenger side), time from impact until the command to use airbags, safety belt tensioners, time from previous event. The data also includes the speed development (delta V) in [MPH] and [km/h] in the event of a longitudinal impact after approx. 10 ms over approx. 200 ms, in the event of a side impact after approx. 4 ms over approx. 100 ms, from the sensors of the control unit, the B-pillar and the C-pillar. There is also a delta-V graph and a maximum (cumulative) value. Pre-crash data is also available from 0 s to 5 s; the first reading is 0.4 s or 0.8 s before the impact, then after 1 s. The data includes speed, brake pressure or accelerator pressure and engine revolutions. There is binary information on the driver's and passenger's safety belt, and driver's seat position.

- Bosch KTS 590 diagnosed the following fault on Toyota RAV4's control units before the crash test;
- P0607 - Control Module Performance – common rail injection system;
- After the test, Bosch KTS 590 identified two new ESP faults on Toyota RAV4's in addition to the original.

4. Rollover Crash Test Simulation

The aim of the test was to simulate an accident of a vehicle that leaves the road at a high speed of 97.3 km/h and then rolls over (Figs. 4-9). Toyota RAV4 was used for the test. The test was carried out on a closed local road in Vlčkovce (district of Trnava, Slovakia). The road met the conditions for the test. The acceleration track had to be at least 400 m in a straight line. Then the road should continue for at least another 400 m in a straight line. There was a ditch of varying depth along the road in the test area. The road was closed for test purposes.

The Toyota RAV4 was attached by a synchroniser with automatic disconnection to a Seat Alhambra The synchroniser unit was custom-made under the VIMOT project. The synchronisation mechanism for the test and towing of the Toyota consisted of a synchroniser, a disconnection plate of the synchroniser, and a vehicle steering mechanism after the towed and towing vehicle disconnect.

The Seat Alhambra pulled the Toyota and increased its speed to the desired value. An inclined plate was placed at the point where the Toyota was to be disconnected from the Seat. A disconnection wheel passed across the plate, pulled out a pin that connected the two vehicles, and at this moment the two vehicles were independent.

Fig. 4 Moment of disconnection of the synchroniser on the disconnection plate

Fig. 5 Maximum steering angle of 7 meters after vehicle disconnection

Fig. 6 Vehicle leaves the road

Fig. 7 Vehicle hits the ground

Fig. 8 Vehicle rotates about a longitudinal axis

Fig. 9 Documented final position of the vehicle (photogrammetrically obtained orthophoto with GSD 1 cm/px with total station measurement outputs)

Front/Rear Event Record Summary at Retrieval

Events Recorded	TRG Count	Crash Type	Time (msec)	Event & Crash Pulse Data Recording Status
Most Recent Frontal/Rear Event	4	Front/Rear Crash	0	Complete (Front/Rear Page 1)
1st Prior Frontal/Rear Event	3	Front/Rear Crash	-620	Complete (Front/Rear Page 2)
Prior Frontal/Rear Event	1	Front/Rear Crash	N/A	Complete (Front/Rear Page 0)

Fig. 10 Events recorded in the CDR protocol

The real speed of the Toyota RAV4 was measured by light gates at 97.3 km/h. The following data were read from the airbag control unit. The primary impact is referred to as “Prior Frontal/Rear Event”, followed by “1st Prior Frontal/Rear Event” and the last one is “Most Recent Frontal/Rear Event”. A vehicle whose EDR data should, according to the analysis, contain data on the vehicle rollover about its X-axis was selected for this crash test. However, the CDR protocol recorded only three events (Fig. 10) (with serial numbers 1, 3 and 4 - event No. 2 was therefore deleted), all of which were identified as front/rear impact. It is subject to discussion whether Event 2 contained such data.

In addition to this negative fact, it should be noted that pre-accident data were recorded for none of the events, only 15 “delta-V” development values after the crash (up to 150 ms). The comparison of the development of acceleration computed from this quantity is shown in the following graphs (Figs. 11-12). The first impact could be matched. It shows the highest acceleration values (around 9 g, which is relatively low, but it should be noted that the collision partner was topsoil that reduced the impact) but also the highest match. The last impact could also be located, i.e. leaving the ground; however, the third impact does not match the development of acceleration according to the reference device.

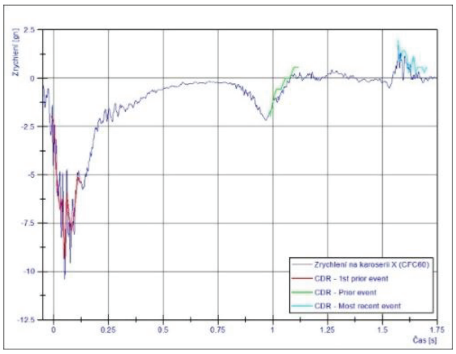

Fig. 11 Comparison of acceleration development according to the reference device and EDR data

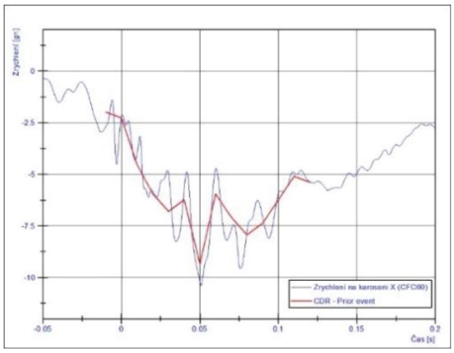

Fig. 12 Comparison of acceleration development – primary impact

The previous figure shows a relatively high match in both shape and value for the primary impact. After the test, Bosch KTS 590 identified two new ESP faults on Toyota RAV4 in addition to the original fault.

5. Conclusions

The trend of modern electronic systems implementation can be observed in various industry branches, especially in automotive. These new systems provide new possibilities for vehicle traffic accident investigations. One of the new devices which is an irreplaceable tool for important data gathering is the EDR function. However, EDR is capable to record certain dynamic vehicle parameters, its accuracy and accessibility do not often meet the required level. The key point of the article is to verify the reliability of the EDR data by comparing it with an independent measuring system. For this purpose, a special rollover accident simulation has been executed. As a result, is a comparison of data gathered from EDR with relevant information from the independent measuring devices. In fact, there was found a relatively high match in the primary impact phase, however the test revealed also some limitations of EDR function which could be imperfectly determination of accident type or partially unmatched development of acceleration. Finally, all new data regarding the reliability of EDR function can be considered as value added information for accidents investigation.

Acknowledgments

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Topological Optimization of Sailplane's Flap System's Bellcrank

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Abstract

The main purpose of this paper is to propose a better design for the sailplane's control system part using topology optimization for additive manufacturing. Multiple computer based simulations of given sailplane‘s flap system‘s part for topological optimization and are completed using SolidWorks software. To have more in-depth results, Femap NASTRAN and Ansys softwares were used to simulate the same problems and to compare results. The sailplane's control system part is originally manufactured from 30ChGSA steel. Because of the greater power to weight ratio and other mechanical properties for a topologically optimized parts for manufacturing chosen material of interest is the Ti6Al4V titanium alloy. Topological optimizations were done with different factors of safety – first optimizations done with an originally designed factor of safety of 1.5, second optimizations done with an increased factor of safety to 2.5 to increase manufacturing capability and mechanical properties. The topologically optimized part was compared to the original part, showing reduced weight and increased mechanical properties. Finally, the fatigue of the final topological optimization was discussed and compared to the original part's lifetime using the official maintenance manual from the sailplane's manufacturer.
KEY WORDS: *topological optimization, sailplane's flap system‘s bellcrank, finite element analysis, factor of safety, additive manufacturing*

1. Introduction

Today‘s aircraft may be greatly improved with new technologies, such as topological optimization and additive manufacturing. Topology optimization is the determination of material distribution throughout the part. This optimization leads to less material usage and reduced final weight of the part while maintaining the same needed properties. Usually topological optimization is determined through the use of computer aided design softwares, that allow for finite element method simulations. The most difficult aspect of topological optimization is the correct usage of computer aided design softwares, therefore experienced user must be in mind [1]. The whole process of topological optimization is used to distribute the material across the part, so the best possible outcome would be received. The mass is distributed using different constraints, such as maximum applicable load, maximum allowable mass, etc. The general workflow of topological optimization is a simple mathematical model. This mathematical model works by introducing load to each possible space of the design area [2]. The most typical approach to topological optimization is called "Solid isotropic material with penalization method" or "SIMP" method but as the name implies, it does not work in every single scenario, therefore algorithm for correct result must be chosen carefully. To show the importance of topological optimization, it was estimated, that only approximately 20% of the dimensions are needed for most components and for their function, therefore it is only needed to find out where is the rest 80% and remove it from the part altogether [3]. Topological optimization is capable of creating many different designs that look as they were created naturally, changing part's inside from monolithic look to different infills. This capability synchronizes well with 3D printing, as it is the only manufacturing method capable of producing parts with difficult infills, such as lattice or vortex based [4]. These different infills can be with variable density, therefore allowing to alter between different part's strength capabilities. The huge possibilities of topological optimization with additive manufacturing are only gaining audience, and understanding the prospect allows to gain great power in manufacturing world and increase the speed of the next industrial revolution.

2. Topological Optimization

2.1. Mathematical Model

The overall workflow of topological optimization may be understood by introducing a purely mathematical model. The main objective is to optimize the layout of material in a given design space Ω. The idea is given in Fig. 1. Generally, the problem consists of design area Ω, loads F^T and boundary Γ conditions. Boundary conditions further are composed of different parts, Γ_t, Γ_u, Γ_s, Γ_o, and other possible constraints. Forces on the surface are introduced in area Γ_t; Γ_u shows support conditions; non-optimizable areas are shown by Γ_s and boundaries of the geometry are shown by Γ_o. For the further layout of material, many different methods may be used, but one of the main problems is the distribution of volume by minimizing specific criterion. The most common criterion is compliance C, where density values x (that are dispersed in Ω) are used for the control of material distribution in Ω. These values x are shown in a small range of 0-1, where 0 means the absence of material [5, 2]. Finally, topological optimization can be written Eq. (1).

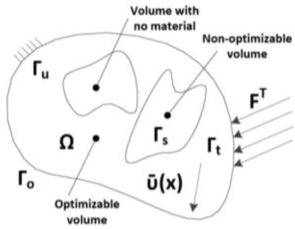

Fig. 1 General topological optimization problem [5]

$$\begin{cases} C(x) = F^T \cdot \bar{u}(x); \\ \dfrac{V(x)}{V_0} = f; \\ F = K(x) \cdot \bar{u}(x); \\ 0 \le x_{min} \le x \le 1, \end{cases} \tag{1}$$

where $C(x)$ – structure's compliance; F^T – force vectors that are applied upon structure; $\bar{u}(x)$ – global displacement vector; $K(x)$ – global stiffness matrix.

The second part of the Eq. (1) indicate the volume constraint, as the f mean fractions of the volume of Ω, where optimized part should be laid out. Third part of Eq. (1) is the equilibrium equation. Last part introduces the density value set. topological optimization consists of multiple stages, where first stage is the set up of geometry, constraints and outer forces. Further on, topological optimization constraints are introduced where manufacturing options are set, so the part would be possible to manufacture after optimization with desired manufacturing technique [5, 2]. Furthermore, most common variation of topological optimization is the solid isotropic material with penalization method or SIMP method. SIMP method Eq. (2) is given:

$$K_{SIMP(\rho)} = \sum_{e=1}^{N} \left[\rho_{\min} + (1 - \rho_{\min}) \cdot \rho_e^p \right] \cdot K_e \,, \tag{2}$$

where K_e – the element stiffness matrix; ρ_{min} – the minimum relative density; ρ_e – the element relative density; p – the penalty factor; N – the number of elements in the design domain.

SIMP method does work similarly to the overall topological optimization method as given in Eq. (1). First difference is that the SIMP method is directly connected to the materials young's modulus and density. Second difference, is that the penalization factor is implemented, which steers the result of one point either to being void or filled with material, so there would not be a chance for the probability of an intermediate result. Finally, the result is given and works only for parts that contain isotropic material properties [6].

2.2. Sailplane‘s Flap System‘s Part

The main purpose of this work is to optimize sailplane's flap system's bellcrank for additive manufacturing. The part is originally manufactured from 30ChGSA steel. Because of greater power to weight ratio and other mechanical properties than 30ChGSA, such as tensile, compressive, yield or other strength properties, the chosen material of interest is Ti6Al4V titanium alloy made by additive manufacturing company - EOS. The drawings of the part are given by the manufacturer, therefore the part itself must firstly be drawn in 3D computer aided design system. For this purpose, SolidWorks software was chosen. The 3D drawing of a part can be seen in Fig. 2. As it can be seen from the position of bearings, fixation points and vectors of applied forces, the part spins around bearing that should be installed in the biggest cylinder. By doing this motion, the force from leftmost cylinder (given as application force vectors) is translated to an axle, which in reality should move the flap. In most simple terms, the force is applied on first bearing, the bellcrank rotates through second bearing making the flap move. The flap is connected with bellcrank through axle. Originally, part is manufactured out of 5-6 different subparts. As the material for this part is known, full weight is also known to be ~83-85 grams. The weight here does not include welding spots or any other connections that would increase final weight, therefore complete weight of the part that would be used in real life is only estimated. The estimation is done, that final part without bearings should not weigh more than 90 grams. Furthermore, according to drawings and to GOST standard specifications, the yield strength of 30ChGSA is 700MPa [7]. To determine the original strength of the part, 1N force must be applied to the part (loading scheme given in Fig. 2). From the resulting stress values, and known material properties the maximum loading force can be obtained. The yield strength of the part is divided from the highest stress value, therefore obtaining complete strength of the original part. Final result of simulation is given in Fig. 3.

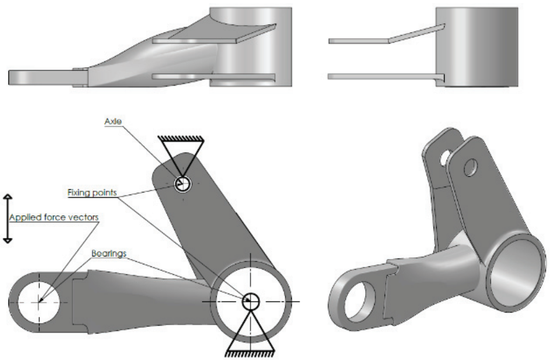

Fig. 2 Sailplane's flap system's bellcrank, drawn in SolidWorks

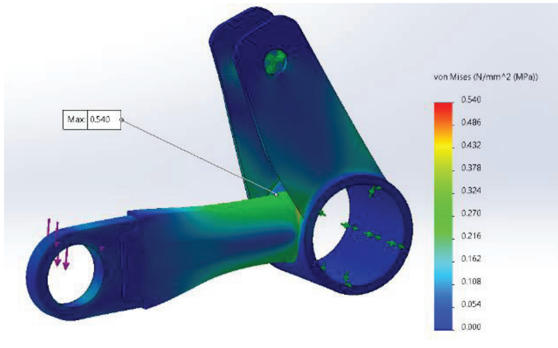

Fig. 3 Von Mises stress results of 1 Newton of force applied to the original part. 30ChGSA material

As all values are known, the maximum force that may be applied to original part can be calculated Eq. (3):

$$x = (1\text{ N}\cdot 700\text{ MPa})/0.54\text{ MPa};\ x \approx 1300\text{ N}. \tag{3}$$

The value here, 1300 N, is supposed to be the force, that the part should be able to withstand, without applied factor of safety. Since the factor of safety value for aviation is typically 1.5, the maximum force that should be applied on the part with safety taken account for, is equal to ~867 N. Further on, as the material properties (ultimate tensile strength) are tested, and the maximum applicable force is known, the topological optimization may be done further. These were done in couple different steps while maintaining strength characteristics and having manufacturability in mind. All of further optimized options are completely manufacturable.

2.3. Multiple Computer Based Simulations and Results

First topological optimization simulation was done with SolidWorks software, the result is given in Fig. 4. The constraints, that were applied, were maximum possible mass reduction and minimum possible factor of safety should be equal to 1. This is because 1300 N is the original applicable force, and the factor of safety was already applied to the original part, making any simulation with applied force of 1300 N to have factor of safety already de facto applied. This would mean that the part would reduce its weight until it reaches the phase, where a force of 1300 N combined with topologically optimized geometry would reach a stress of 1000 MPa. Once such point is found, optimization is finished, and final solution is given. The next topological optimization was done with Ansys software. The topological optimization was done with the original shape and there were enough elements to conduct reliable topological optimization. Result of Ansys topological optimization can be seen in Fig. 5. The constraints that were set in Ansys simulation, were similar to the ones, set in SolidWorks topological optimization. One constraint was again maximum possible mass reduction, and second one, instead of factor of safety, maximum allowable stress was set to 1000 MPa. Results of static loading (of 1300 N) on a part that was topologically optimized by SolidWorks are seen in Fig. 6-7. The third software, Femap NASTRAN, does not offer topological optimization simulations and therefore will only be used for finite element analysis. The conditions that were set in finite element analysis: Mesh size – 1.1-1.3 mm; Constraints – radial growth and axial constraints on fixed cylinders, while leaving tangential movement free to simulate bearings and movement conditions; Force – 1300 N on the surface of frontal cylinder.

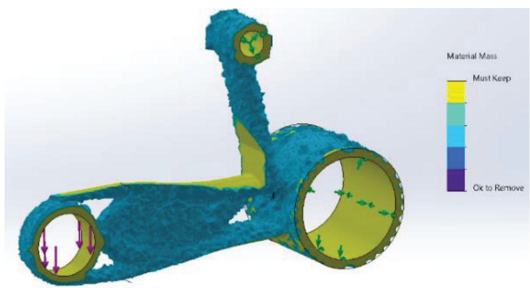

Fig. 4 Topologically optimized part by SolidWorks software

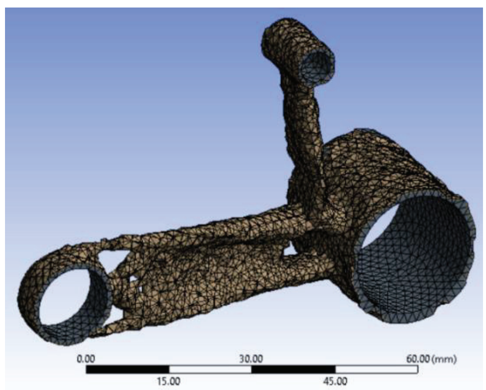

Fig. 5 Topologically optimized part by Ansys

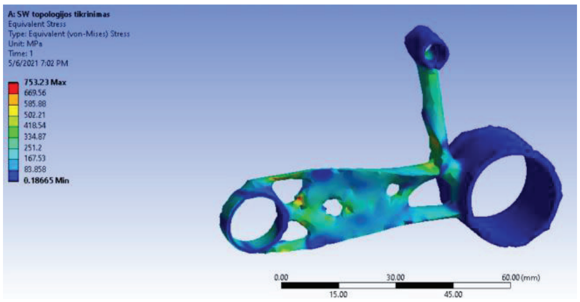

Fig. 6 Part optimized with SolidWorks topological optimization. Von Mises stress results from Ansys software. Ti6Al4V material

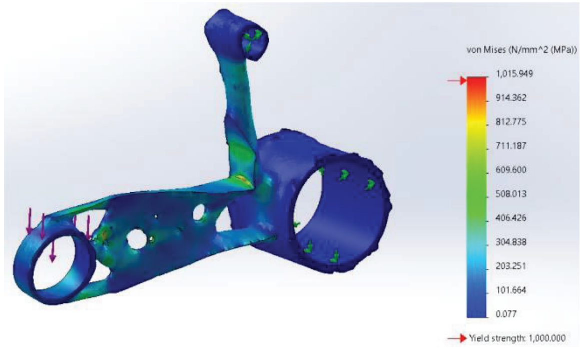

Fig. 7 Part optimized with SolidWorks topological optimization. Von Mises stress results from SolidWorks software. Ti6Al4V material

It can be seen, that only SolidWorks software does show the resulting 1000 MPa, and in Ansys or Femap softwares, maximum stress does not reach 900 MPa. The reason, why Ansys does not reach such high stress, is because of the lack of the elements and nodes. As mentioned before, topological optimization does not have smooth surface, therefore meaning that each of the triangle elements, that are gained through optimization should be transformed into continuous mesh, but as the number is limited, aggressive reduction of geometry takes place and therefore some elements are removed at all and some elements become smaller than they should be. The average stress points do show correct values. As for Femap NASTRAN – the software is capable of very high level meshing and solving stress accumulations, therefore result is once again different, but as it may be seen, the other areas show similar or same results and color schemes, therefore the difference between these softwares in this case lies in the stress accumulated area. The static results of topologically optimized part by Ansys software are given in Figs. 8-11.

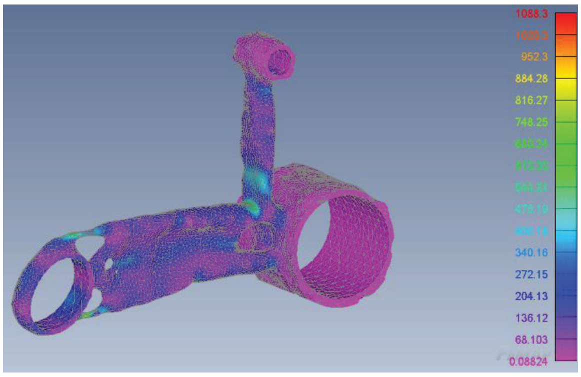

Fig. 8 Part optimized with Ansys topological optimization. Von Mises stress results from Femap NASTRAN software. Ti6Al4V material

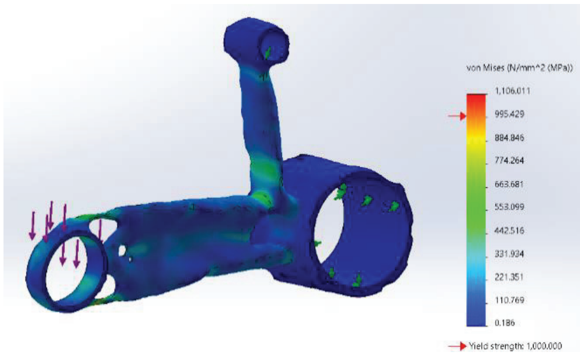

Fig. 9 Part optimized with Ansys topological optimization. Von Mises stress results from SolidWorks software. Ti6Al4V material

Table 1

Finite element analysis results of different topological optimizations

	FEA software	Von Mises maximum stress, MPa	Total deformation, mm	Maximum strain, mm/mm	Buckling factor of safety
Topological optimization by SolidWorks	Ansys	753.23	1.186	0.0069	4.455
	Femap NASTRAN	868.53	1.149	0.0065	4.607
	SolidWorks	1015.95	1.153	0.0061	4.415
Topological optimization by Ansys	Ansys	1154.00	0.954	0.0099	7.895
	Femap NASTRAN	1088.30	0.943	0.0080	7.879
	SolidWorks	1106.01	0.951	0.0071	7.872

As seen from figures, the difference between results is quite small and maximum stress is almost the same, through all simulations. This could be the reason that Ansys software does export better meshed topologically optimization files. The mesh smoothing difference between SolidWorks and Ansys topological optimization is very big, as SolidWorks only optimizes some areas and the smoothing of the mesh does not seem to be highly dominant on sharp edges, while on the other hand Ansys does optimize every single detail around the part and smoothing of the mesh is done more aggressively, therefore the final file is more applicable in different softwares or higher quality 3D printing. Complete results of different studies are given in the Table 1.

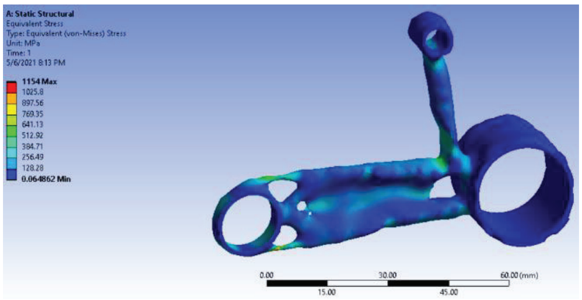

Fig. 10 Part optimized with Ansys topological optimization. Von Mises stress results from Ansys software. Ti6Al4V material

Fig. 11 Final iteration of topological optimization by Ansys software. This iteration is chosen for manufacturing

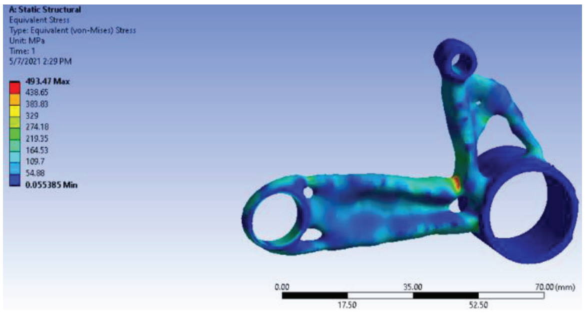

Fig. 12 Final part optimization with Ansys topological optimization. Von Mises stress results from Ansys software. Ti6Al4V material

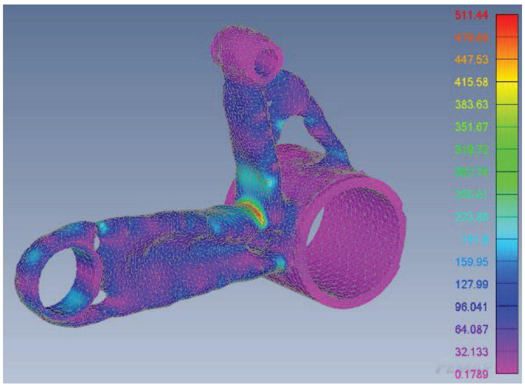

Fig. 13 Final part optimization with Ansys topological optimization. Von Mises stress results from Femap NASTRAN software. Ti6Al4V material

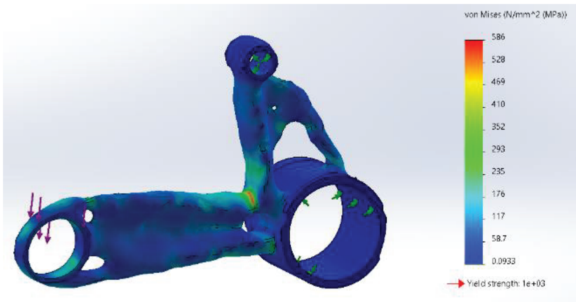

Fig. 14 Final part optimization with Ansys topological optimization. Von Mises stress results from SolidWorks software. Ti6Al4V material

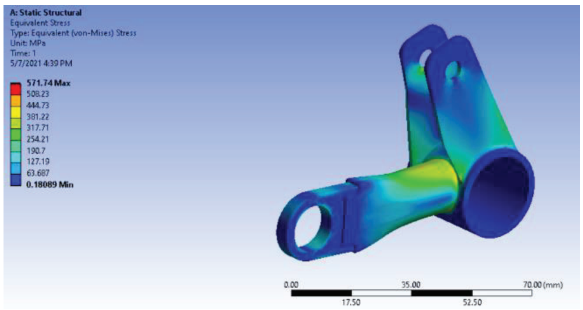

Fig. 15 Von Mises stress results of original part from Ansys software. 30ChGSA material

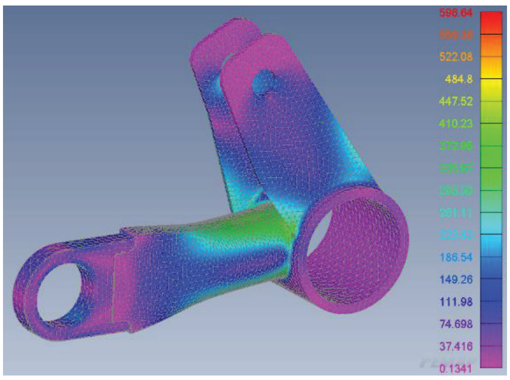

Fig. 16 Von Mises stress results of original part from Femap NASTRAN software. 30ChGSA material

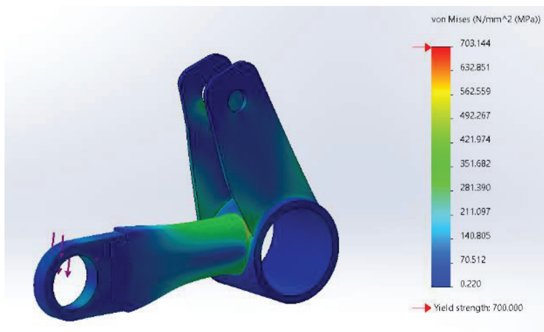

Fig. 17 Von Mises stress results of original part from SolidWorks software. 30ChGSA material

As it can be seen, all results of one topological optimization are almost the same, only in the SolidWorks topological optimization there is a bigger difference in stress value. This is high because of the meshing in different softwares, and how different softwares cope with very difficult geometries. Furthermore, it is impossible to obtain same results, because Ansys does limit the number of nodes for simulations and studies. Finally, the mass values that were received by these topological optimizations were: SolidWorks topologically optimized part – 32.06 grams; Ansys topologically optimized part – 36.83 grams. As these two topologically optimized options are too risky for manufacturing, the third topological optimization should be introduced. Even though the first parts are completely manufacturable, there is high risk of having prototypes manufactured with big deformations, having the prototype not manufactured at all or broken while cleaning from support structures, therefore a safer route for this work is chosen. It is known, that the prototyping phase is quite long and the constant communication with manufacturer must take place and many different iterations should be 3D printed before obtaining final part that is manufacturable with 100 percent repetition of the same quality. Because of all of these reasons, final part is chosen to be manufactured with ~2.5 factor of safety from original part. Because from earlier topological optimizations Ansys showed rather better results for both, overall strength and file meshing control, it was chosen for optimization of final part that would be manufactured. Although the method of Ansys showed to be safer, as it reduced less weight, the bigger value in this sense is complete, easy and deformationless manufacturing, therefore the difference of weight result is disregarded at this point. As it can be seen in Fig. 11, the final part does have extra geometrical features when compared to first topological optimizations, when it comes to the tension and compression. Furthermore, overall visual of the part is the same. Therefore same studies will be done using three different softwares. The results furthermore will be compared to the ones that are of original part. As it can be seen from Fig. 12-14, the results are more or less similar to each other. SolidWorks software gives out the most different result, but as it was for the last time, only in stress accumulated area. As it was mentioned before, since Ansys software offer very high detail mesh smoothing, once the topological optimization is done, the files are easier to work with, easier to mesh and therefore results show more uniform. Fig. 15-17 show the original part's stress values with 30ChGSA material applied. As it can be seen, the SolidWorks software does come out with the most different value out of all three software. This, as it was for all of the previous studies, is only in the stress accumulated areas. All of this not only shows that different software have a different way of treating problems, but also that there is a difference between how specific software targets the problem of topological optimization, as even though the algorithm is similar, differences are still visible.

3. Final Results and Discussions

As for topological optimization and finite element analysis, the software of choice was carefully examined. Even though the results of finite element analysis are similar (only stress accumulated areas show different results), the results of topological optimization are a bit more different. The Ansys software does a better job at smoothing the whole part, but at the same time is a bit more "careful" than SolidWorks. This software does optimize part with more aggressive approach, therefore calculations must be performed to know if final part is strong enough to withstand needed forces. As it is shown in the Table 2, topologically optimized part does not only show better values, but also reduced amount of stress. This means that changed geometry does not have such spots, where stress could easily accumulate. Furthermore, factor of safety in case of buckling is increased greatly, this is because geometry changes that were applied, increased bulky areas where it was needed, therefore risk of buckling decreased by a lot. The weights are as follows: Topologically optimized part for manufacturing – 54 grams; Original part – 83-85 grams. According to the weights, the reduction of weight in topologically optimized part would be ~35%. Moreover, while weight was reduced, the strength of the part was increased, deformation values and risk of buckling decreased. As the studies have shown, riskier options with more weight reduction are possible, but because of the reasons mentioned before, the latest topological optimization will be the choice for additive manufacturing. The maximum strength of the final topological optimization was checked, using the same method as with the Eq. (3) and 1N force.

Table 2

Finite element analysis of final topological optimization compared to original part

	Material	FEA Software	Von Mises maximum stress, MPa	Total deformation, mm	Maximum strain, mm/mm	Buckling factor of safety
Topologically optimized part for manufacturing	Ti6Al4V by EOS	Ansys	493.47	0.591	0.0043	28.854
		Femap NASTRAN	511.44	0.589	0.0039	28.095
		SolidWorks	586.00	0.591	0.0035	29.213
Original part	30ChGSA	Ansys	571.74	0.729	0.0030	18.15
		Femap NASTRAN	596.64	0.730	0.0027	17.86
		SolidWorks	703.14	0.732	0.0026	17.91

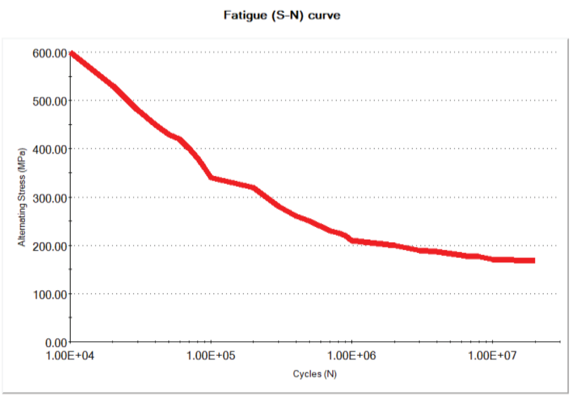

Fig. 18 S-N curve of Ti6Al4V + HIP treatment [8]

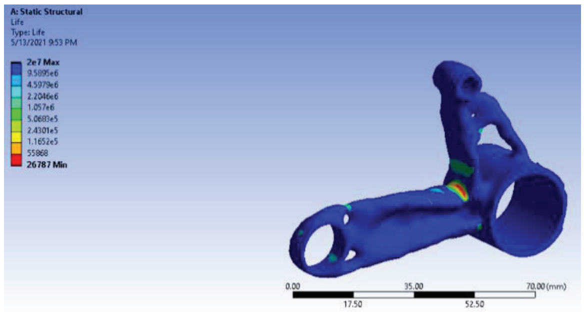

Fig. 19 Sensitivity of a part according to fatigue calculated using Ansys software

The maximum force that should be applied to the part is as follows: Ansys software – 2542 N; Femap NASTRAN software – 2217 N; SolidWorks software – 2634 N. As the maximum force for the original part was chosen 1300 N, it can be seen, that the final factor of safety of the part is 2.5. This not only leads to a safe choice for use but also shows how topological optimization may greatly improve every single aspect of the part. Finally, the fatigue of the final topological optimization should be discussed, therefore according to S-N curve Fig. 18 [8], the lifetime of a part is calculated using Ansys software Fig. 18. As it can be seen from figure Fig. 19, the maximum number of cycles this part could withstand with maximum loading is approximately 27 000. One of the reasons behind this is that there is no further information on cyclic loading and fatigue under higher stress than 600 MPa. According to studies, if the part is post-processed using any kind of sanding or machining, so the surface would be smooth, the available life would increase drastically, but this needs further research and is out of the scope of this paperwork. The fatigue is not calculated using other software, as the S-N curve is always going to be the same. According to the sailplane's maintenance manual, the lifetime is 6000 hours [9], therefore the lifetime of this part could be calculated approximately. As there is no actual statistic loading data available, the cycles and overall loading principle should be approximated. It can be easily calculated, that the part is capable of maximum loading once every 13.3 minutes in the full lifetime, and it is known that typically sailplane's do not fly in difficult and high loading conditions or it happens very rarely. Fatigue calculations would be a lot more precise if actual data of loading was known and fatigue of material was tested. Finally, as the calculations with current information show, the bellcrank may be changed or renewed at the same time as the original part would be.

4. Conclusions

Because from topological optimizations Ansys showed rather better results for both, overall strength and file meshing control, it was chosen for optimization of the final part that would be manufactured. The final part does have extra geometrical features when compared to the first topological optimizations, but the overall visual of the part is the same.

The topological optimizations that were done to parts with a factor of safety 1 (that would break on 1300 N force) had mechanical properties that would satisfy needed strength requirements. The final topological optimization with a factor of safety 2.5 was conducted and the part showed better mechanical properties with the decrease of stress by approximately 15%, deformation values decrease by 19% and increase of buckling factor of safety almost twice and static factor of safety by the same amount. The maximum force that was calculated for the topologically optimized part with Ansys software was 2542N and this resulting force is about 2 times higher than it was needed to break the original part.

According to the original part and topologically optimized part weights, the reduction of weight in the topologically optimized part would be ~35%. As more than one topological optimization was done, it is known that further weight reduction could be implemented further increasing the percentage of reduced weight up to 60% or even more with additional constraints and iterations. Finally, using same topological optimization techniques and same manufacturing technology, it would be possible to reduce the whole weight of an aircraft by a significant amount.

The topologically optimized part is capable of withstanding the needed 6000 hours before breaking under conditions, that sailplane would only reach maximum loading every 13.3 minutes. This could be increased by smoothing down the surface of 3D printed part and therefore would have the unlimited possibility to reach maximum loading, but nonetheless would be capable of withstanding the same 6000 hours. The fatigue is not improved, but under different surface treatments better results would occur.

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Methodology of Metrological Support of Technological Processes of Transport Monitoring Systems

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Abstract

The metrological support of technological processes of monitoring and diagnostic monitoring systems on transport is considered, the main problems are identified and the ways of their solution are presented. Metrological support of monitoring systems at power facilities, including transport, which allows to solve many problems related to the registration of power systems, determination of electrical and time parameters, finding damage to power lines, diagnostics of electrical equipment and many others. The system analysis of metrological maintenance of reliable, economic and qualitative work of electric power objects is used.

It is determined that the technical basis of metrological support is a system of state standards and exemplary measuring instruments, which ensures their reproduction with the highest accuracy; a system of working standards and exemplary measuring instruments, by means of which the transfer of the sizes of units of physical quantities to the working measuring instruments is carried out. It is analyzed that the most effective way to increase the reliability, efficiency and safety of electrical equipment is the use of methods and tools for technical diagnostics. The application of monitoring systems for monitoring and diagnostics of electrical parameters of railway power facilities minimizes both the time of restoration of electricity supply and the corresponding economic losses caused by emergency power outages, as well as reduces the costs associated with the repair of damage.

Comparisons of accuracy of measurements of various devices of registration of parameters of modes show similar indicators and confirm possibility of application of system of monitoring of mode parameters in problems of an estimation of a condition of power systems. The results of the study can be used in the technological processes of monitoring and diagnostic systems in transport using digital devices as a measuring instrument for parameter control and monitoring of electrical networks.

KEY WORDS: *metrology, information, monitoring system, control, diagnostics, method, management, technological process.*

1. Introduction

Metrological support is the establishment and application of metrological norms and rules, as well as the development, manufacture and application of technical means that ensure the unity and the required accuracy of measurement. Metrological support consists of scientific, legislative, technical and organizational bases.

The scientific basis of metrological support is metrology. The legislative basis of metrological support is the Law of Ukraine, decrees and resolutions of the Cabinet of Ministers of Ukraine, which are aimed at ensuring the unity of measurements. The normative basis of metrological support is the State standards and other documents of the State system of ensuring the unity of measurements, the relevant normative documents of the State Standard of Ukraine, methodical instructions and recommendations.

The technical basis is a system of state standards and exemplary measuring instruments, which ensures their reproduction with the highest accuracy; a system of working standards and exemplary measuring instruments, which are used to transfer the size of units of physical quantities to the working measuring instruments. As well as a system of standard samples of the composition and properties of substances and materials, which provides reproduction of units, composition and properties of substances and materials. A system of working measuring equipment used in the development, production, testing and operation of products, research and other activities.

The organizational basis of metrological support is the metrological service of Ukraine.

The purpose of metrological support is to improve quality, increase production efficiency, use of material values and energy resources, as well as scientific research.

2. Research Materials and Results

We can identify the main tasks of metrological support of the technological process, it is - the establishment of units of physical quantities; formation of a system of state standards of units of physical quantities and ensuring their functioning; development of methods and means of transfer of the sizes of units of physical sizes from standards to exemplary and working means of measurement. As well as the development of scientific and methodological, legal and organizational frameworks that are necessary to achieve unity and the required accuracy of measurement. Development and implementation in metrological practice of the rules of legislative metrology. State and departmental supervision over the development, production, condition, use and repair of measuring instruments. Conducting state tests, verification, calibration and metrological certification of measuring instruments. Certification of measuring instruments. Development and certification of measurement methods. Creation and certification of standard samples of composition and properties of substances and materials. Conducting metrological examination, design, engineering and technological documentation [1].

Methodology of research Metrological support is a rather broad concept. Therefore, when it comes to metrological support of the technological process (production, enterprises, departments, etc.), they mean metrological support of measurements of this technological process, specific production, enterprise).

Metrological support of the technological process of the enterprise includes analysis of the state of measurements at the enterprise, establishment of a rational nomenclature of measured quantities, nomenclature of working and exemplary measuring instruments, optimal measurement norms, accuracy. Selection, verification and metrological certification of the necessary tools, development of measurement methods depending on the established accuracy standards. Creation and maintenance of conditions necessary for carrying out measurements, metrological examination of technical tasks, design and technological documentation. In the absence of measuring instruments serially produced by industry and necessary for the control of the technological process, metrological support includes the creation and recognition by law of the so-called non-standardized measuring instruments. Metrological support also includes the introduction of state and departmental regulatory and technical documents, development of regulatory and departmental documents of enterprises on metrological issues, control over production, condition, use and repair of measuring instruments and compliance with metrological rules, regulations and requirements at the enterprise.

An important type of metrological support is the creation of working and sample measuring instruments and their readiness for use.

An important part of the process of designing and manufacturing various technical systems is testing. As a result of tests receive almost all data on parameters and characteristics of systems at all stages of their creation. Here it is fashionable to highlight the following highlights

The information obtained during the tests is the technical basis for improving and optimizing critical circuit solutions.

Quality assurance of systems at the production stage largely depends on testing.

A significant part of the funds allocated for testing is spent on testing. First of all, it is test equipment, ie technical means for reproducing test conditions.

Measuring devices are an integral part of the test equipment. They can be built into the test equipment or stand-alone. Their functions include measuring the parameters of the test object or monitoring the test conditions.

Test aids also include technical assistive devices for fixing test objects and recording and equipping the results. The test equipment must be performed in full compliance with the requirements of the single design documentation and certified in a timely manner. Certification of test equipment involves determining its standardized accuracy characteristics and establishing suitability for work.

Metrological support of power consumption systems and devices in railway transport is an important task of management. Quite a difficult task due to the specifics of the processes of electricity supply to traction trains, the processes of control and safety of trains.

The issue of ensuring reliable, economical and high-quality operation of power facilities is solved through their comprehensive automation and informatization, one of the strategic directions of which is the introduction of large power facilities digital power meters recording devices synchronized measurements [2]. Their use at these facilities is becoming a common norm and significantly facilitates the working conditions of service personnel and increases the reliability of equipment through constant monitoring of its modes of operation and information support. The technical data of these devices allow you to solve many problems related to registration.

Results and discussion of the study. It is known that experimental research and testing require significant funds, the share of which in the total design costs is constantly growing. When it comes to modern complex technical systems, the cost of creating appropriate control and measurement and testing equipment is much greater than the cost of developing the systems themselves. Therefore, the automation of control and measurement and testing processes is one of the most important ways to improve the efficiency of system design [3].

Usually, enterprises engaged in the creation of complex technical systems have test equipment that can simulate virtually all types of external influences, namely high and low temperatures, high humidity, salt fog, vibration, shock, etc. The high complexity and duration of tests is partly explained by the fact that testing on such equipment requires significant time for preparatory operations, including the installation of systems on test equipment, connection of control and measuring equipment, etc. The use of universal equipment, which allows on one installation to conduct tests of different types and in different sequences, leads to a significant increase in test efficiency.

The most effective way to increase the reliability, efficiency and safety of electrical equipment is to use methods and tools for technical diagnostics. Due to the use of monitoring systems and diagnostics of electrical parameters of electric power facilities of railways, both the time of restoration of power supply (associated with the restoration of train traffic) and the corresponding economic losses due to emergency power outages, as well as reduced costs associated with operational performing repair work to eliminate the effects of damage [4-5].

The characteristics of digital recorders and monitoring systems offered on the market of electric power systems by leading manufacturers are regulated by international standards [6-8]. The performed comparisons of the accuracy of measurements of different devices for recording the parameters of PMUs [9] demonstrate similar indicators and confirm the possibility of using the mode monitoring system (WAMS) in the tasks of assessing the state of energy systems. At the same time, work is underway to improve distributed measurements, including the estimation and compensation of errors related to transport delays of information transmission lines.

ABB is one of the leaders in the field of electrical equipment, one of the first to establish the production of digital recorders such as RES 521 [10] and the introduction of WAMS for UES in Central Europe. The characteristics of RES 521 recorders became the basis for the formation of international standards for the characteristics of measuring channels, accuracy of time synchronization, specialized modifications of network protocols and message formats [11].

Arbiter Systems implements and maintains monitoring systems based on Power Sentinel 1133A recorders. Arbiter Systems product specifications set standards for the accuracy of GPS-based measurement synchronization, as satellite-based devices are one of the company's specializations. The results of comparing the accuracy of power measurements using PMU Power Sentinel 1133A (0.025%) and standard wattmeter (0.1%), indicate the possibility of increasing the efficiency of electricity metering by means of Power Sentinel recorders [12]. A feature of analog signal measurement channels is the use of real-time autocalibration, which eliminates a number of sources of errors that could degrade accuracy. The calibration process is implemented on the principle of injection into the measuring channel of the internal reference signal, with a complete set of auxiliary measurements is performed once a second.

General Electric, the market leader in power equipment in the North American region, produces general control, protection and monitoring systems based on Multilin N-60 devices [13]. The considered devices are intended for realization of intelligent systems of protection of electric power object, are a basis of construction of the automated information and control networks of EC. The system is able to generate intelligent solutions for controlling the modes of power systems.

Turkey's UES energy quality monitoring system is based on GPS-linked digital recorders called Power Quality (PQ) analyzers, which emphasizes the use of the system mainly for commercial electricity metering. GPRS, ADSL and fiber-optic data transmission channels are used to build the information network. The system is certified according to international standards [6-8], while the channels for measuring currents and voltages provide sampling at 512 values for the period of the fundamental harmonic (50 Hz), and GPS time synchronization is provided with an error not exceeding 100 ns.

On the basis of territorially distributed high-precision recorders "Regina-F" created a system for monitoring transient modes (SMTM), which is designed for continuous monitoring of the parameters of power systems, assessment and forecast of current modes of operation and issuance of digital information to control systems and information systems used in the power industry.

To monitor the modes of the integrated power system of Ukraine at the system-forming power facilities introduced diagnostic complex “Regina-F” [14], which is a joint development of leading domestic research institutions. The characteristics of domestic registrars are not inferior to foreign counterparts and meet international standards [15]. WAMS based on Regina-F devices provides modern functionality for power system diagnostics, including condition assessment, monitoring of transient modes and low-frequency oscillations.

The multifunctionality of the digital electric measuring device of synchronized measurements (DEMDSM), which consists in determining the quantities of different physical nature, in turn requires a comprehensive approach to its metrological support. Consider the main methods and means of their implementation to determine the metrological characteristics of DEMDSM, developed for measuring and monitoring the parameters of electrical networks.

The main parameters to be determined in the monitoring process are:

1) the current values of the first harmonics of each phase;
2) current values of active and reactive power; the values of the angles between the phases of the voltage vectors;
3) the value of the voltage frequency of each phase;
4) the value of the exact time of transition of the phase voltage through zero;
5) the angle between the sine wave of the mains voltage and the sine wave of 50 Hz, tied to the signals of the exact time.

In order to determine the metrological characteristics of the electric measuring recording device ("Regina F") the state metrological certification was carried out, during which the errors of measurement of the following values were determined: alternating current; alternating current voltage; alternating current frequency; active power; reactive power;

electrical angles between voltage vectors; electric angles between current vectors; electrical angles between voltage and current vectors; power factor; synchronization of the device "Regina F" from GPS.

The following equipment was used during the state metrological certification: frequency meter Ч3-63; calibrator universal H4-6; phase difference meter F2-34; measure of resistance of alternating current RT-1; ED8421 installation with the EPZ 303-5 reference counter, accuracy class 0,02.

The ratio of the limits of permissible values of errors of the reference means of measuring equipment and electrical measurement of the recording device Regina F does not exceed 1/3.

Since the devices "Regina F" are designed to work in normal modes, the range of changes in the input signals for current, voltage and power, respectively, is limited by their nominal values. To experimentally determine its normalized metrological characteristics, it is necessary to apply a calibrated signal of current, voltage or power to the input of the device "Regina F" and determine the error of its measurement.

One of the main metrological characteristics of the device "Regina F" for frequency monitoring is the error of measuring the frequency of the input voltage, the absolute value of which is normalized within ± 0.001 Hz. To determine this metrological characteristic, an electrical circuit is proposed using as a source of frequency-stable voltage calibrator universal H4-6, as a working standard for measuring frequency used frequency meter F3-63.

Measurement of frequency with such accuracy is possible only under the condition of correct and rational choice of signal sampling frequency with the subsequent approximation of transitions of a sinusoid through zero that provides the set accuracy of measurements.

The information that is registered "Regina F" is considered discrete, as the device is digital.

To ensure the same interpretation of the results of synchronized measurements of the parameters of the modes of operation of the systems, the method of synchronization of the measuring modules of the systems of registration of the parameters of the distributed power facilities is used. This method is to link all measurements, including the angle of the voltage vector to the so-called ideal sine wave. To do this, for example, at 12 o'clock 00 minutes 00 seconds 000 milliseconds 000 microseconds on all recorders of synchronized measurements located on power facilities, a virtual sine wave with a frequency of 50 Hz and zero phase is started. Further, all measurements of quantities, including angles of voltage vectors, are made with respect to this sinusoid, at each of its periods. In essence, the synchronization of the measuring modules of the registration systems installed on different objects is to link the transitions through zero of the measured voltage sine wave to the GPS time scale produced after 20 milliseconds.

Steppe polynomial approximation is used to determine the transitions through zero of the fundamental harmonic of the sinusoidal voltage. It is assumed that after registration the signal was passed through a filter, the output of which has discrete values of the fundamental harmonic of the sinusoidal signal.

$$u(t) = f_0 + f_1(t - t_0), \tag{1}$$

where $f_0 = u(t_0)$, $f_1 = \dfrac{u(t_1 - u(t_0))}{t_1 - t_0}$.

Since it is necessary to find the transition through zero, we equate (1) to zero and find *t*.

$$t = \frac{f_1 t_0 - f_0}{f_1}. \tag{2}$$

An important temporal parameter of the mode is the voltage phases of various nodes of power systems, measured in a single format of astronomical time. That is, measuring the angle of the voltage vector of the network of controlled connections with reference to the time signals received from the GPS receiver. Measurement of this parameter with the set accuracy is necessary for synchronous work of various parts of electric power systems; control of capacity flows in systems; expert assessment of the state of networks; control of states of systems at connection to it of electric power objects; control of operation of differential phase protections on power lines; periodic control of the state of electric power systems by power consuming organizations.

The synchronization error of the measuring modules of the network mode registration system from GPS should not exceed ± 20 μs, and the error of the angle of the voltage vector of the measured sinusoid relative to the sinusoid tied to astronomical time should not exceed ± 1˚.

The specified error of synchronization of measuring modules of the registration system was confirmed during their metrological tests, in the process of conducting state certification in Ukrmetrteststandart in accordance with the requirements [15].

According to the results of experimental studies, you can calculate the average value of the absolute error of the binding of the transition through the zero sinusoidal signal to the time scale by Eq. (3):

$$\Delta_{av} = \frac{1}{n}\sum_{i=1}^{n} \Delta_i, \tag{3}$$

where $\Delta_i = X_f - X_d$ is the absolute error of the *i*-th measurement; X_f − results of measurements by means of a frequency meter; X_d − results of measurements by means of the device "Regina F"; n − the number of measurements.

If the error value does not meet the requirements standardized in the technical documentation for the device "Regina F", it is necessary to enter in its program an appropriate correction for the error, calculated by Eq. (3) with the opposite sign and repeat the described measurement procedure.

State certification has shown that the device "Regina F" meets all the requirements of its regulatory documentation and can be used as a measuring instrument to control the parameters and monitoring of electrical networks.

After analyzing the market for high-precision measuring equipment, it was found that at least the following instruments meet these conditions: the Fluke 9100 universal calibration rig, manufactured by Fluke Corporation, and the F6150 universal signal generator, manufactured by Doble Engineering Company.

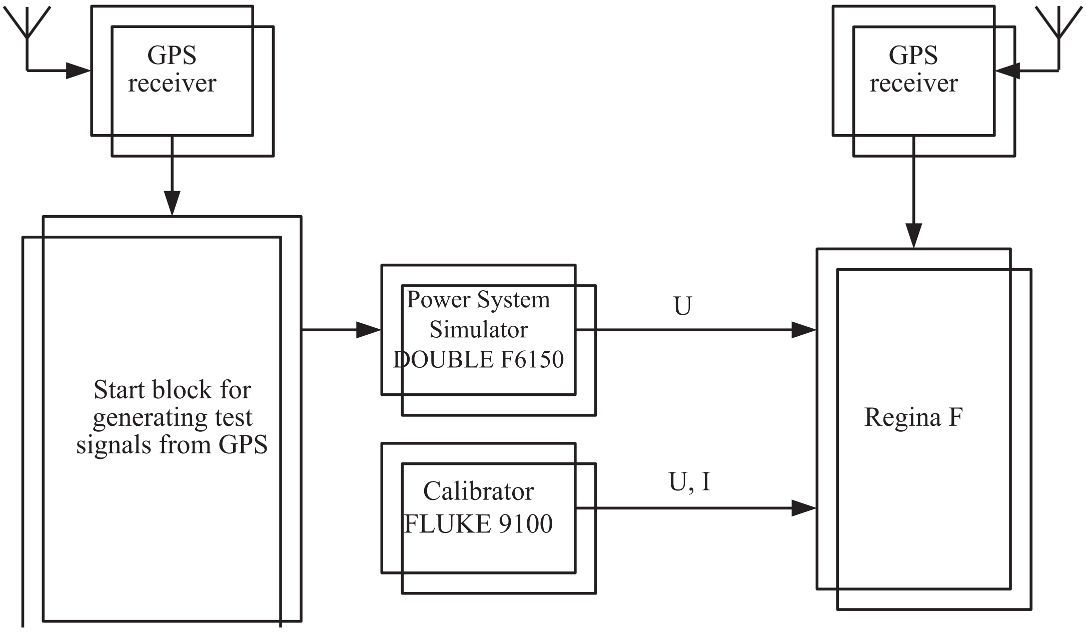

Fig. 1 Scheme of metrological certification "Regina-F" in operating conditions

For the correct functioning of the SMTM, it is necessary to organize the verification of its technical means under operating conditions.

The proposed approach to metrological support of SMTM means allows:

– to increase the metrological reliability of the measuring instruments used in the SMTM;

– to simplify the process of determining the metrological characteristics of SMTM tools in operation, taking into account the conditions for their verification.

3. Conclusions

Measurement of electrical parameters of power systems and objects in real astronomical time is an urgent and timely task, the implementation of which requires high-precision and metrologically equipped devices.

The main aspects of metrological support of technological process and means in information-measuring systems are analyzed.

The main components of their metrological support are identified. The tasks of metrological support of the technological process of enterprises are given.

The metrological support of digital electric measuring recording devices of synchronized measurements such as "Regina F" is analyzed.

The issue of control of metrological characteristics of technical means of the system of monitoring of transient modes of power systems is considered.

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Means for Reducing Adverse Effects of Transport

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Abstract

The impact of transport on the human environment has long been a current global issue and the urgency of its active solution will continue to increase. The negative effects that transport, in general, brings with it problems that threaten economic stability, mobility, and living standards. Therefore, the states jointly participate in the creation of measures leading to the mitigation of the negative effects of individual modes of transport. Restricting traffic without negative consequences in other areas is not realistic. Therefore, research priorities are shifting to more environmentally friendly modes of transport and focusing on alternative fuels.
This article will analyze current modes of transport and their adverse effects on the human environment. The introduction of the article will describe the various modes of transport and specific adverse effects. Their occurrence will be evaluated and compared, the system of emission allowances and their impact will be marginally analyzed. At the end of the article, an analysis of the future development of individual modes of transport will be performed and the current possibilities of mitigating their adverse effects will be summarized. The final discussion will be devoted to new evolving technologies, their benefits, and possible risks. Means for reducing adverse effects of transport.
KEY WORDS: *adverse impacts, alternative fuels, emissions, environment, influence, noise, restrictions, transport*

1. Introduction

Transport has been an integral part of human life since the beginning of history. Until the third millennium BC, animal or human force was used to transport people or things. After that, water transport was the most widespread transport due to the establishment of human settlements in river deltas. Although the invention of the first wheel dates back to 4500 BC, this transport required the construction of roads. Their absence made this transport uncomfortable, slow, and generally inefficient. Over time, however, they were built and with it improved vehicles such as wagons pulled by cattle or horse-drawn carriages. The revolution in transport then took place in 1765, when the steam engine was invented. In 1830, the first railway with a steam locomotive was opened, and in 1879 with a locomotive powered by an electric motor. Rail transport became very popular until 1876, when the first internal combustion engine was produced, thus beginning the era of motoring, which continues to this day. The car has become indispensable for the vast majority of people in the world. The field of air transport was started by the invention of a hot air balloon in 1783, and the invention of an aircraft with an internal combustion engine continued. Today, aviation uses a jet engine developed during World War II. Due to its speed, air transport is the most popular means of long-distance travel.

It is obvious that even today, everyday life could not work without transport. We wouldn't get to work, school, family, or fun. No state's economy and the market could function more without transport. Unfortunately, the positive contribution of transport to the quality of human life also has its negative side, namely the fact that transport is the biggest environmental pollution. For the reasons set out above, it is clear that it is not possible to restrict traffic. On the contrary, it can rather be assumed that further development of transport is inevitable and necessary in the future. Therefore, one of the greatest challenges for science in the future is to explore and develop alternative modes of transport and fuels that are most environmentally friendly.

Here comes the role of the state, which consists of removing barriers to equal access of the population to the possibilities of more environmentally friendly transport and further support for the type of transport that serves everyone, such as urban transport. Transport infrastructure and its systems should be developed and operated in such a way as to sufficiently support the economy and at the same time ensure an acceptable quality of the company's environment. This goal can only be achieved through environmentally friendly modes of transport (Fig. 1). The economic instruments used to influence transport in most countries include the following means:

Economic instruments include:

- tolls (motorway tolls, tolls, tolls, parking fees, noise charges);
- taxes (road tax, excise duty on fuel);
- subsidies (eg for fleet renewal);
- tax relief;
- tradable permits and so-called emission allowances;
- insurance (liability for damage caused by traffic in road, air, and maritime transport).

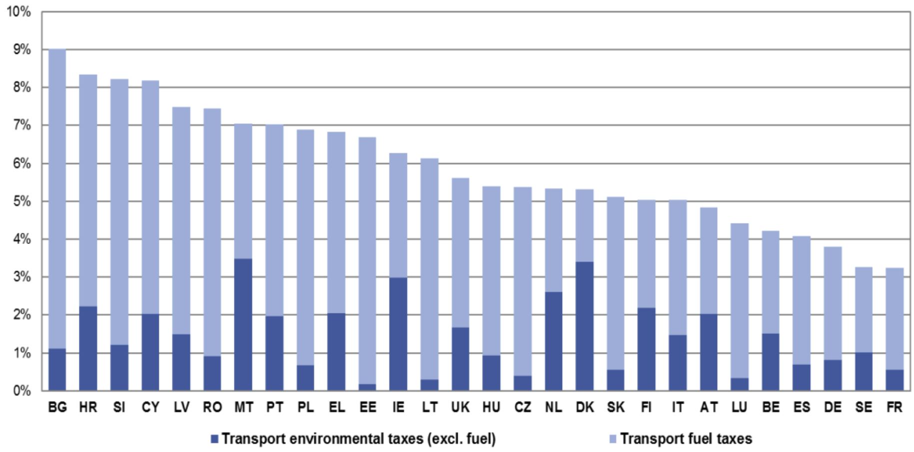

Fig. 1 Taxation trends in the European Union, 2018 [1]

At a time of climate change, the need to move to emission-free transport and thus to the sustainable development of society is crucial. Each state should use all available regulatory tools (direct and indirect) that will lead to the development of emission-free transport and at the same time to improve the quality of the environment. Indirect instruments can use state support, while direct instruments can be used to initiate programs to improve the quality of the environment, action plans, and create low-emission zones. These tools play an important role in the development of alternative infrastructure and alternative vehicles. It is also up to each of us to realize that the environment needs to be protected, and to use less comfortable but much more environmentally friendly transport for his journey.

2. Transport Modes and their Adverse Effects

Transport is an important part of human life and the economy, as it holds an indispensable social and economic function. It allows the movement of people and goods, information, access to services, raw materials, or job opportunities. Each of these functions requires a different approach and therefore several modes of transport are currently being developed in parallel. Nevertheless, the individual species are competitive, as the following Fig. 2 shows (situation in the Czech Republic):

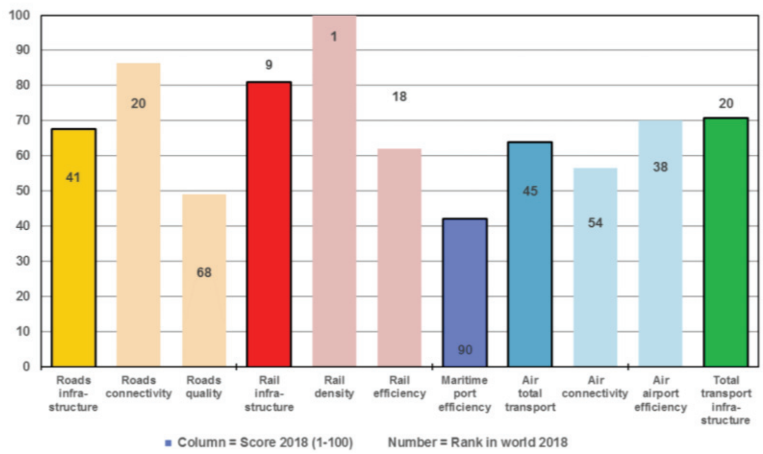

Fig. 2 Competitiveness of individual modes of transport [1]

The columns represent the quality scores in each area from 1 to 100 (best). Efficiency is measured as frequency, punctuality, speed and price (includes access to seaport services for landlocked countries). Roads connectivity relates to the average speed and straightness of a driving itinerary connecting the cities that together account for at least 15% of the total population. Airport connectivity measures the degree of integration of a country within the global air transport network. Maritime connectivity relates to the quantity of services provided by liner companies.

A. Characteristics of individual modes of transport

Road transport

Road transport is widely used for the transport of people, animals, and goods, especially for short and medium distances. The advantages include great operability, speed, and availability, the disadvantage is a then high negative burden on the environment and higher accidents. Road transport accounts for a decisive part of the transport market in most developed countries, and its use is also conditioned by the diversity of the vehicle fleet. Especially in passenger transport, thanks to its availability and financial simplicity, it is the most used transport. In the future, its development depends on the quality of the transport network, the building of capacity multi-lane roads, and the density of the motorway network.

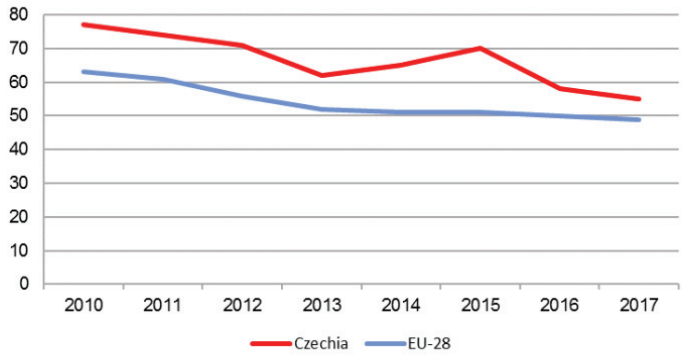

Fig. 3 Road fatalities per million inhabitants [1]

The number of road fatalities has decreased since 2010 (Fig. 3). However, the number of road fatalities is still above the EU average: in 2017, there were about 55 road fatalities per million inhabitants in Czechia. Data for 2017 shows an impressive decrease of 28% on fatalities since 2010 compared to 20% for the EU average.

Rail transport

Rail transport is a part of rail transport, it also includes tram and trolleybus transport. Large volumes can be transported, the range is rather medium to long distances and there is a relatively high level of safety. At present, motor and electric traction vehicles are used. Electricians have lower energy consumption and emissions of harmful substances compared to other modes of transport. Compared to the road network, however, there is an impact on the achievement of the objectives by geographical conditions. The railway has a lower ability to overcome elevation gain, which is the cause of higher financial demands when building new lines. However, when it comes to comparing the speed of freight transport, it compares with road transport.

Water transport

This type of transport is one of the oldest. Waterways can be divided into inland and maritime. Nowadays, natural paths are further supplemented by artificially built canals, waterworks, and canals. However, their high price does not allow for the necessary expansion, and therefore in the future, it will be rather an effort to maintain and expand the existing ones. Water transport is used mainly for the transport of goods, in passenger transport very marginally.

Air Transport

Air transport is the youngest mode of transport. It is used primarily for the transport of passengers and cargo by air [2]. In freight transport, it is represented only in the transport of mail and small parcels. Its advantages include high speed, long-distance transport, and safety. The disadvantages are the great loss of life in the event of an accident, the great burden on the environment, and the need to use another mode of transport to and from the airport.

Bicycle and pedestrian transport

It is mainly used for short transfers, especially in combination with other modes of transport. Both are environmentally friendly, do not cause disturbing noise, and have a positive effect on human health. Disadvantages include the lack of infrastructure, which causes injuries to cyclists and pedestrians, often with fatal consequences. In the future, special lanes, safe storage for bicycles, and footpaths need to be built. In this way, we can expect a reduction in accidents and an increase in individual car traffic in cities.

B. Negative effects of transport on human health

There are more side effects of transport, so the article deals only with the most fundamental ones such as noise pollution, greenhouse gas emissions, and air pollution. They cause additional transport costs for society that cannot be satisfactorily addressed and are unfortunately not paid for by the originators. The European Union is trying to solve this problem in the form of taxes, as described above. These effects are serious, especially in relation to human health. Currently, there is an increase in cardiovascular, respiratory, and chronic diseases.

According to the magnitude and significance of the negative effect, these effects can be divided into:

- local, which have negative effects only in the immediate vicinity of the source of pollution and their action is not further transmitted;
- regional, the negative effects of which are passed on from their source of pollution;
- continental, whose negative effects and pollutants affect the whole continent;
- global, which affects the majority of the world's population - the greenhouse effect. [2]

The European Union is currently facing poor air quality. In most countries, this situation is stagnant, in some places, it is even getting worse.1 The causes of this situation are several - energy, industry and especially car transport. It is one of the biggest air pollutants and worsens the global climate in the long run. It produces a large number of harmful substances, which can be divided into two groups:

1. Substances that contribute to climate deterioration. In this respect, carbon dioxide (CO2) can be clearly mentioned, its concentration of 3-5% in the air is life-threatening even after half an hour of exposure, 8-10% causes loss of consciousness and death.

2. The second group consists of pollutants emitted by cars. This group includes in particular nitrogen oxides (NOX), carbon monoxide (CO), carbohydrates, and particulate matter (PM). Increased concentration of these substances endangers the health of humans, animals, and plant species.

- Nitrogen oxides (NOx) have irritating effects, causing mild to severe inflammation of the bronchi or lungs (bronchitis, bronchopneumonia, acute pulmonary edema).
- Carbon monoxide (CO) blocks the release of oxygen from hematopoiesis. The result is heart, brain, vision, and hearing problems, stomach upset, or abdominal pain. In case of severe poisoning, unconsciousness occurs, at a concentration above 750 mg.m-3 death occurs by suffocation.
- Suspended particulate matter (PM) causes heart disease, lung disease, and lung cancer. Furthermore, changes in the human immune system. It is mainly lead (Pb) that causes anorexia, headaches, and joint pain. Cadmium (Cd) then kidney and liver damage, osteoporosis, and anemia.

However, in addition to road transport, other modes of transport also contribute to pollution. Even electrified railways consume energy, which is produced in fossil fuel power plants. A special group of effects caused by transport on human health is the effect of noise and vibration. They cause a reduction in the body's resistance to stress, damage to the auditory system, cardiovascular system, and sleep disorders. This also includes human inactivity, due to the use of cars instead of cycling or walking.

C. Negative effects of transport on the environment

The sharp increase in transport performance and the related increase in the number of cars and trucks is reflected in the increasing burden on the environment. In connection with the negative effects of transport, the most frequently mentioned are:

- Air pollution: pollutants produced by transport can be divided into limited ones (carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter) to which emission limits apply. Furthermore, unlimited substances (which contribute mainly to the warming of the planet - carbon dioxide, methane, nitrous oxide, and more).
- Water pollution by waterborne traffic causes ship traffic, tanker accidents, and port traffic. Road transport then contributes to fuel, oil, and operating fluid leaks during traffic and accidents.
- Soil pollution is mainly caused by normal operation and maintenance on the roads, the use of spray and antifreeze fluids. In the case of railways, the chemical treatment of wooden sleepers [1].
- Threats to fauna and flora in connection with the development of transport, there is extensive construction of infrastructure and thus a reduction in the size of ecosystem areas, there is a threat to animal and plant species [3].

3. Comparison of Emissions Production in Transport

The Czech Republic was selected as a reference element for comparing emissions from transport. The results published in the 2019 yearbook by the SYDOS traffic statistics system were used. Total emissions from individual modes of transport for 2019 are shown in Fig. 4 [4].

Emissions individual transport modes	2019							
	CO2	CO	NOx	N2O	*compound	CH4	SO2	particles
Transport - total	21 118	75 974	59 921	705	14 209	949	215	4 400
Individual car transport	12 223	62 948	29 050	344	11 146	734	85	2 521
Public transport by road	601	768	2 749	12	93	82	3	103
Road freight transport	6 693	7 030	20 119	209	942	68	43	1 630
Motorbikes	46	2 197	59	1	891	40	0	10
Rail transport	270	1 657	2 848	103	394	15	2	128
Water transport	10	59	102	0,3	14	0,9	0,1	8
Air transport	1 275	1 314	4 994	36	728	9	82	0

*volatile organic compounds

Fig. 4 Overview of the production of emissions of individual modes of transport in 2019 [4]

The largest amount of emissions, taking into account the volume of transport, is produced by air transport. Given that water transport is minimally represented in the Czech Republic and its transport, it appears to be the most environmentally friendly mode of transport in terms of emissions. On the other hand, passenger and freight transport have the largest share, followed by public transport. Individual types of emissions from road transport in the Czech Republic from 2010 to 2019 in Fig. 5 show a slight decrease compared to previous years, which is attributed to the tightening of emission standards for newly manufactured vehicles.

Emission problems, as faced by the Czech Republic, exist in all Member States of the European Union. They differ only to the extent that depends on the use of individual modes of transport. The solution is the joint identification of problems and trends in the European transport area, the development of transport infrastructure networks in EU countries, and the external costs of transport. The condition of road and rail infrastructure throughout the EU is not good, mainly due to low maintenance. Maintenance budgets are often reduced and repairs are not based on the necessary repairs due to their age [5]. The result is the deterioration of roads in many European countries, leading to higher accidents, congestion, increased noise, and overall poor service to society. Increasing the quality of infrastructure to the current requirements of society and building stations for clean alternative fuels is the only way to motivate people to change the preferences of individual modes of transport. However, this represents an urgent need for significant investment. Pressure on zero-emission transport makes the introduction of alternative fuel vehicles inevitable and it will be necessary to assess which tools to support the transition to alternative fuels will be most effective [6].

Comparison of year-on-year growth of total emissions in transport						
	Year/(in thousand in a tons)					
Harmful emissions	2010	2015	2016	2017	2018	2019
CO2	18 144,40	19 057,00	19 869,40	20 501,30	20 838,70	21 118,00
CO	202,3	104	102,3	95,7	87,7	76
NOx	78,4	67	65,3	66,5	63,6	59,9
N2O	0,6	0,6	0,7	0,7	0,7	0,7
volatile organic compounds	27,1	17	16,1	15,7	15,6	14,2
CH4	1,7	1,1	1,1	1	1	0,9
SO2	0,2	0,2	0,2	0,2	0,2	0,2
particles	5,2	4,5	4,5	4,6	4,6	4,4
Pb	0	0	0	0	0	0

Fig. 5 Comparison of emissions production in years 2010-2019 - Author

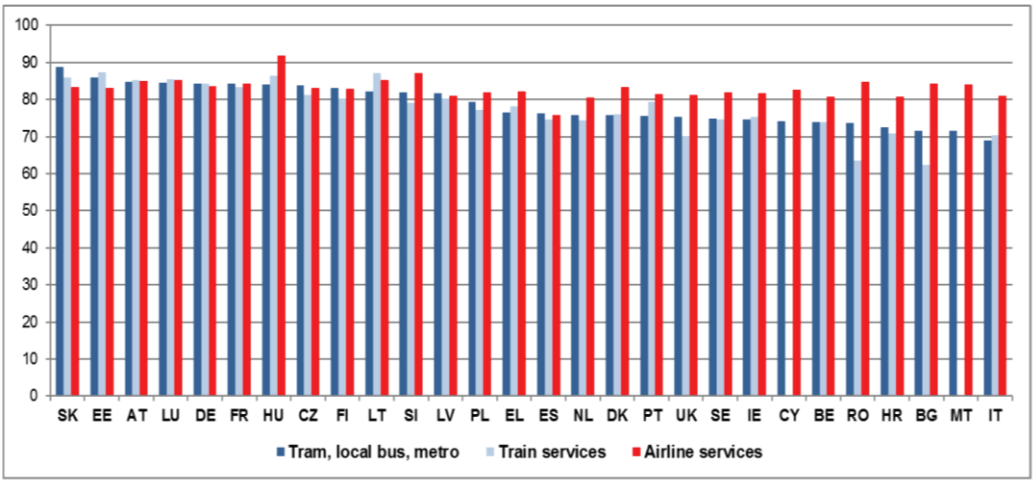

Fig. 6 Comparison of the ratio of services of individual modes of transport and user satisfaction [1]

Another suitable way to reduce the emission impact even with the current composition of vehicles in current transport is the large-scale development of multimodal transport. This mode of transport is characterized by cooperation between the various modes of transport, at least three (Fig. 6). This method makes it possible to use the most suitable type of transport for each part of the journey. The criteria can be economically beneficial reasons and at the same time beneficial to health and the environment. Cooperation between modes of transport is relatively new and the issue of competition between modes of transport must be addressed. It is also important to build common transshipment points between modes of transport and to introduce unified transport units (eg standardized containers). Only these would allow the transfer of goods from one mode of transport to another.

4. Conclusions

At present, low-emission and zero-emission transport appear to be one of the best possible solutions to the global emissions problem. With the development of alternative sources of electricity, including solar power plants, wind farms, and others, the development of alternative cars is an effective means of combating climate change and environmental degradation in human health [7]. As little CO2 as possible must be produced in the production of electricity, which will ensure that vehicles with alternative propulsion are an emission-free source of transport. The total greenhouse gas emissions emitted by diesel vehicles with battery-electric vehicles were compared. In the individual EU Member States, battery electric vehicles have been found to produce more than 80% fewer greenhouse gases in their life cycle in the Nordic countries. In Poland, on the other hand, battery electric vehicles emit about 25% fewer greenhouse gases than diesel cars. It can therefore be deduced that, for example, in the Czech energy mix, these cars will emit about 30% less CO2 in the Czech Republic than diesel cars. It is therefore clear that it is already worthwhile to support alternative propulsion vehicles, especially electric cars.

Finally, other options are known but not used to such an extent that their benefits are clear. For example, the introduction of regulations, where the municipality has the opportunity to restrict traffic in its territory, will contribute to reducing the level of pollution. It is also possible to build bypasses around individual municipalities, which will ensure a reduction in air pollution in the municipality. Another significant trend is the gradual tightening of individual Euro emission standards and support for the sale of alternative propulsion vehicles by individual states [8]. There is direct and indirect support for alternative infrastructure, fuels, and vehicles, but this is not a sufficient incentive. As mentioned above, people do not like to limit themselves to their comfort, and a more accommodating approach to the issue requires different thinking of individual members of society. It is this equally important stimulus that is improved satisfaction with other modes of transport, which will ultimately ensure the greatest benefit to human health and the environment.

Acknowledgments

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Evaluation of the Baltic Sea Sound Speed Profiling Data for Ship's Underwater Noise Modelling

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Abstract

The sound speed data are needful for underwater sound and noise modelling and measurement in many types of application, including the definition of the shipborne noise spectral characteristics. The sound speed data are usually obtained while measuring it using the Conductivity-Temperature-Depth (CTD) probes. However, the *in-situ* measurements can be long-lasting and costly if automatic oceanographic stations are not available in the areas of interest. For this purpose the modelled sound speed profiling data can be used, that can be modelled applying well known empirical approximations if salinity-temperature-depth modelled data is available. The European Union data base called "Copernicus" provides various global data sets, including Baltic Sea salinity-temperature-depth data for any chosen location. In this paper the analysis of such data, obtained for Lithuanian area of the Baltic Sea, is presented. The applicability of this data for shipborne underwater noise modelling is discussed.
KEY WORDS: *Underwater noise, ships, modelling, sound speed data, Baltic Sea*

1. Introduction

The sound speed in the ocean environments is the function of temperature, salinity and pressure (depth). This function is usually not a constant with the depth. Typical deep sea sound speed profile can be divided in to the few layers: surface layer that is susceptible to daily and local heat changes and wind action; seasonal thermocline; main thermocline (under the seasonal one) and deep isothermal layer that extends to the bottom [1]. This generic sound speed profile of the ocean often is called the *Munk profile* [2].The sound speed of the deep layer increases with the depth due to the pressure effect on sound [1]. Still, these sound speed changes of the sea water column are mostly affected by the temperature variation of the water layers [3]. The sound speed changes of the sea waterbody will have a direct effect on the sound wave propagation. It is known form the *Snell's law* that the sound wave front (ray) traveling through the different layers of the medium will bend or refract towards the medium with the lower sound velocity. This feature makes the sound waves emanating from the sound source to refract while propagating in the horizontally stratified ocean and often to be trapped in the extended ocean layers (channels), that has the minimum sound speed at the mid depth of the channel or similar configuration [1]. In the shallow seas, the sound speed profiles has a great influence on the propagating sound waves, these are usually refracting downward (summer profiles) or are nearly constant over depth (*Iso-velocity profiles*), where the long-range sound wave propagation takes place exclusively via bottom-interacting paths [4]. While modelling sound propagation is completed for anthropogenic noise distributuion evaluation purposes the geometrical sound propagation models can be used, where the negligence of the sound speed profile variations and asumption of the Iso velocity profiles instead, can lead to some rate of errors in the desired results [5]. Improved geometrical models can be used along with the sound speed data [6] as well, the numerical models ussually incorporate the options that allows to use the sound speed data for sound propagation modelling as the model's input [7]. Often the sound speed data can be absent for some marine areas of particular interest. These data however, can be modelled if salinity and temperature modelling data is available [8]. For the Baltic Sea area the salinity and temperature data provided in the SMHI HIROMB model can be used to model the sound speed data that can be used to modell the ships spectral noise characteristics [9]. Although, oceanographic data time series in the data sets are often provided as the daily means [10]. The resulting sound speed data, that covers the daily means, can daviate from the real conditions slightly due to the daily (or even hourly) changes of the local sea surface conditions [1].

In this manuscript, we focus on the analysis of the ocenographic data, that can be used to modell the sound speed data needed for sound propagation modelling at Lithuanian arera of the Baltic Sea and the resulting sound speed data it self.

2. Methods

The sound speed profiling data (the daily means) for the period of 2019 (365+1 profiles) were retrieved from the SMHI Baltic Sea Physics Reanalysis Model [10]. The model provides the variables at 56 depth levels at any chosen location of the Baltic Sea: sea surface height variations, ice concentration and thickness, temperature, salinity, horizontal velocities (eastward and northward), bottom temperature, bottom salinity, mixed layer depth, although to obtain the SSP data the salinity and temperature data were of particular interest. The data was acquired for the hydrological survey measurement station No.20 at Lithuanian waters of the Baltic Sea at the location E20°48.0’ N55°38.0’ (WGS) (Fig 1).

Fig. 1 The location of the data acquisition (figure Google Earth®).

The sound speed data were computed using the model suitable for all Seas [8]:

$$C = 1402.5 + 5T - 5.44 \cdot 10^{-2} T^2 + 2.1 \cdot 10^{-4} T^3 + 1.33S - 1.23 \cdot 10^{-2} ST + 8.7 \cdot 10^{-5} ST^2 + 1.56 \cdot 10^{-2} Z + \\ + 2.55 \cdot 10^{-7} Z^2 - 7.3 \cdot 10^{-12} Z^3 + 1.2 \cdot 10^{-6} Z(\varphi - 45) - 9.5 \cdot 10^{-13} TZ^3 + 3 \cdot 10^{-7} T^2 Z + 1.43 \cdot 10^{-5} SZ \quad (1)$$

Where *C* is the sound speed in meters per second, *T* is the temperature in C° at different water depth *Z, S* is the water salinity PSU at different water depth, and *Z* is the water depth in meters, *φ* is latitude in degrees (at particular case 55°).

The sound speed profiling measurement data for comparison with the modelled SSP daily means were acquired for the same location for the dates of 2019-04-18, 08:11; 2019-05-22, 07:54 and 2019-08-21, 08:05 (UTC) using *in-situ* data collected with CTD probe equipped with sensors. During measurements sound velocity values are calculated based on UNESCO Svun-83 standard formula using temperature, pressure and salinity raw measurement data. Standard Data Acquisition Program „SST – SDA“ provided by the CTD probe manufacturer was used to process the data. To compare the resulting sound propagation errors for modelled and measured sound speed profiling data the Parabolic Equation (PE) RAMGeo sound propagation model was used, provided in the Acoustic Toolbox V2.2*l*[a] [7] in Matlab® software suit. The sound transmission losses were modelled for environments having the constant water depths (42 meters depth) and sediment thickness [11], the 20 km range, setting the noise source at 10 m depth and sound receiver at 29 meters depth. The sound transmission losses were modelled for 63 Hz frequency, where this frequency band represents the lower shipping noise frequency as intended to capture shipping noise minimising the contribution from natural sources and used as frequency for EU standard ambient noise monitoring [12].

The graphs were visualized using the Matlab® software.

3. Results

The analysis of the daily modelled sound speed data revealed (Fig. 2) the occurrence of the *Iso-velocity* profile during the winter season in 2019 and prominent negative sound speed gradient after the day 200 in the year. At the summer environmental conditions the sound speed at the sea surface reached the 1490 m/s and the sea bottom the 1430 m/s, the conditions that will result the sound waves to travel exceptionally as bottom bouncing in the Lithuanian area of the Baltic Sea [4].

The comparison of the modelled sound speed data results against the available in-situ measurements revealed slight deviations of the results either in spring and summer seasons. These results are provided in Fig. 3.

In Fig. 3 can be observed the deviation of the modelled results in the summer season with the hump in the 25 meters depth, where the difference in the sound speed reached 6.3 m/s. The obtained differences in the modelled and measured results in the summer season were of particular interest, i.e. how these differences can influence the sound transmission losses in the shallow area located at the Lithuanian marine waters. For this purpose the sound transmission losses were modelled and compared using the two different sound speed profiles obtained for 2019-08-21 using the model and in-situ measurements (see section methods). The sound transmission loss modelling (PE) results are provided in Fig. 4.

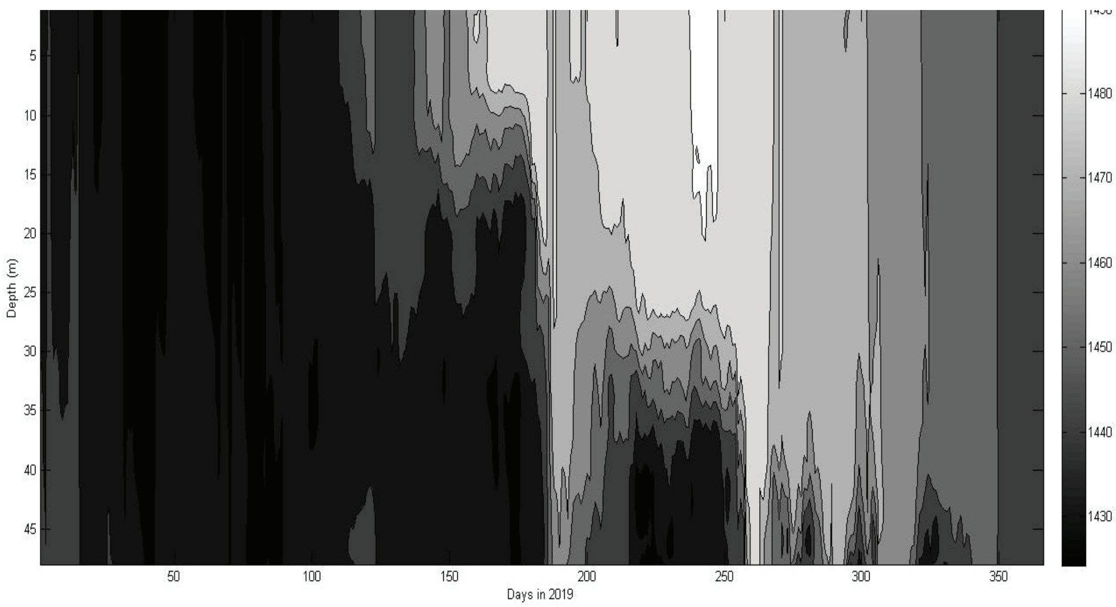

Fig. 2 Modelled daily sound speed variation in 2019. The colour bar represents sound speed in meters per second

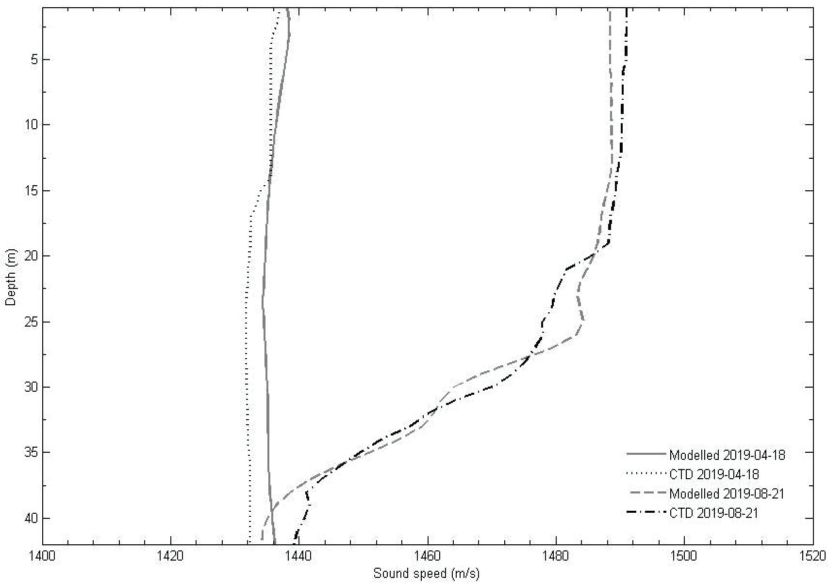

Fig. 3 Measured vs modelled sound speed data at the research location

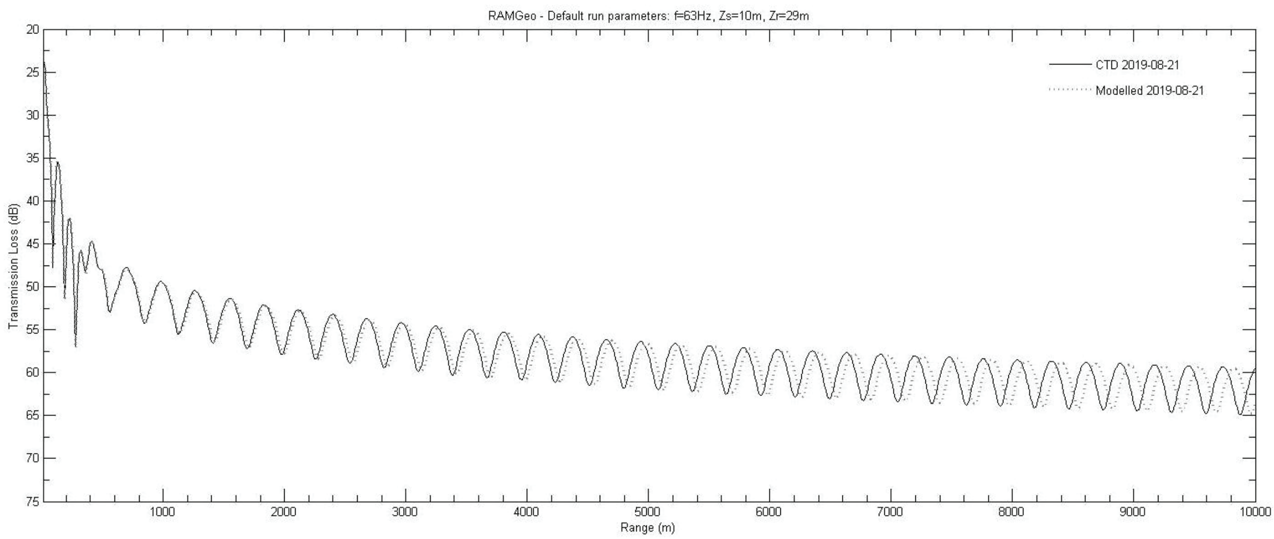

Fig. 4 Modelled sound transmission loss using the sound speed profile measured on 2019-08-21 and modelled for the same date (Figure: configuration- range 10 km, constant water depth 42 m)

In Fig. 4 can be seen the deviation of the sound transmission losses due to the difference of the sound speed profiling data modelled and measured in-situ. At 10 000 meters range the difference of sound transmission losses are observable in the graph. The deviations of the sound transmission losses modelled using two different sound speed profiling scenarios are plotted in Fig. 5.

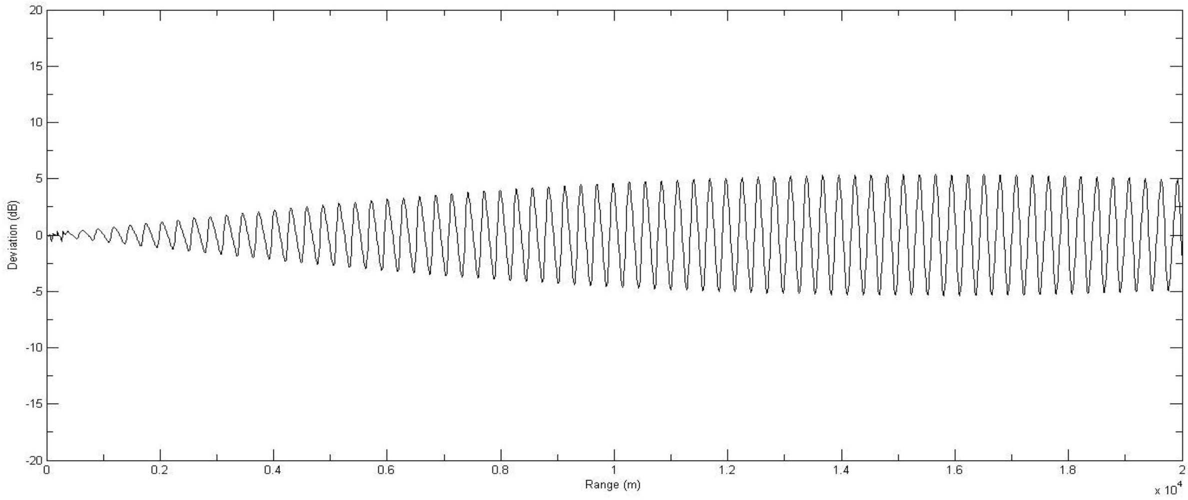

Fig. 5 Resulting deviation between sound transmission losses modeled using measured and modelled sound speed profiles for 2019-08-21 9Figure: configuration 20 km range)

It can be observed in Fig. 5 the deviation of modelled sound transmission losses reached the value of ~ 5 decibel at the range of 10 000 meters form the sound source and remained constant as sound propagates trough the water medium up to 20 kilometres.

4. Discusion

The sound speed profiling data for the research area was modelled using the model suitable for all seas including the Baltic Sea [8]. The modelling results revealed the prominent negative sound speed gradients in the warm water season, after the day 200, resulting with sound propagation conditions that result with sound wave bottom substrate interaction [4]. The obtained results of the sound speed profiling data along the sound transmission loss results further suggest that the modelled sound speed profiling daily average data can be used to model the shipping noise spectral characteristics. Although, some deviations of the modelled sound transmission loss data emerges due to the deviations of the modelled sound speed data from the real measurement data, that occurs due to the hourly changes of the water surface temperature and other oceanographic conditions. The deviation of the modelled sound transmission losses reached the value of ~5dB at the range of nearly 10 000 meters and remained constant at further distances.

Despite these obtained deviations of sound wave transmission losses the modelled sound speed data can be used to model spectral characteristics of the ship's noise [9]. For instance, some solutions of sound transmission loss models i.e. 2D x N and 3D models with azimuthal coupling if compared vs each other can have the deviations reaching the 15 decibel at ranges above the 20 kilometers [13]. The known deviations of sound speed modelled data if known, preferably should be noted when the ship's noise along with sound propagation loss is modelled.

5. Conclusions

The sound speed data for ship's noise modelling can be obtained from oceanographic data bases such as SMHI model and can be used in the Lithuania area of the Baltic Sea;

The modelled daily sound speed data deviates from the in-situ real measurements slightly;

The modelled sound speed data deviations from the real in-situ data produces some errors in the sound propagation modelling;

Despite the resulting errors of the sound transmission losses due to the modelled sound speed data, it can be stated that the modelled sound speed data can be used to model the ship's noise and its propagation losses at Lithuania area of the Baltic Sea.

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Life Cycle and Repairs of Military Mobile Equipment

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Abstract

The life cycle of a product is characterized by certain phases, which represent the period from its development to its decommissioning. The length and course of the life cycle cannot be determined in advance. The length and course of the product life cycle is different. Each technique that is introduced into the armed forces has its own focus and is exploited differently. The actual implementation of the life cycle system and subsequent application in a military environment is an extremely demanding and lengthy process. The most important thing in the whole implementation is the cooperation of individual components (sections) of the Ministry of Defense as well as other components of the ministries that are interested in the project. The more intensive the cooperation, the shorter the overall time of the introduction of military equipment and supplies into the armed forces and the better the defense capabilities of the armed forces in times of peace or war.
KEY WORDS: *life cycle, maintenance, repair, infantry fighting vehicle*

1. Introduction

The development of a new product begins with an idea, which then expands with other ideas needed to implement the production of a new product or modernize the original product (vehicle). The product is not sold at the given stage but is only being developed. At this stage, manufacturing companies are not yet profitable, but spending on R&D is increasing. Furthermore, these are the expenses necessary for the technical preparation and production of a prototype of, for example, an armored vehicle.

The development phase consists of the following phases [1]:

a) Preparatory phase (assesses how to secure the request);
b) Analytical phase (develops a proposal for an effective method of security);
c) Approval phase (translates the assignment to the Commission for discussion);
d) Implementation phase (develops a request to secure the throw).

The developer of the project proposal for a complex armored vehicle project will propose to carry out a feasibility study. The feasibility study consists of three parts: military - technical, economic and final part. In the military - technical part, the current state, possibilities of development and production, risks are analyzed. It also contains information on the use of the armored vehicle. In the economic part, financial requirements are addressed.

The final part contains a general summary and a recommended variant with a justification. After the elaboration of the feasibility study, it is submitted to the opponent's board [1].

After approval of the design for the armored vehicle project, the new project is registered in the armament plan and program plan. The National Armaments Director shall instruct the section employee or the project manager to draw up the project assignment for the armored vehicle. At the same time, it will issue methodological instructions in order to ensure the same procedure when performing work in a given phase [1].

2. Project Design

The developer of the project proposal for a complex armored vehicle project will propose to carry out a feasibility study. The feasibility study consists of three parts: military - technical, economic and final part. In the military - technical part, the current state, possibilities of development and production, risks are analyzed. It also contains information on the use of the armored vehicle. In the economic part, financial requirements are addressed.

The final part contains a general summary and a recommended variant with a justification. After the elaboration of the feasibility study, it is submitted to the opponent's board [1].

The design of the armored vehicle must include:

a) basic information about the project request;
b) general information about the applicant;
c) an overall summary of the proposed project;
d) a preliminary explanatory memorandum on the project;
e) project subject proposal;

f) proposal of the scope and outputs of the project itself;
g) proposal of tangible and property funds intended for the implementation of the project;
h) proposal of human and financial resources for the implementation of the project;
i) the basic boundaries of the project and the criteria needed for decision-making;
j) analysis of possible risks;
k) draft project plan in terms of time.

After approval of the design for the armored vehicle project, the new project is registered in the armament plan and program plan. The National Armaments Director shall instruct the section employee or the project manager to draw up the project assignment for the armored vehicle. At the same time, it will issue methodological instructions in order to ensure the same procedure when performing work in a given phase [1].

Accompanying documentation for the project output is supplied by the supplier, which is in Slovak language and contains [1, 2].

a) **vehicle training documentation** - basic data concerning the product (description of its function, diagrams and pictures of the product);

b) **vehicle operating documentation** –Description of product handling and description of basic types of treatments;

c) **repair documentation**- description of product diagnostics, technological procedures for repairs and use of special preparations, spare parts catalog;

d) **vehicle disposal documentation** - procedures and methods of carrying out the disposal of the vehicle with due regard for the environment;

e) **documentation on control and measuring techniques** - procedures and methods for checking and measuring individual vehicle parameters using a technician designated for that purpose;

f) **documentation for professional examinations and inspections -** procedures and methods of performing individual types of tests and inspections.

Repair documentation is necessary for repairs of military mobile equipment within the life cycle, the system of which must be thoroughly reworked, as they depend on the combat readiness of equipment and armaments of the armed forces.

3. System for Monitoring the Maintenance and Repair of Military Equipment

Within the Armed Forces of the Slovak Republic is an integrated SAP information system with various modules specifically for our department. Within this program, a "PM module" - Plant Maintenance is created, in which the operation, maintenance and repairs of ground armaments and equipment, materials and equipment of aviation and air defense equipment (hereinafter referred to as equipment) are planned and evaluated. The module manages, plans and evaluates planned, unplanned treatments and repairs of equipment, technical inspections and technical tests of dedicated technical equipment and, together with the PRETECH subsystem, ensures the use of equipment in operation.

3.1. BMP Repairs in 2017-2020

Within the life cycle of technology in the Armed Forces of the Slovak Republic, the service life of technology is set at 20 years. Despite the extensive modernization of the equipment of the Armed Forces of the Slovak Republic, a considerable part of the equipment after the service life and especially the belt equipment with an average age of about 30 years is also one of the key combat equipment. In track technology, we decided to pay attention to infantry fighting vehicles, as they have the largest representation in this category of vehicles with its modifications. In 2018, the BVP-1 and BVP-2 were replaced and upgraded to BMP-M, but only in smaller quantities [4].

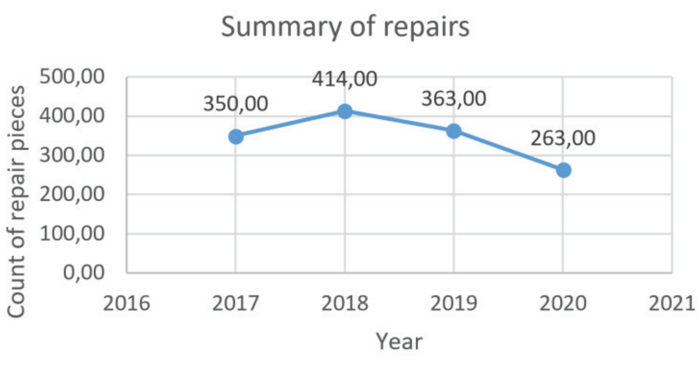

Fig. 1 Scope of treatments and repairs for the years 2017-2020

Maintenance reports based on the IIS SAP / PM environment served as source data for evaluating fixes. Individual reports were filtered after the years 2017 - 2020 in the following tables are converted from IIS SAP to Excel for the selected type of BVP chassis and its modifications in order to obtain information on the numbers and types of BVP treatments and repairs [3].

For the years 2017-2020, according to Table, the reports for the years 2017-2020 were filtered to compare the number of maintenance and repairs, which were summarized for individual years according to Fig. 1.

Table

List of BMP chassis reports for 2020

1	P.č.	Ohlasovate	Zodp.pracovis	Hlásení	Zákazka	Status (	Vybave	Označenie	Označenie	Sériové	Popis	Zmenené	Techn.m	Založené dň	Priorita
110	172		P211	30008028	310013	ÚTVA	1008547	2370 MT mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	9066847.	VO-AKB,BVP-2,2ksAKB150Ah,9066847,2.mr	18.05.2020	2370-00	17.03.2020	
111	10		P211	30008009	309993	ÚTVA	1008555	2370 MT mpr	VOZIDLO UVOĽŇOVACIE PÁSOVÉ VPV	8690917.	VO-AKB,BVPUPV,2ksAKB150Ah,8690917,rbz	18.05.2020	2370-00	11.03.2020	
112	120		20	20055001		5728	1005387	1046 NR mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8952026.	VO-BO BVP-2 8952026.	26.05.2021	1046-00	24.11.2020	
113	119		P212	20055000		JEDN	1005385	1046 NR mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8972954.	VO-BO BVP-2 8972954.	25.11.2020	1046-00	24.11.2020	
114	132		P213	20054199	10069922	ÚTVA	1007995	2207 LV mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8304917.	VO-BO- BVP-2,830 49 17, 2.mr	27.04.2021	2207-00	21.09.2020	
115	243		21-DTAPT	10034974	10065368	5728	1020693	5728 Martin ZZ II - CMM	TRANSPORTÉR OBRNENÝ PÁSOVÝ OT-90	7501199.	VO-BO- OT-90 - 7501199.	04.11.2020	5728-90	29.01.2020	
116	186		P610	20051588		ÚTVA	1020578	1037 MT Str. výcvi.,zab. a podpo.	VOZIDLO BOJOVÉ PECHOTY BVP-1	7502077.	VO-BO podvozok BVP1 7502077	13.04.2021	1037-06	18.03.2020	Stredná
117	189		P610	20051587		ÚTVA	1020601	1037 MT Str. výcvi.,zab. a podpo.	VOZIDLO BOJOVÉ PECHOTY BVP-1	8445728.	VO-BO podvozok BVP1 8445728	18.03.2020	1037-06	18.03.2020	Stredná
118	188		P610	20052152		ÚTVA	1020601	1037 MT Str. výcvi.,zab. a podpo.	VOZIDLO BOJOVÉ PECHOTY BVP-1	8445728.	VO-BO podvozok BVP-1 8445728		1037-06	23.04.2020	Stredná
119	263		P610	20052151		ÚTVA	1020706	1037 MT Str. výcvi.,zab. a podpo.	TRANSPORTÉR OBRNENÝ PÁSOVÝ OT-90	8592466.	VO-BO podvozok OT-90 8592466	06.05.2020	1037-06	23.04.2020	Stredná
120	9		11	20054056	10069768	8009	1010771	8009 MT Opravárenský prápor	VOZIDLO UVOĽŇOVACIE PÁSOVÉ VPV	9056545.	VO-BO UPV 905-65-45 únik nafty.	10.12.2020	8009-00	09.09.2020	
121	25		P213	20052366	10067531	JEDN	1007980	2207 LV mpr	VOZIDLO BOJOVÉ PRIESKUMNÉ BPSV	9037526.	VO-BO, BPSV, 9037526,vstek.čerpad, rbp	30.04.2020	2207-00	30.04.2020	
122	26		P213	20051970	10067090	JEDN	1007980	2207 LV mpr	VOZIDLO BOJOVÉ PRIESKUMNÉ BPSV	9037526.	VO-BO, BPSV, 9037526,vstek.čerpad, rbp	17.04.2020	2207-00	07.04.2020	
123	128		P213	20052403	10067599	JEDN	1007993	2207 LV mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	9030020.	VO-BO, BVP-2, 9030020,vstek.čerpad, 2mr	09.05.2020	2207-00	06.05.2020	
124	142		P213	20055118	10071444	ÚTVA	1008001	2207 LV mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8940278.	VO-BO, BVP-2,8940278, BCN, 2.mr	20.04.2021	2207-00	08.12.2020	Vysoká
125	118		11	20053892	10069887	8009	1005385	1046 NR mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8972954.	VO-BO, BVP-2,el.sústava, 8972954.	01.10.2020	1046-00	25.08.2020	Veľmi vysoká
126	117		21-DTAPT	20052739	10068320	5728	1005384	1046 NR mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8304948.	VO-BO, BVP-2,eletrická sústava,8304948.	12.08.2020	1046-00	27.05.2020	Veľmi vysoká
127	116		P212	20053079	10068507	JEDN	1005366	1046 NR mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8816823.	VO-BO, BVP-2,palivová sústava,8816823.	20.08.2020	1046-00	18.06.2020	
128	182		60	20052843	10068407	1007	1007190	1102 MI mpr	VOZIDLO BOJOVÉ PECHOTY BVP-1	8005135.	VO-BO, čerpadlo, BVP-1-8005135.	04.12.2020	1102-00	03.06.2020	Stredná
129	185		P610	20051208		ÚTVA	1020578	1037 MT Str. výcvi.,zab. a podpo.	VOZIDLO BOJOVÉ PECHOTY BVP-1	7502077.	VO-BO, elektro, BVP1, 7502077	13.04.2021	1037-06	20.02.2020	
130	62		14	20053993		8009	1083184	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9060623.	VO-BO, elektroinštalácia, BPsV-I,9060623	19.11.2020	1008-00	07.09.2020	
131	63		P229	20054459		ÚTVA	1083185	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9064144.	VO-BO, korba, BPsV-I, 9064144	14.01.2021	1008-00	08.10.2020	Vysoká
132	55		60	20054168	10069877	1007	1083174	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9035948.	VO-BO, nosná kladka BPsV-I,9035948	08.10.2020	1008-00	17.09.2020	
133	36		60	10037336		1007	1083173	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9035258.	VO-BO, oprava po výc., BPsV-I, 9035258	03.02.2021	1008-00	23.10.2020	
134	57		P229	20054454		ÚTVA	1083176	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9041743.	VO-BO, oprava po výc., BPsV-I, 9041743	14.01.2021	1008-00	08.10.2020	Stredná
135	42		60	10037337		1007	1083177	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9041767.	VO-BO, oprava po výc., BPsV-I, 9041767	04.03.2021	1008-00	23.10.2020	
136	60		P229	20054460	10070347	JEDN	1083180	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9058178.	VO-BO, oprava po výc., BPsV-I, 9058178	08.10.2020	1008-00	08.10.2020	
137	89		P212	10035986		JEDN	1005388	1046 NR mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8302409.	VO-BO, TO č.2 , BVP-2 8302409.	10.11.2020	1046-00	25.05.2020	
138	73		P212	10036118	10068206	JEDN	1005371	1046 NR mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8866905.	VO-BO, TO č.2 ,BVP-2, 8866905.	20.08.2020	1046-00	03.06.2020	
139	56		60	20050658	10065478	1007	1083176	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9041743.	VO-BO, uv. spoj. komp., BPsV-I, 9041743	03.03.2020	1008-00	24.01.2020	
140	61		60	20050656	10065479	1007	1083181	1008 PO prápor ISTAR	VOZIDLO BOJOVÉ PRIESKUMNÉ	9058387.	VO-BO, výmena gufera, BPsV-I, 905 83 87	18.02.2020	1008-00	24.01.2020	Veľmi vysoká
141	27		P211	20054340	10070167	ÚTVA	1008520	2370 MT mpr	VOZIDLO BOJOVÉ PRIESKUMNÉ BPSV	9096060.	VO-BO,BPsV,hadica paliva,9096060rbp	20.10.2020	2370-00	30.09.2020	
142	187		P610	20053395	10069165	ÚTVA	1020592	1037 MT Str. výcvi.,zab. a podpo.	VOZIDLO BOJOVÉ PECHOTY BVP-1	8862220.	VO-BO,BVP-1,palivová sústava,8862220	06.08.2020	1037-06	15.07.2020	Stredná
143	16		P213	20054949	10071073	ÚTVA	1007981	2207 LV mpr	VOZIDLO BOJOVÉ VELITEĽSKÉ BVP-1 K	8448253.	VO-BO,BVP1K,8448253,AKB,rbz	31.03.2021	2207-00	12.11.2020	
144	147		P213	20052364	10067529	JEDN	1008004	2207 LV mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8304753.	VO-BO,BVP-2, 8304753, vstrek cerpadlo	30.04.2020	2207-00	30.04.2020	
145	138		P213	20052363	10067528	JEDN	1007997	2207 LV mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8304986.	VO-BO,BVP-2, 8304986, vstrek cerpadlo	30.04.2020	2207-00	30.04.2020	
146	151		P213	20053225	10068692	ÚTVA	1008005	2207 LV mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8949561.	VO-BO,BVP-2, 8949561,PSU,1.mr	17.07.2020	2207-00	01.07.2020	Vysoká
147	125		P213	20052729	10068016	ÚTVA	1007990	2207 LV mpr	VOZIDLO BOJOVÉ PECHOTY BVP-2	8950239.	VO-BO,BVP-2, 8950239,riadenie,1.mr	06.05.2021	2207-00	26.05.2020	Vysoká

After evaluating the data in the tables for individual years, we decided to pay attention to the motor group and its subgroups due to the occurrence of the most common failures in this group. The repairs of the engine group are the most extensive in terms of the extent of the repair, since in engine repairs in most cases the engine mounting block with a gearbox is removed from the body of the vehicle (Fig. 2).

Fig. 2 Repair of the BVP engine group

During our working career, we have experienced that about 90 percent of BMP had after the initial defect a failure in the engine part such as leaks in cylinder heads, cooling and lubrication system, leaks in fuel system and injection pump, exhaust system, etc., which eventually exceeded repairs exceeded the repair by more than 200 normhours. After filtering and sorting the data of the generated reports on the BMP technique and its modifications, we can see in Fig. 3 the number of selected types of corrections for the years 2017-2020.

The above graph shows that the largest types in terms of quantity are individual types of technical treatment, non-military repairs, advertising and modernization of equipment, which are performed by suppliers from the civil sector and treatments least demanding on the length of treatment and repairs. Other repairs belonging to the more numerous are repairs of chassis and engine parts of BVP. We consider these groups to be the most important in order to maintain the highest possible combat readiness and mobility of combat equipment in the field and during combat operations. In the event of failures of the mentioned groups, the vehicle becomes immovable and the vulnerability of the vehicle crew increases. In order to increase the reliability of the technology, it is therefore important to maintain the best possible preparation of the vehicle for the given type of activity with the necessary actions to prevent the occurrence of possible vehicle failures.

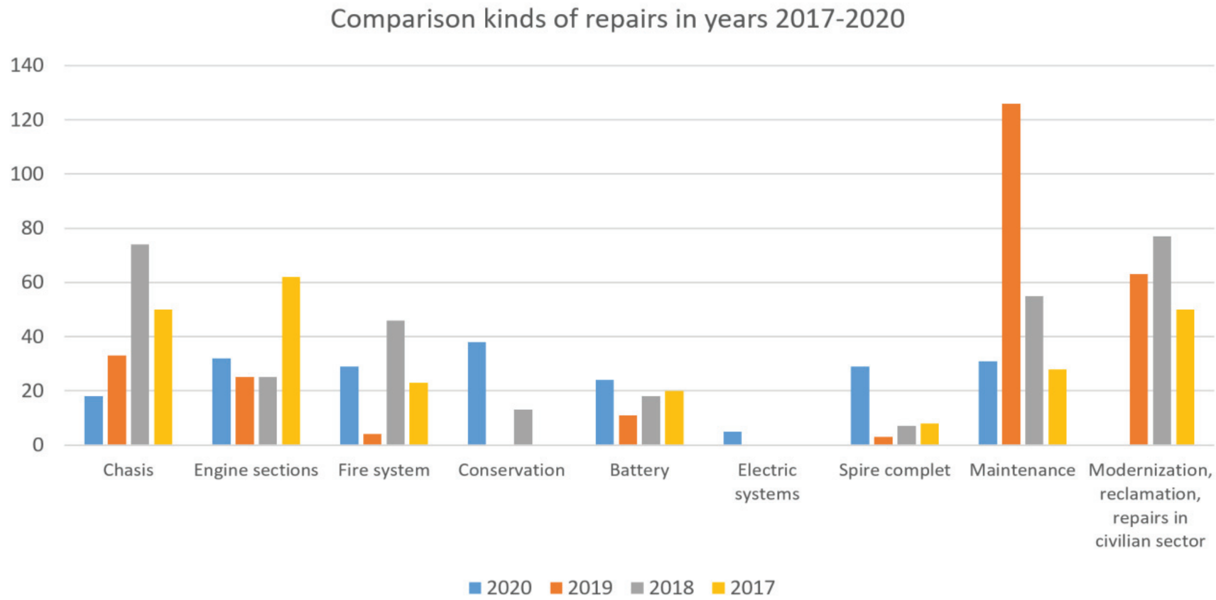

Fig. 3 Comparison of repairs of groups of BVP vehicles for the years 2017-2020

4. Conclusions

The prediction of failures of chassis, engine groups as well as other groups of military mobile equipment will increase reliability, combat capability and subsequently prolong the life cycle of the type of equipment. In order to create an algorithm for predicting vehicle failures, it is necessary to analyze the data on vehicle repairs for the longest possible period, which occurs after the departure of a certain number of operating units or after the use of a vehicle with an increased load. The longer the period of use of the technique we will check and obtain the necessary data, the more accurate will be the prediction of possible failures, treatments, maintenance, repairs before using the technique in the given conditions or after the departure of a specified number of operating units. The resulting higher reliability of the operation of the equipment, its combat readiness and, last but not least, the extension of the life cycle.

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Methods of Determining the Position of the Train

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Abstract

This paper proposes methods for positioning a train on a railroad track. Traditional ones based on railroad infrastructure will be presented. Satellite ones based on signals from GNSS satellite systems and radio ones using 3G, 4G (Long-Term Evolution) and 5G technologies. Operational problems of these systems and the concept of using radio communication systems based on 5G technology will be discussed. The possibility of using Kalman filtering for estimation of train position measurements on the railroad track will also be presented. The problems of Time of Arrival (TOA) and Angle of Divergence (AOD) measurements, which are estimated from the beams formed in the radio-communication channel and the will be presented problems of synchronization of radio transmission with GNSS signals. GSM-R equipment is fast approaching the end of its shelf life and is expected to become obsolete by 2030. The International Union of Railways (UIC) sees FRMCS as the key element to support the digitalisation of railways, while cellular services will maintain their role in connecting the train to the wayside. The technology is currently being finalised and is due for its first trials in 2023, with the wider migration of the service targeted between 2025 and 2035.
KEY WORDS: *Telematics, GNSS, LTE,GSM-R, 5G*

1. Introduction

Train control systems currently in use are built to complement the conventional structure formed by signal boxes, which means that train localisation and train completeness control is performed by fixed devices such as track circuits or axle counters. State-of-the-art train control systems are designed to realize the function of block spacing localization and train completeness control in the train itself, which greatly simplifies and reduces the fixed devices installed in the track [14]. Therefore, the efficiency and flexibility of train interaction systems depends on the method of data transmission between the trackside equipment and the train [4, 5 11]. It can be point-to-point i.e. for a limited time when the train passes over the corresponding equipment installed in the track, or continuous i.e. with uninterrupted communication between the train and the fixed equipment. Apart from the old, technically uncomplicated systems of point interference with a train, today we have at our disposal systems of information transmission with high binary flow and low probability of wrong decision, and we have access to systems of precise location of stationary and moving objects, by receiving and processing signals sent by these systems. Such systems include track circuits with Balises and modern counter systems for track and turnout unoccupancy detection as well as satellite systems supported by GSM-R, 4G or 5G wireless communication system [1-3, 6, 7, 10].

2. Localization with the Use of ETCS GPS i GSMR, 4G and 5G

The right localization of vehicles in the line is particularly important from the railway traffic control point of view as well as from information destined for passengers. These factors determine the division into the applications requiring high safety level and applications not requiring high safety level for example those serving to inform passengers. The localization of the train is realized by axle counters as well as the modern methods using in ETCS systems and exploiting Eurobalis and odometers [8, 9]. The localization method basing on GSM, 4G and 5G technology is also known:

- COO method (Cell Of Origin);
- EOTD method;
- AOA method (Angle Of Arrival);
- A-GPS method (Assisted GPS);
- TOA method (Time Of Arrival).

However, localization methods of ETCS system are more accurate what implies the application of this system into the railway traffic controlling system. Localization methods basing on GSM standard are used to coarse localization and to trace the goods carried by railway transport. The system advantage is its multi-functionality, what means the localization is one of many services provided by this system. Additionally, this system does not require special interfaces. The determination of the position is carried out without participation of devices being installed in the vehicle.

The most famous positioning systems are those basing on the satellite navigation and GPS system. This system is used to manage and trace trains and goods. GALILEO is the most prospective navigation system. In railway transport, GALILEO is foreseen to concatenate controlling functions with supervising functions and increase the safety basing on ERTMS/ETCS systems. High safety requiring in railway transport can be achieved by the usage of signals coming from GALILEO system along with other sensors installed in vehicles such as kilometer counters, balises and gyroscopes. The introduction of satellite navigation in European railway lines (ETCS)/ERTMS can mainly improve the traffic efficiency in trunk lines and decrease the cost in the local lines [9, 15, 16, 17].

GALILEO could boost the safety in railway lines, particularly in areas not being fitted with wayside devices. Changing requirements concerning railway traffic cause that no all countries can afford to control the railway traffic through modern railway traffic controlling systems. Many lines are not prepared to automatic train control. The introduction of GALILEO system in railway transport allows for:

- Management of trains and goods;
- Management of information for passengers;
- Optimization of energy consuming;
- Creation of timetables.

Of course, the GALILEO functionality is the same as GPS functionality. It is necessary to point out that GALILEO will offer more precise navigation service and rescue service SAR than presented systems.

However, advantages of GALILEO system should not be overestimated. Hybrid concatenation of GALILEO system with GNSS system seems to be the prospective solution. Hybrid positioning the train in ETCS with the use of precise GNSS signal is achieved by:

- High accessibility and precision of GNSS signal
- Temporary deterioration in positioning quality- reflection of satellite signals (tunnels, forests, mountains) is supplemented by additional sensors:
  - odometer – distance and speed;
  - Doppler's radar;
  - acceleration meter;
  - angular speed meter;
- Electronic map of the track.

The presented Fig. 1 shows the algorithm of the cooperation of on-board ETCS devices with GNSS system. Additionally, parameters achieved by hybridization are also presented.

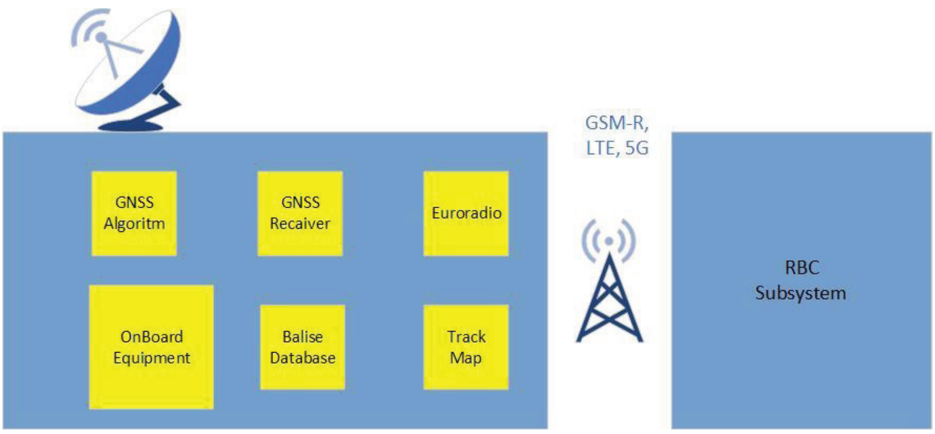

Fig 1. Absolute Positioning – Architecture

2.1. A Classical Method for Determining Spatial Orientation in Means of Transport

The method using the aforementioned satellite systems makes it possible to determine the spatial orientation on the basis of measurements of phase differences of signals induced in several receiving antennas, arranged in a specific spatial configuration on the measuring object. The phase shift of signals broadcast by a satellite and received by two distant antennas, related to the distance between these antennas, is proportional to the angle contained between: the straight line formed by these antennas and the straight line formed by the antenna and the satellite (Fig. 2).

$$d\varphi_a^k = S_a^k X_a - N_a^k + \upsilon_a^k \,, \tag{1}$$

where $d\varphi_a^k$ – phase differences of the signals induced in the antennas, defining the base A, from the satellite k; X_a – base vector (vector between the antennas); S_a^k – unit vector located on the satellite-antenna line; N_a^k – number of occurrences of the carrier wave periods (lengths); υ_a^k – interferences arising in the transmission channel and noise of the receiving system.

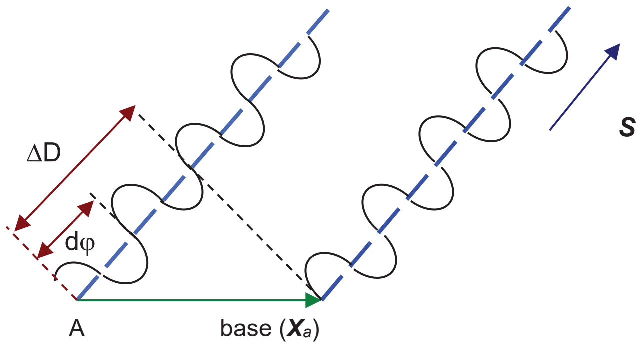

Fig. 2 Phase difference of signals received by two antennas from one satellite k

The knowledge of these angles (at least from two satellites) allows to determine the values of roll or pitch and yaw of the segment formed by the antennas (at least three) used for measurements. Installation of an array of antennas and a specialized receiver of signals from satellites on board the object, allows to determine the roll, pitch and yaw angles of the object.

Measurement of the phase difference of the carrier signal from the Galileo system, although having better parameters than from the GPS system, can nevertheless be burdened with a number of errors whose sources should be sought not only in the type of the signal propagation medium (e.g. ionosphere, troposphere), but also in the accuracy of the receiver clock, the geometry of antenna arrangement, antenna vibrations, differences between the actual distance of antennas and the electrical distance of those antennas. Errors in determining the spatial orientation by methods using the Galileo system are also dependent on the satellite constellation used for measurements.

In the currently used solutions, the determination of the spatial orientation on the basis of the indirectly measured distance difference (Fig. 2) at a known distance between the antennas $\|X_a\|$ "base" and the unit vector of the satellite S^k is realized by minimizing the sum of squares of the quality function values:

$$J(A) = \sum_{a=1}^{m}\sum_{k=1}^{n}\left(\Delta D_a^k - X_a^T A S^k\right), \qquad (2)$$

where ΔD_a^k – difference of distances from antennas forming the base A to the satellite k; m – number of bases used in the process; n – number of satellites used in the process; X_a^T – the base vector (between antennas) described in the coordinate system associated with the object; S^k – the unit vector of the satellite described in the local horizontal coordinate system $S^k = [S^x; S^y; S^z]T$; A – spatial orientation transformation matrix from the local horizon coordinate system to the object related coordinate system.

The realizations of the process of determining the spatial orientation currently used with the use of GPS signals [13] are based on multiple measurements and determining on their basis the averaged values of roll, pitch and yaw angles (Fig. 3).

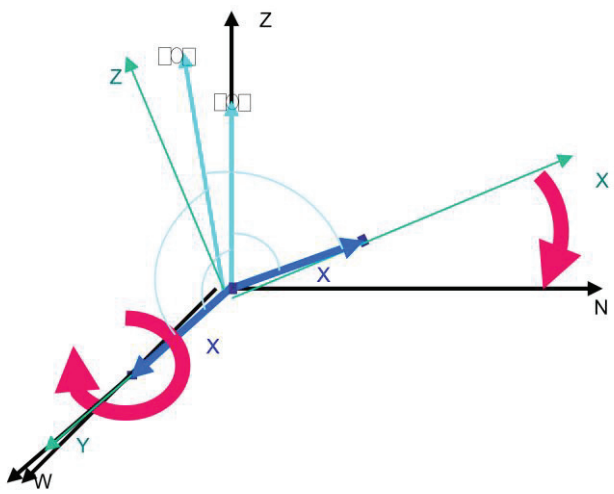

Fig. 3 Physical interpretation of the process of the classical method of determining spatial orientation

It follows from the above that the reduction of errors takes place in the process of solving the task of determining the angles of roll, pitch and yaw, and not at the stage of signal processing. Therefore, it seems reasonable to apply solutions in the area of processing the signals received from satellites allowing the reduction of interference associated with the propagation of electromagnetic waves and errors arising in the measurement process, in order to improve accuracy and increase the dynamics of determination of spatial orientation.

2.2. Use of Kalman Filtering and Mobile Communication Technology to Improve the Accuracy of Train Setting Using GNSS Technology

The Kalman filter is a recursive algorithm which determines a minimum-variance estimate of the state vector of a linear model of a discrete dynamic system, based on measurements of the output and input of this system. The advantage of this type of filtering is that there is no need to store a large number of historical measurement data in the system memory and to repeat previously performed arithmetic operations. Based on a known model of the system, the Kalman filter evaluates the state of the system at each time step, then receives feedback through measurements that are subject to errors. The operation of a Kalman filter consists of two stages: prediction and correction. In the prediction phase, the current state of the system and the covariance matrix are propagated from step *k*-1 to step *k*. In the correction phase, the measurements are used to update the previous estimates, thus improving the last estimate.

The Kalman filter algorithm consists of the following steps [12]:

Step 1: Process initialization.

He initial values of the state vector $\hat{x}_0$ and the covariance matrix P_0 should be estimated. Estimation of these values results from the assumed model of initial conditions. The initial values of the process disturbance covariance matrix Q_0 and the measurement error covariance matrix R_0 should also be estimated. This is done on the basis of previous experience with the system.

Step 2: Prediction.

The state transit matrix Φ s determined, and then the value of the state vector $\hat{x}_k(-)$ from step *k*-1 to step *k* is determined using this matrix.

$$x_k(-) = \Phi_{k|k-1}\hat{x}_{k-1}(+). \tag{3}$$

The predicted value of the error covariance matrix is then determined P_k, which is based on the determined state transition matrix Φ and on the error covariance matrices determined in the previous step (*k*-1) $P_{k\text{-}1}$ and covariance matrix of the discrete process disturbances $Q_{k\text{-}1}$.

$$P_k(-) = \Phi_{k|k-1}P_{k-1}(+)\Phi^T_{k|k-1} + Q_{k-1}. \tag{4}$$

Step 3: Correction.

The Kalman gain matrix is determined, which depends on the (a priori) predicted error covariance matrix $P_k(–)$, from the observation matrix H_k and on the covariance matrix of measurement errors R_k.

$$K_k = \frac{P_k(-)H_k^T}{H_kP_k(-)H_k^T + R_k}. \tag{5}$$

Based on the determined Kalman gain and information from measurements and observations, the corrected value of the state vector is determined $\hat{x}(+)$.

$$\hat{x}_k(+) = \hat{x}_k(-) + K_k\left[z_k - H_k\hat{x}_k(-)\right]. \tag{6}$$

In the next step the (a posteriori) corrected error covariance matrix is determined $P_k(+)$, influenced by Kalman amplification K_k, the observation matrix H_k and the error covariance matrix $P_k(–)$ determined at the prediction stage.

$$P_k(+) = P_k(-) - K_kH_kP_k(-). \tag{7}$$

Step 4: Looping the filtration process.

After passing through the stages described in turn, the system is looped. The a posteriori relations of the state vector determined in the above way $\hat{x}(+)$ and error covariance matrix $P(+)$ will be a priori estimates for the determined values of the state vector $\hat{x}(-)$ and the error covariance matrix $P(–)$ in the next step.

The Kalman filter uses all available measurements (also from the noisy environment) regardless of the accuracy and precision with which they were taken. On their basis it makes the best estimation of the state vector. The described filter uses a recursive type algorithm, so it does not store all past data and does not recalculate them in every traffic jam. The information is processed successively, based on the values calculated in the previous step. By knowing the input and output of the system, unavailable (unmeasurable) values can be derived from available (measurable) data, e.g. from different sensors.

The use of Kalman filtering and position measurements using cellular technology in GNSS satellite receivers improves the positioning accuracy of moving objects, which include the train. The above-mentioned features of the Kalman filter make it an optimal estimator in e.g.: the method of train continuity control, moving block spacing, or radio visibility driving with the addition of GSM-R, 4G, 5G technology.

3. Conclusions

The train positioning systems play a big role both in safety boosting and in the logistic means of transport. Wayside positioning systems are vulnerable to devastation what makes systems based on GSM and GNSS have the advantage. The usage of additional signals from assisting sensors along with GNSS allows for safe positioning of the train. Solutions based on GNSS are particularly attractive for local lines, where the maintenance of wayside infrastructure is very expensive. Imperfections in positioning the train (reflections) can be suppressed by the application of special filters, for example, Kalman filter. However, all these actions should be preceded by standardizing and certification procedures. It should be pointed out, institutions responsible for the introduction of modern technologies are willing to purchase satellite systems. The investigations do not only concern already existing systems (GPS, GLONAS), but also focus on the systems (GALILEO). We hope elaboration and devices realizing in projects trig widespread application of satellite technology in railway transport, which in turn increases its safety and reliability.

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To the Calculation of Heat Transfer During Steam Condensation in Heat Exchanger Pipes of the Diesel Locomotive Engine Cooling System

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Abstract

The article provides some of the best-known calculation dependencies to define the heat transfer coefficient during condensation inside the pipes, as well as analyzes the convergence of their results when applying the same initial data. As a result of the calculations of the required heat exchange surface of the condensers, there is a significant discrepancy in the results obtained. It was found that the calculated dependences obtained by different scientists differ significantly from each other.
KEY WORDS: *heat transfer coefficient, condensation, steam, pipes, calculation, error*

1. Introduction

The application of phase transitions in the diesel locomotive engine cooling system is possible and promising, while the use of conventional radiator sections as steam condensers is possible and has advantages over radiators with round tubes [1, 2].

Condensation inside heat-exchange apparatus pipes is a common process in refrigerating appliances, energetics and transport. As part of designing new equipment, one frequently assigns a task to calculate the required surface of heat-exchange apparatuses – condensers. With the development of the mathematical model and calculation dependencies of heat exchange processes being a complicated and time-consuming task, the most appropriate way is to use off-the-shelf mathematical tools created earlier by other scientists. Besides, engineers will be able to choose among several experimentally proven calculation dependencies.

Despite the permanent nature of heat exchange processes during condensation inside the pipes, calculation dependencies for determining the heat transfer coefficient were derived by several scientists independently of each other given various mathematical formulations of initial conditions. Therewith, calculation dependencies obtained by different scientists substantially differ from each other.

As film condensation occurs in the majority of heat-exchange apparatuses, the article does not examine drop condensation. Provided calculation dependencies involve two condensation cases:

a) motive steam with the condensate film laminar flow;
b) motive steam with the condensate film turbulent flow.

Both cases examine the once-through circulation of vapor and condensate.

Steam condensation in the pipe results in the pressure and volume change (related to phase transition), which causes absorption of steam. Thus, steam is unable to remain motionless and is always in motion.

2. Research Analysis

Heat exchange during condensation was investigated for the first time by W. Nusselt [3], one of the founders of heat exchange fundamental pillars, at the beginning of the 20th century. W. Nusselt derived a general criterion for all heat exchange processes:

$$N_u = \frac{\alpha \cdot d}{\lambda_c} \Rightarrow \alpha = \frac{N_u \cdot \lambda_c}{d}, \quad (1)$$

where N_u – the Nusselt number; α – an average heat transfer coefficient from steam to pipe walls; λ_c – a heat conduction coefficient; d – a pipe inner diameter.

Index *«c»* indicates the belonging of values to liquid (condensate).

Problems formulated by Nusselt W. were revised and solved by Hartmann H. [4]. According to his theory, the heat transfer coefficient during steam condensation inside the pipes for a) and b) cases can be found out using the formulas:

$$N_u = 0,28 \cdot \mathrm{Re}_s^{0,6} \cdot \left[\mathrm{Pr}_c \cdot \frac{d}{l} \cdot \frac{\rho_s}{\rho_c} \cdot \left(\frac{v_s}{v_c} \right)^2 \right]^{\frac{1}{3}}, \tag{2}$$

where l – length of the pipe; ρ – density; v_c – kinematic viscosity; Re is the Reynolds criterion:

$$Re_s = \frac{4 \cdot G_m}{\pi \cdot d \cdot \mu_s}, \tag{3}$$

where G_m – the mass flow rate; μ_s – the dynamic viscosity:

$$\mu_s = \frac{r}{c_c \cdot (T_b - T_w)}, \tag{4}$$

where r – specific heat of evaporation; c_c – heating capacity; T_b – condensation (boiling) temperature; T_w – wall temperature; Pr – the Prandtl number:

$$Pr_c = \frac{c_c \cdot \mu_c}{\lambda_c}. \tag{5}$$

Indices *«s», «c», «m»* indicate the belonging of values to steam, liquid (condensate) and mixture.

Later on, based on the above-mentioned theory, V.P. Isachenko specified and transformed the formulas [5], obtaining the calculation dependence for both a) and b) cases. Therein, the Nusselt number is calculated due to the formula:

$$Nu = C \cdot Re_c^{0,8} \cdot Pr_c^{0,43} \cdot \frac{1}{2} \left[\sqrt{1 + x_1 \cdot \left(\frac{\rho_c}{\rho_s} - 1 \right)} + \sqrt{1 + x_2 \cdot \left(\frac{\rho_c}{\rho_s} - 1 \right)} \right], \tag{6}$$

where C – a proportionality coefficient (for steel pipes $C = 0.024$; for copper pipes $C = 0.032$); Re – the Reynolds criterion that can be calculated using the formula:

$$Re_c = \frac{4 \cdot G_m}{\pi \cdot d \cdot \mu_c}, \tag{7}$$

where Pr – the Prandtl number that can be calculated using the formula (5); x_1, x_2 – mass consumable steam content in entry and exit sections of the pipe:

$$x = \frac{G_s}{G_c}, \tag{8}$$

Well-known scientist Wong H. included the following formula to calculate the heat transfer coefficient for a) and b) cases in his collection [6]:

$$N_u = 0,065 \cdot \left[\frac{c_c \cdot \rho_c \cdot d^2 \cdot f}{2 \cdot \lambda_c \cdot \mu_c \cdot \rho_s} \cdot \frac{u_{s\_1}^2 + u_{s\_1} \cdot u_{s\_2}}{3} \right]^{\frac{1}{2}}, \tag{9}$$

where the values of liquid properties are taken at the temperature:

$$T_s = \frac{1}{4} \cdot T_b + \frac{3}{4} \cdot T_w, \tag{10}$$

u_s – the mass rate of steam:

$$u_s = \frac{4 \cdot G_s}{\pi \cdot d^2}. \tag{11}$$

Indices *1, 2* indicate values at the pipe entry and exit.

f – a coefficient of friction of liquid film and pipe walls:
for case a):

$$f = 0,664 \cdot Re_c^{-\frac{1}{2}}; \tag{12}$$

for case b):

$$f = 0,059 \cdot \mathrm{Re}_c^{-\frac{1}{5}}, \tag{13}$$

Re – the Reynolds criterion that can be calculated using the formula (3).

F. Crate and W. Black [7], as well as A.V. Bolgarsky, G.A. Mukhachev and V.K. Shchukin [8], suggested that to calculate the heat transfer coefficient for a) and b) cases, one could use the same formula as for condensation on the vertical plate:

$$\alpha = 0,942 \left[\frac{\rho_c \cdot (\rho_c - \rho_s) \cdot g \cdot \left(r + \frac{3}{8} c_c \cdot (T_b - T_w) \right) \cdot \lambda_c^3}{\mu_c \cdot l \cdot (T_b - T_w)} \right]^{\frac{1}{4}}, \tag{14}$$

where *g* – acceleration of gravity.

That, in case of motive steam given the friction, transforms into the formula derived by E.P. Ananiev, G.N. Kruzhylin and L.D. Boyko:

$$N_u = 0,023 \cdot Re_s^{0,8} \cdot Pr_c^{0,4} \cdot \sqrt{1 + x \cdot \left(\frac{\rho_c}{\rho_s} - 1 \right)}, \tag{15}$$

where *x* – mass consumable steam content in the examined section.

As the maximum intensity of heat transfer can be observed at the pipe entry, and steam content transformation due to pipe passing changes according to the parabolic law, one can apply:

$$x = \frac{1}{3} \cdot x_1 + \frac{2}{3} \cdot x_2, \tag{16}$$

to find out the average in pipe length value of the Nusselt number using the formula (15).

According to recommendations by M.A. Mikheev and I.M. Mikheeva [9], one can use the following formulas to calculate the heat transfer coefficient for a) and b) cases:

$$N_u = \left[0,021 \cdot Re_c^{0,8} \cdot Pr_c^{0,43} \cdot \left(\frac{Pr_c}{Pr_w} \right)^{0,25} \right] \cdot \varepsilon \cdot \frac{1}{2} \cdot \left(\sqrt{\frac{\rho_c}{\rho_{m1}}} + \sqrt{\frac{\rho_c}{\rho_{m2}}} \right), \tag{17}$$

where *Pr* – the Prandtl number of liquid at the temperature T_c, which is calculated similarly to the formula (5); ε – a correction coefficient taking into account the change in the average heat transfer coefficient along the pipe length:

$$l/d > 50 \Rightarrow \varepsilon = 1. \tag{18}$$

It is obvious that the above-mentioned formulas defining the heat transfer coefficient during steam condensation inside the pipes substantially differ from each other. It can mean discrepancies in their results.

3. Research Results

To find out the precision of the results obtained using formulas (2), (6), (9) (15) and (17), one carried out the calculation and compare the results. Calculations involved the value of the pipe inner diameter: $d = 0.01$ m (10 mm). Condensation temperature: $T_b = 100$°C, wall temperature: $T_w = 98$°C. The value of steam mass flow G_{s1} at the pipe entry was set in the range of $1 \cdot 10^{-5} \ldots 0.05$ kg/s, corresponding in this case to the value $Re_s = 106.5 \ldots 5.3 \cdot 10^5$ according the formula (3). Obtained values of heat transfer coefficients are displayed on the graph $\alpha = f(Re_s)$.

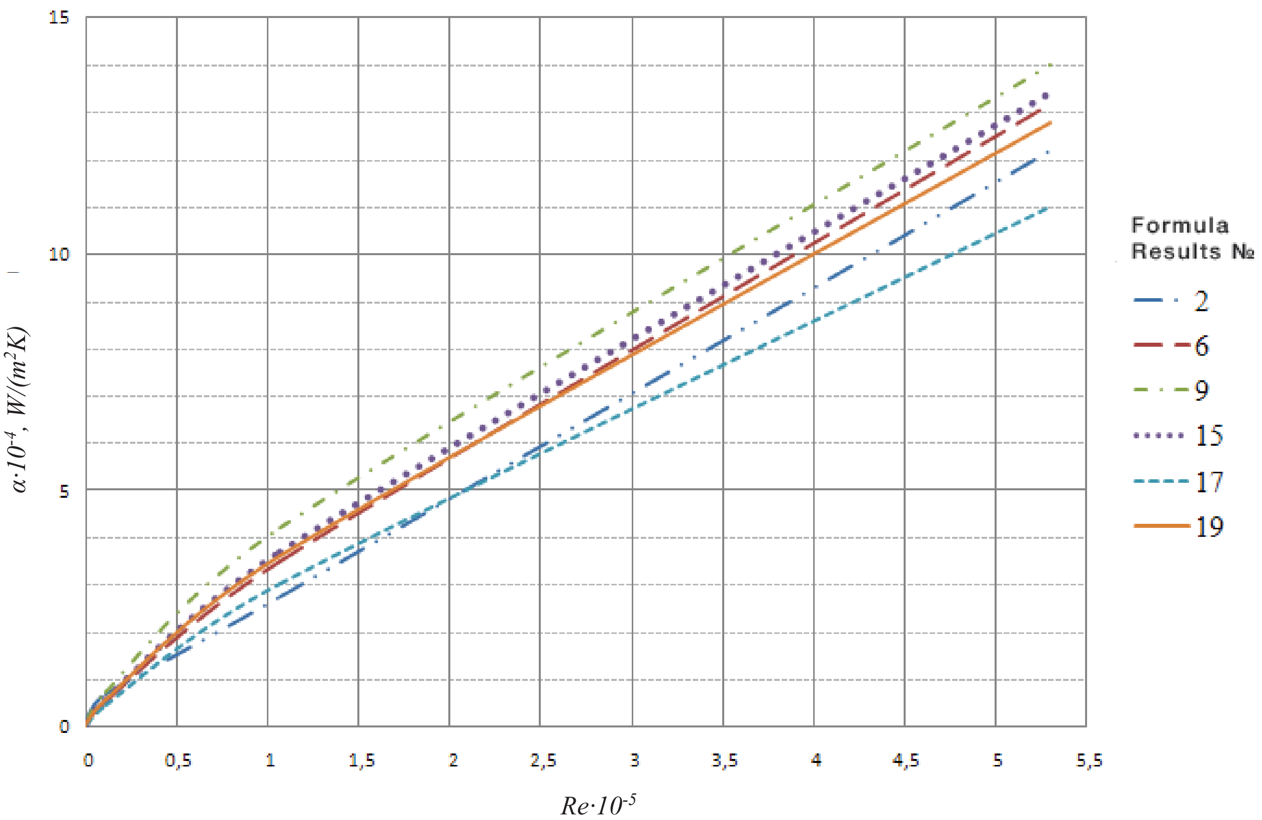

Fig. 1 Graph of the dependance of heat transfer coefficient α during steam condensation inside the pipes on the Reynolds criterion of steam Re_s

To assess the results Fig. 1 also shows averaged values of heat transfer coefficient α_a – calculated using the average arithmetical value formula [10]:

$$\alpha_{ai} = \frac{1}{n} \cdot \sum_{j=1}^{n} \alpha_{ij}, \tag{19}$$

where i indicates the dependence of α on Re_s; j − the number of the calculation formula option for α; n – the amount of calculation formula options for α.

To define the average deviation of values of heat transfer coefficient α obtained using formulas (2), (6), (9) (15) and (17) from the value of heat transfer coefficient α_a, one applied the average linear deviation formula [10]:

$$\Delta\alpha_{ai} = \frac{1}{n} \cdot j = 1\sum^{n} \left|\alpha_{ij} - \alpha\right|, \tag{20}$$

where $\Delta\alpha_i$ is the average linear deviation depending on Re_s.

The maximum value of the average linear deviation of the heat transfer coefficient reaches ±23.4% while the averaged one is similar to the formula (19) – ±14.08% (the ± sign is given for illustration purposes and means the deviation to both sides).

Note the fact that some of the above-mentioned calculation dependencies for defining the heat transfer coefficient during steam condensation inside the pipes are based on dependencies for condensation on the vertical plate. It can cause inadequate operations of calculation dependencies during particular values of the pipe inner diameter.

To find out the precision, from this perspective, of values α obtained using formulas (2), (6), (9) (15) and (17), one carried out the calculation and compare the results. Calculations involved the value of Reynolds criterion $Re_s = 1 \cdot 10^4$ while the pipe inner diameter was set in the range of $d = 0.01\ldots0.1$ m (pipes of larger diameter can be considered as a plane wall, and pipes of smaller diameter require additional data, as condensate can fill all the space). Obtained values of heat transfer coefficients are displayed on the graph $\alpha = f(d)$ at $Re_s = constant$ (Fig. 2):

The maximum value of the average linear deviation of the heat transfer coefficient, in this case, reaches ±14% while the average one is equal to ±13.1%.

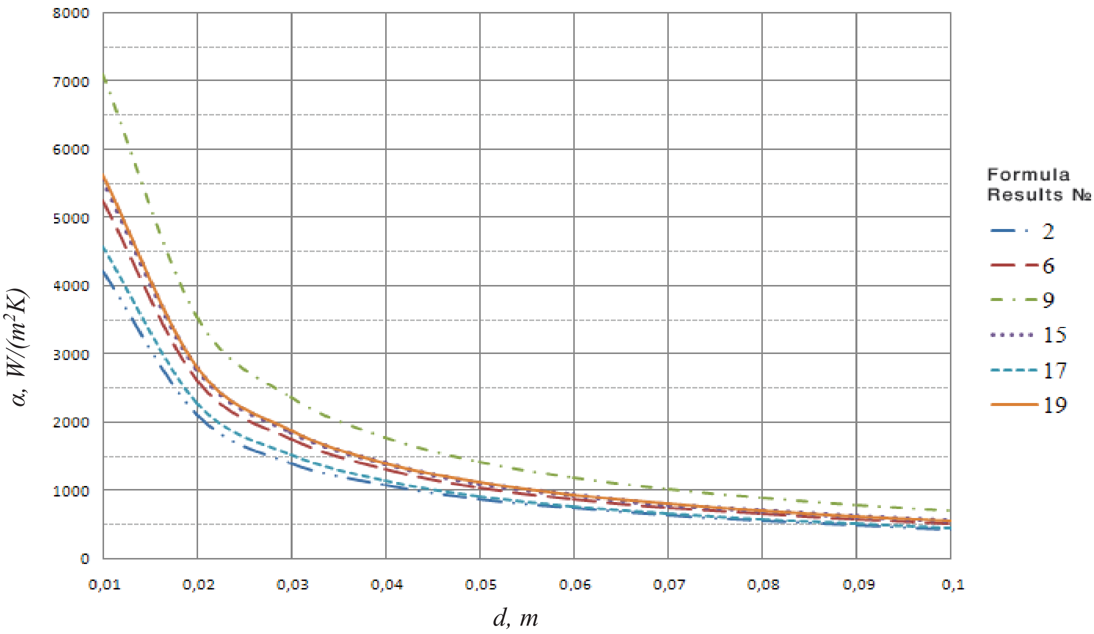

Fig. 2 Graph of the dependence of heat transfer coefficient *α* during steam condensation inside the pipes on the value of pipe inner diameter *d* at $Re_s = constant$

4. Conclusions

Calculating the required surface of condenser heat exchange, we can see a significant discrepancy between obtained results. The deviation of the value of heat transfer coefficient *α* during steam condensation inside the pipes obtained in different calculation dependencies from its average value reaches ±23.4%. Besides, the results of various formulas can differ from each other up to 46.8%. It is also worth paying attention to the fact that the equivalent diameter [11] is used in calculations during steam condensation in noncircular pipes. This simplification does not take into account surface tension forces during condensate film allocation and, consequently, increases the error of obtained results.

For further development of the heat exchange theory, one should conduct a study aimed at obtaining more precise calculation dependencies for both circular and noncircular pipes. The increase in the accuracy of calculation dependencies will result in a positive economic effect [12, 13].

Acknowledgement

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Use of Alternative Energy Sources in Road Freight Transport

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Abstract

The article presented here discusses the possibility of use of alternative sources of energy in road freight transport. It deals with emissions from road freight transport and their modelling including the description of emission models, it further introduces a simulation model for fuel consumption and emission calculation, the process of design of optimization of a network charging stations and a concept of charging stations and hydrogen power.
The aim is to determine a proper way of implementing alternative energy sources (AES) in freight road transport, to create a simulation model for fuel consumption and emission calculation and therefore to compare the impact of different types of alternative fuels on the environment and to assess emissions in a broader cycle. The work further aims at proposing a method of optimization of a network of charging stations and discussing the concept of charging stations and hydrogen power.
KEY WORDS: *freight transport, alternative energy, emissions, fuel consumption*

1. Introduction

This paper is focused on introduction of relevant methods for three critical parts of introduction on alternative energy sources in road freight transport. These three critical areas are estimation of fuel consumption, estimation of corresponding pollutions and charging station placement.

2. Simulation Model for Fuel Consumption and Emissions Calculation

Planning a future strategy for freight transport in the Czech Republic includes the consideration of various scenarios and their environmental and economical assessment. This task requires a convenient software that enables modelling traffic flows on any present or planned network, both for the present mix of vehicles (with respect to vehicle and fuel types) and for prospective future technologies. These conditions are satisfied by the set of open simulation programs SUMO (Simulation of Urban Mobility) developed at Deutsches Zentrum für Luft- und Raumfahrt, Institut für Verkehrssystemtechnik, and its commercial extension PHEMLight for emissions calculation, based the model PHEM developed at Technische Universität Graz (see 3, 4, 6). This software was used to model a substantial part of the traffic network in the Czech Republic, simulation of traffic flows and calculation of energy and fuel consumption for present types of vehicles and for various possible future scenarios.

2.1. Physical Principles of Traffic Model

Power calculation carried out by the model PHEMLight is based on fundamental physical principles described in authors' previous paper **Klaida! Nerastas nuorodos šaltinis.**. If a vehicle with vehicle weight m_V and load weight m_N moves with an acceleration *a*, the second Newton's motion law implies the relation:

$$\left(m_V + m_N\right)a = F - R_{RP} - R_{AD} - R_{RR} - R_{RG}\,, \tag{1}$$

where the right side contains the driving force *F* and resistances acting in the opposite direction. The total resistance consists of the acceleration resistance of rotating parts $R_{RP} = m_V \xi a$, where ξ denotes a coefficient including the inertia of rotating parts, aerodynamic drag $R_{AD} = \frac{1}{2}\rho c_d A v^2$, where ρ – stands for air density, α – aerodynamic drag coefficient, A – projected front area and v – vehicle velocity, tire rolling resistance $R_{RR} = \left(f_0 + f_1 v + f_2 v^4\right)\left(m_V + m_N\right)\cdot g$ approximated by a fourth-degree polynomial with coefficients f_0, f_1, f_2, and climbing resistance corresponding to a road grade *RG*, expressed in the form $R_{RG} = \left(m_V + m_N\right)\cdot g \cdot RG \cdot 0.01$. To understand these relations, let us consider the angle α between the road and a horizontal plane. If the road grade does not exceed 10 percent, it is usual to approximate $\cos\alpha$ (that should otherwise be present in the formula for the rolling resistance) by 1, and $\sin\alpha$ by the function $\tan\alpha$, the value of which multiplied by 100 gives the road grade *RG* expressed as a percentage. Eq. (1) implies the expression of the driving force *F* as a sum:

$$F = (m_V + m_N)a + R_{RP} + R_{AD} + R_{RR} + R_{RG} . \quad (2)$$

In the simulation, the power is computed in individual segments travelled by a vehicle in 1 second. Within each segment, the velocity is considered constant and the energy necessary for a force F to act along a distance s is computed by the simple formula $W = F \cdot s$. The corresponding power is therefore:

$$P = W / t = F \cdot s / t = F \cdot v . \quad (3)$$

The resulting engine power necessary for the motion of a vehicle with an acceleration a is therefore computed by the formula:

$$P_E = (P_{acc} + P_{RP} + P_{AD} + P_{RR} + P_{RG}) / \eta_p , \quad (4)$$

where η_p is the transmission efficiency and the following relations hold: $P_{acc} = (m_V + m_N)a \cdot v$; $P_{RP} = m_V \xi \cdot a \cdot v$; $P_{RR} = (f_{V0} + f_{V1}v + f_{V4}v^4)(m_V + m_N) \cdot g \cdot v$; $P_{AD} = \frac{1}{2}\rho c_x S_x v^3$; $P_{RG} = (m_V + m_N) \cdot g \cdot PS \cdot 0{,}01 \cdot v$.

The computation of fuel consumption is based on full engine characteristics, i.e., a two-variable empirical function expressing the dependence of the specific fuel consumption (an amount of fuel consumed by a vehicle per 1 kWh) on engine torque and revolutions. Values of this function were obtained by testing individual engines and a direct fuel consumption measuring. Similarly, the calculation of selected emitted pollutants (see part 1 of this paper) is based on empirically determined values per 1 kWh.

2.2. Fuel Consumption and Emissions Calculation Based on Programs SUMO and PHEMLight

For the simulation, it was necessary to create a road map in a form convenient for the SUMO programs. The map of the Czech Republic was obtained from Open Street Maps, simplified by the program Osmfilter to keep only transport-related elements, and finally converted by the program Netconvert into a network formed by edges (individual traffic lanes) and nodes, saved in the form of a list of nodes determined by coordinates (x, y) in a rectangle formed by the map, together with their connections. This resulting xml file then represents one of inputs for the SUMO simulation. Another input was based on the information from the toll system obtained from the Directorate of Roads and Highways of the Czech Republic, namely on traffic intensities at individual toll gates and the total amount of vehicle-kilometres for trucks above 3.5 t of various categories (in the division given in Table 1). The output of the simulation were data on fuel consumption and emitted pollutants for individual truck types.

Table 1

Calculated fuel consumption and pollutant emissions per 100 km for various types of diesel trucks

Emission category	Number of axles	Emissions per 100 km [g]					Fuel Consumption [l]
		CO_2	CO	HC	NO_x	$PM_{2.5}$	
Euro 0-2	2	48171.81	121.39	22.90	633.16	167.25	18.33
	3	86884.69	238.93	42.94	1077.56	268.83	33.00
	4+	97858.39	265.63	44.04	1221.07	297.33	37.16
Euro 3-4	2	51677.07	66.61	4.88	287.08	30.38	19.60
	3	89074.95	121.71	9.00	527.75	57.61	33.79
	4+	101143.10	128.63	9.34	580.81	62.13	38.36
Euro 5	2	56970.44	67.40	2.17	182.95	22.23	21.60
	3	92232.44	95.32	3.29	306.94	31.80	34.96
	4+	104578.25	102.52	3.62	281.64	33.82	39.64
Euro 6	2	57211.69	5.04	1.38	12.46	2.02	21.65
	3	93269.72	7.22	2.12	17.16	2.99	35.30
	4+	106050.55	6.91	2.20	18.72	3.22	40.14

Table 2

Calculated fuel consumption and pollutant emissions per 100 km for various types of CNG (compressed natural gas) powered trucks

Power source	Number of axles	Emissions per 100 km [g]					Fuel Consumption [kg]
		CO_2	CO	HC	NO_x	$PM_{2.5}$	
CNG	2	45769.35	4.54	1.38	12.97	1.84	17.32
	3	74615.78	6.49	2.12	17.85	2.72	28.24
	4+	84840.44	6.22	2.20	19.48	2.93	32.11

Table 3

Calculated fuel consumption and pollutant emissions per 100 km for various types of battery electric trucks

Power source	Number of axles	Emissions per 100 km [g]					Consumed energy [kWh]
		CO_2	CO	HC	NO_x	$PM_{2.5}$	
Electric batteries	2	0	0	0	0	0	64.72
	3	0	0	0	0	0	105.50
	4+	0	0	0	0	0	119.96

Table 4

Calculated fuel consumption and pollutant emissions per 100 km for various types of hydrogen fuel cell electric trucks

Power source	Number of axles	Emissions per 100 km [g]					Consumption [kg hydrogen]
		CO_2	CO	HC	NO_x	$PM_{2.5}$	
Hydrogen fuel cells	2	0	0	0	0	0	4.86
	3	0	0	0	0	0	7.92
	4+	0	0	0	0	0	9.00

Table 5

Calculated fuel consumption and pollutant emissions related to trucks operation in 2019 - data from toll system

Emission category	Number of axles	Vehicle-kilometres travelled	Emissions [t]					Fuel consumption [thousand l]
			CO_2	CO	HC	NO_x	$PM_{2.5}$	
Euro 0-2	2	23 026 444	11 092	28	5	146	39	4 220
	3	4 985 167	4 331	12	2	54	13	1 645
	4+	6 187 366	6 055	16	3	76	18	2 299
Euro 3-4	2	119 015 855	61 504	79	6	342	36	23 327
	3	25 555 686	22 764	31	2	135	15	8 635
	4+	86 565 326	87 555	111	8	503	54	33 207
Euro 5	2	111 119 738	63 305	75	2	203	25	24 002
	3	37 410 384	34 505	36	1	115	12	13 079
	4+	503 968 355	527 041	517	18	1419	170	199 757
Euro 6	2	180 818 043	103 449	9	3	23	4	39 152
	3	89 697 002	83 660	6	2	15	3	31 663
	4+	1 715 041 161	1 818 811	118	38	321	55	688 346
Total		**2 903 390 527**	**2 824 072**	**1039**	**90**	**3351**	**444**	**1 069 333**

Further, four hypothetic scenarios were modelled (Tables 2-5). Two of them were conservative, relying on fossil fuel combustion, two were progressive, consisting in the transition to electric trucks, either with batteries or with hydrogen fuel cells. The first conservative scenario considered the preservation of trucks with internal combustion engines but satisfying the highest standard Euro 6. With present technologies and vehicle parameters (above all size, weight and power that has substantially increased in recent years), the benefit would lie especially in a considerable reduction of toxic emissions, but not CO2 and fossil fuels (Table 6).

The second conservative scenario considered the global change to CNG, i.e., another type of fossil fuel, which would allow for the reduction of not only toxic emissions but also CO2, namely by ca. 19% compared to the present state (Table 7).

In the first of progressive scenarios, a complete transition to battery electric trucks was considered (Table 8). This situation would mean zero emissions related to engine operation. Nevertheless, a problem with particle pollution due to abrasion processes persists, and the overall environmental benefit is substantially influenced by the way in which electric energy is produced and by the production, recycling and disposal of batteries.

Table 6

Scenario 1 – All trucks satisfying Euro 6 levels, toll roads

Emission category	Number of axles	Vehicle-kilometres travelled	Emissions [t]					Fuel consumption [thousand l]
			CO_2	CO	HC	NO_x	$PM_{2.5}$	
Euro 6	2	433 980 080	248 287	22	6	54	9	93 969
	3	157 648 239	147 038	11	3	27	5	55 649
	4+	2 311 762 208	2 451 636	160	51	433	74	927 845
Total		**2 903 390 527**	**2 846 962**	**193**	**60**	**514**	**88**	**1 077 463**

Table 7

Scenario 2 – All trucks powered by CNG, toll system data from 2019

Power source	Number of axles	Vehicle-kilometres travelled	Emissions [t]					Fuel consumption [t]
			CO_2	CO	HC	NO_x	$PM_{2.5}$	
CNG	2	433 980 080	198 630	18	6	48	8	75 176
	3	157 648 239	117 630	9	3	24	4	44 519
	4+	2 311 762 208	1 961 309	129	48	383	64	742 276
Total		**2 903 390 527**	**2 277 569**	**156**	**57**	**455**	**76**	**861 971**

Table 8

Scenarios 3 and 4 – All trucks electric, powered by batteries or hydrogen fuel cells, toll system data from 2019

Number of axles	Vehicle-kilometres travelled	Power source	
		Electric batteries	Hydrogen fuel cells
		Energy consumption [GWh]	[t hydrogen]
2	433 980 080	281	16 863
3	157 648 239	166	9 986
4+	2 311 762 208	2 773	166 503
Total	**2 903 390 527**	**3 220**	**193 352**

The last modelled scenario considered a complete transition to electric trucks powered by hydrogen fuel cells (see the last column in Table 8), i.e., trucks with electric engine where a battery is continuously charged by a hydrogen fuel cell, which allows for a substantial weight reduction compared to classical electric trucks, and thus a greater load weight. Hydrogen consumption of these vehicles was calculated on the basis of energy consumption of battery electric trucks of the same category, taking hydrogen heating value of 33.31 kWh/kg and efficiency 0.5 into account. An efficiency of a hydrogen cell itself is ca. 60 percent under optimal conditions. Nevertheless, there are efficiencies of other devices as, e.g., voltage transformer and recharge battery efficiency – see 2 and 5 (efficiency of an electromotor is already comprised in the calculation of consumed energy for a battery electric vehicle). Similarly, as in the case of scenario 3, despite zero operational emissions, overall environmental impact substantially depends on the way in which hydrogen is produced. If solely hydrogen created as a by-product of chemical manufacturing were used, transportation would have represented a negligible environmental burden. Nevertheless, only ca. 1500 t waste hydrogen is annually produced in the Czech Republic. At present, total annual production capacity by fossil fuels reforming is ca. 15 000 t hydrogen, additional 4 000 t could be produced by electrolysis, using electric energy surplus from renewable energy sources and nuclear power stations 2. Freight transport would therefore require a significantly greater hydrogen production capacity, and thus building a huge infrastructure for this purpose. An assessment of the total impact of scenarios 3 and 4 will be subject of subsequent research.

2.3. Fuel Consumption and Emissions Calculation for the Whole Traffic Network in the Czech Republic

SUMO programs were used for the calculation of a energy demands, fuel consumption and emissions for roads included into the toll system where information on not only total vehicle-kilometres travelled, but also on the distribution of vehicles with respect to Euro categories were known. For the whole traffic network of the Czech Republic, data can be gained from the traffic counting organized by the Directorate of Roads and Highways of the Czech Republic[1] in 2016 (without distinguishing individual Euro categories). According to the Ministry of Transport, the number of travelled vehicle-kilometres increased between the years 2016 and 2019 by 16% on highways, by 8% on first class roads and by 5 % on second- and third-class roads. Considering the calculated consumption values per 100 km, we thus obtain the following data for scenarios (Tables 9-11) considered in the previous section.

Table 9

Scenario 1 – All trucks satisfying Euro 6 levels, the whole traffic network of the Czech Republic

Emission category	Number of axles	Vehicle-kilometres travelled	Emissions [t]					Fuel consumption [thousand l]
			CO_2	CO	HC	NO_x	$PM_{2.5}$	
Euro 6	2	2 785 744 969	1 593 772	140	39	347	56	603 196
	3	1 499 546 095	1 398 622	108	32	257	45	529 334
	4+	7 012 163 346	7 436 438	484	155	1 313	226	2 814 389
Total		**11 297 454 409**	**10 428 832**	**733**	**225**	**1 917**	**327**	**3 946 919**

[1] http://scitani2016.rsd.cz/

Table 10

Scenario 2 – All trucks powered by CNG, the whole traffic network

Power source	Number of axles	Vehicle-kilometres travelled	Emissions [t]					Fuel consumption [t]
			CO_2	CO	HC	NO_x	$PM_{2.5}$	
CNG	2	2 785 744 969	1 275 017	126	39	361	51	482 557
	3	1 499 546 095	1 118 898	97	32	268	41	423 468
	4+	7 012 163 346	5 949 150	436	155	1 366	206	2 251 512
Total		**11 297 454 409**	**8 343 065**	**660**	**225**	**1 995**	**298**	**3 157 536**

Table 11

Scenarios 3 and 4 – All trucks electric, powered by batteries or hydrogen fuel cells, respectively

Number of axles	Vehicle-kilometres travelled	Power source	
		Electric batteries	Hydrogen fuel cells
		Energy consumption [GWh]	[t hydrogen]
2	2 785 744 969	1 803	108 244
3	1 499 546 095	1 582	94 990
4+	7 012 163 346	8 412	505 045
Total	**11 297 454 409**	**11 796**	**708 278**

3. Methodology for Choice of Optimal Charging Station Concept in Road Freight Transport

For the correct approach to planning EV charging infrastructure, it is necessary to consider the traffic load and the available capacity of an electric distribution network in the monitored area. Replacing trucks with conventional combustion engines by EVs can cause many issues associated with the electric distribution network. Especially, the uncontrolled connections of the EVs into the electric distribution network may result in several issues e.g. overload, undervoltage, power losses increase and power quality deterioration [7]. Thus, the charging infrastructure has to be designed appropriately with the help of the methodology for EV charging infrastructure design, which is being developed. The methodology in the development deals with the design of one EV charging station instead of placement optimization for EV charging stations. The block diagram of proposed methodology is shown in Fig. 1.

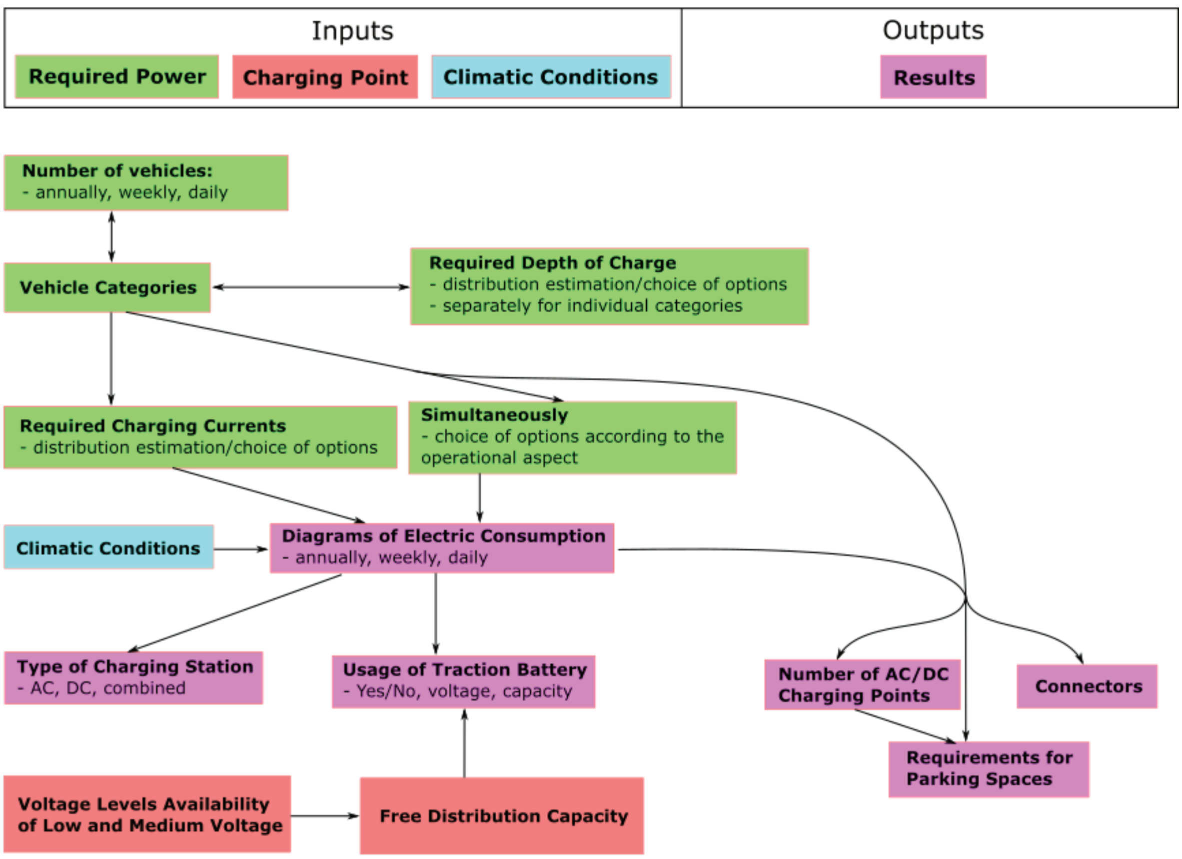

Fig. 1 Block diagram of the methodology for choice of optimal charging station concept in road freight transport

The methodology will also deal with the utilization of a traction battery and its basic parameters. The methodology will also include the possibility of shifting load peaks within the daily diagram (so-called "Smart Charging") for cases when there is more time for charging, such as overnight. The aspects which shall be taken into account:

Map of The Czech Republic Electricity Grid The map is available under reference [8]. From the EV charging stations design point of view it is necessary to study the availability of the 110 kV/medium-voltage transformer stations in the given area.

Parameters in medium voltage distribution network. The voltage levels of the medium voltage distribution network for connecting charging stations in the Czech Republic are 35 kV, 22 kV and 10 kV. Distribution network operators in the Czech Republic are ČEZ Distribuce, E-ON Distribuce and PRE Distribuce companies. The characteristic values of available power (Free Transformer Capacity) for the individual 110 kV/medium - voltage transformer stations for distribution network of companies ČEZ Distribuce and E-ON Distribuce are included in the report [9].

Technical-technological conditions for establishing EV Charging Stations The technical-technological conditions for establishing of EV charging stations are stated in [10] and related standards such as Czech National Standards (ČSN), European Standards (EN) and technical standards PNE. We mention the most important conditions below.

1. The design and development rules of the distribution network are given by [10] in section 3.5. The user of the charging station may operate only the devices which are suitable for a given purpose and environment, satisfy the requirements for safety and they do not interfere negatively with the distribution network and its other users.
2. Technical requirements for the connection to the charging station are given by [10] in section 3.7. A charging station operator must be capable to disconnect user installation by allowing the device on the ownership boundaries. Types of protection and their settings, transmission of information, including the influence of user protections on the ownership boundaries, must fulfill the standards of distribution system operation
3. The way of connection to the charging station is given by attachment number 6 in the distribution system operation rules (PPDS) [11]. This attachment defines three categories of charging stations, namely DoS1 to DoS3. DoS3 category contains the stations with charging power above 22 kW. In order to connect the stations of this category, it is necessary to conclude a connection contract with PPDS. Reserve capacity of the power line, interference limits, communication interface are specified among others in this contract.
4. Evaluation of the customer's interference on of power grid is calculated according to [12]. The calculations are based on the determination of short-circuit power in the connection point. Furthermore, the changes in voltage fluctuating, flicker effect, asymmetry and higher harmonics are calculated. The results of the calculations for individual criteria are the interference limit values, which must be met by the customer during operation.

4. Conclusions

The possibility to decrease the amount of emission without introducing new alternative energy sources in road freight transport. Emissions of CO_2 are directly linked to fuel consumption thus even switching to EURO6 doesn´t mean a decreased in these emissions. If the CNG would be the fuel, there would be decrease in the emissions. When compared to EURO6 scenario, the decrease would be most significant for CO_2 and NO_x emissions. With scenario 3, all the road freight transport powered by batteries, that it would be necessary to produce about 12TWh of electricity. With estimation 0,28 tonnes of CO2 1MWh electricity (based on electricity production mix from Q1 of 2020) the total CO_2 production would be about 3 360 000 tonnes. This represents decrease of CO_2 production compared to EURO6 scenario of more than 65%. The change in other emissions may differ due to different emissions factors of each electricity source, but in general it is probable that NO_x emissions would remain about same, PM, HC and CO would decrease but there would be additional emissions of sulfuric oxides. The actual emissions may vary significantly because for energy mix of the given country. With the increased percentage of renewable electric sources, the total emissions factors would decrease. But it is important to mention, that due to life cycle assent even for renewable sources the emission will never be zero.

From aforementioned it is visible that there is no all solving solution. Switch to CNG would decrease NOx emissions but the decrease of CO_2 would not be as high as with switch to electricity. Electricity brings a decrease in CO_2 emissions but the decrease in other emissions dependant on the source of the electricity power. Hydrogen, that seems to be a suitable solution, is not produced in significant amounts which would be necessary and its emissions, therefore, are difficult to estimate due to unknown methods of production in the future.

This paper summarizes the approach of how it is possible to estimate impacts of switching energy source for road transport and stress the aspects which shall be taken into consideration when charging station placement is considered.

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Approaches to the Improving the Locomotive Fleet Management System

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Abstract

During the operation of the locomotive fleet, the efficiency of its work depends on organizing the fleet management system. Organizing the operation of the locomotive fleet also affects the efficiency of the maintenance services at a locomotive depot. The authors analyzed the application of the locomotive fleet management system of leading railway companies. One of the directions for improving the system of locomotive fleet management is to develop methods and techniques for optimized operational planning of processes related to the operation and repair of locomotives. A key role in solving the issue under consideration is simulation modelling that allows us to conduct research of systems without recourse to extra costs. In order to improve the locomotive fleet management system, the authors performed an analysis of approaches and methods of modelling in this field. The purpose of improving systems-of-interest is to reduce idle time and expenses in the maintenance of transportation facilities. The paper presents the formulation of the problem with describing the input and output information and highlights the key factors that affect the work organization of the locomotive fleet management system. We proposed criteria for the assessment of the efficiency of the locomotive fleet management system.
KEY WORDS: *locomotive fleet, locomotive fleet management, operational efficiency of the locomotive fleet, control model of the locomotive fleet*

1. Introduction

Every year railway companies in the world spend significant funds for the development and implementation of the fleet management system of rolling stock in order to minimize costs for their repair and operation. One of the contemporary directions of improving the management systems of rolling stock in many companies is to develop methods and techniques for optimized operational planning of processes related to the operation and repair of locomotives. A key role in solving the issue is simulation modelling, especially digital twins built using this technology. A digital twin is a virtual copy of the physical system and its processes. Such simulation models can be constantly updated using actual data from different sources, and thus reflect the real state of their own models. The locomotive fleet management is a range of measures aimed at optimizing costs and organizing the processes of exploitation and maintenance of the traction rolling stock fleet. In a given period of time, the effective functioning of railway enterprises is impossible without qualitative predicting their working conditions. Owing to this prediction, the work planning of structural divisions is carried out, potential risks are evaluated and more effective models of functioning have developed that help in predicting the enterprises' performance. Currently, qualitative prediction is impossible without the use of modern information technologies and mathematical methods. As the analysis shows, one of the actual problems at the railway enterprises is the cases of irrational planning in the locomotive fleet work, resulting in increasing inactivity of locomotives while in operation and repairs. Operational planning for locomotives work and the organization of overhauls can be implemented through the modelling of the locomotive fleet management system. The central task of such modelling is to analyze the impact of various factors on the locomotive fleet management system taking into consideration risks associated with the operation and repair organization.

The locomotive fleet management system includes many aspects, the main directions are maintenance and operation of the locomotive fleet. Most manufacturers and operators of locomotives in the world have been introducing a system of maintenance for a long time, with respect to the actual technical condition of locomotives with elements of technical diagnostics. This allows predicting the state of nodes and aggregates and preparing in advance technological equipment for the repair of a locomotive before its servicing. Also, this system makes it possible to significantly reduce the labor intensity and expenditures for servicing traction rolling stock. An important component of the locomotive fleet management system is the process structuring for the exploitation of a locomotive including operational control of the dislocation and reallocation of locomotives during the organizing trains traffic.

2. Theoretical Background

If we consider a locomotive fleet management system in a broader sense, then such a system includes a range of organizational and technical measures designed to maintain rolling stock in good working order during its operation (Fig. 1.). The aim of the locomotive fleet management system is the timely providing in the transportation process by traction rolling stock and locomotive crews.

Fig. 1 Scheme of the locomotive fleet management system

The locomotive fleet management system is organizational and technical measures designed to maintain a rolling stock in good working order during its operation. The management system consists of operation, maintenance, routine and major repairs. With maintenance, a complex of works that ensures the safety of movement, serviceability of all nodes and equipment, fire safety, as well as the proper sanitary and hygienic state of rolling stock is carried out. During repairs, a series of activities for restoration of proper functionality, working efficiency, and resource of rolling stock is put into practice.

When analyzing the locomotive fleet management system from the viewpoint of maintenance strategy there are the following systems: a routine-preventive system, a servicing system, a repair system on the real situation, a support system for failure and a combined service system [1].

If we are talking about the railways of Ukraine, then at this stage, the locomotive fleet management system is implemented using a routine-preventive system of repair, in so doing, there is also the servicing system. This system is used on the Prydniprovska railroad for the maintenance of diesel locomotives TE33AC. This is the first stage in the transition of Ukrzaliznytsia to a new locomotive fleet management system.

In the existing locomotive fleet management system at a low level, the indicators of reliability in the arrival of locomotives for planned and unscheduled types of repair, determination of probabilities in the transition of a locomotive from one state to another, as well as an accounting of reliability indicators in determining the volumes of repair work are used. Methods and approaches describing in the next section allow us to highlight these issues when improving the locomotive fleet management system.

3. Materials

Simulation modelling is a wide range with a large number of applied areas, each of which has its own modelling techniques. From the viewpoint of the classification of systems, we distinguish dynamic systems, a system of discrete-event modelling, and multi-agent systems.

The system of discrete-event modelling is used while modelling the railway transport systems. In accordance with this system, a number of requests are transmitting as per a structural scheme that represents a system of railway transport. Requests expect in queues, compete for the usage of resources and blocks that carry out their maintenance, and at the end leave the system. The structure of the system is a block diagram – blocks and their directed links.

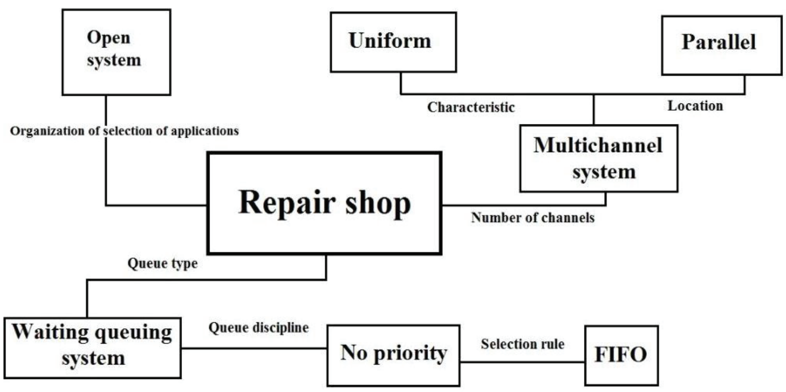

Fig. 2 The repair shop of a locomotive as a mass service system

When analyzing approaches and methods for improving the locomotive fleet management system, it is established that in papers [2, 14] a description of the repair shop of locomotives with the help of the terms and a concept of mass service systems was presented (Fig. 2). This description of the structure of the mass service system is a repair shop for locomotives. The authors formulated tasks that are solved while modelling the work of the repair shop. Based on the analysis of the modelling results the authors propose to optimize the structure of the repair shop and the required number of staff, the equipment reliability, the rules for selecting locomotives from the waiting queue, the number of repair positions.

In papers [3, 15] the locomotive depot is presented as an object of mass service system. The simulation model of the locomotive repair depot work (Fig. 3.) is developed using the Simulink software, which allows us to analyze the impact of various factors on the system organization of repairing locomotives at the depot. The authors present a model of the repair shop, which makes it possible to rationally plan the use of equipment, deadline of locomotives taking into account the uniformity of the shop workload, as well as improving the logistics in supplies of spare parts. The paper presents a model describing the process of repairing the mainline locomotives fleet. The results of this work allow determining the impact of operational indicators and reliability of locomotives on organizing the locomotive repair depot work. Also, the developed model can be used to improve the repair management system on the road network when introducing new series of locomotives and changes in their maintenance strategy.

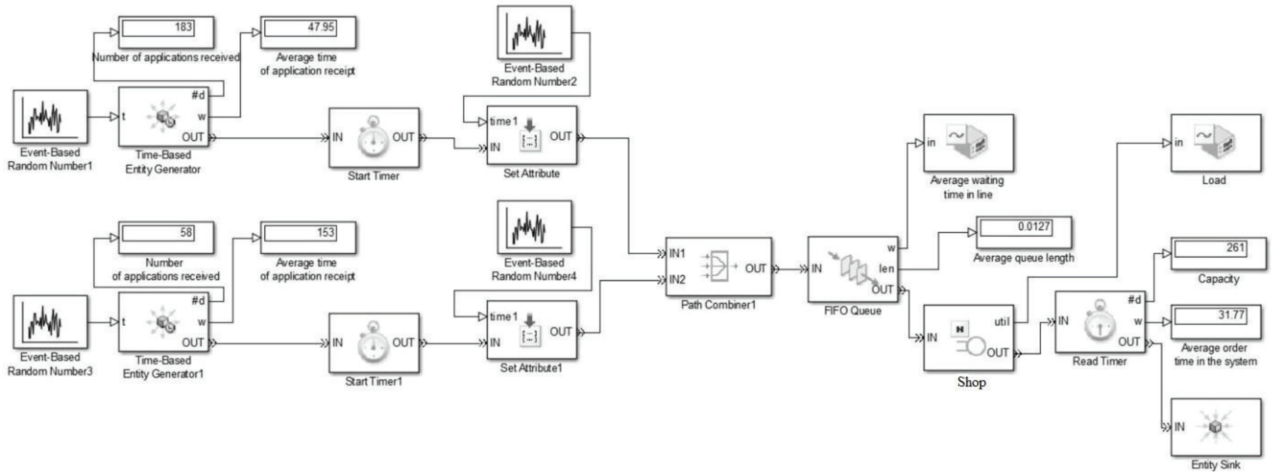

Fig. 3 The simulation model of the locomotive depot work

Improving processes of automated exploitation of locomotives fleet with regard to the parameters of current and predicted states are represented by authors in paper [4]. The information model of operation of the locomotive fleet allowed developing a method of dynamic interactive optimization in the assignment of locomotives to the freight trains class. It is based on predicting the readiness intervals of locomotives and trains, taking into account current information concerning the actual status of the technological process, and includes the conditions for minimizing the risk of downtimes calculated by the formula (1). With the method of statistical modelling, it has been established that values for the risk of downtimes and conditions in achieving its minimum depend essentially both on the predicted time in the readiness of locomotives and trains and on the accuracy of the prediction.

$$r_{lf} = \int_{\tau_0}^{\Delta_4} c_{lf}(\Delta) \bullet \{1 - \int_{\Delta} \rho_{lf}(\Delta) \mathrm{d}\Delta\} d\Delta, \quad (1)$$

where r_{lf} − the expected cost of losses from locomotive downtime is above the norm; c_{lf} − specific cost of losses from locomotive downtime above the norm; p_{lf} − the density of the distribution of idle locomotive waiting for the train; Δ − waiting time is a random variable with a distribution density p_{lf}.

The structural model of an electronic passport and the information model for the process of the pre-route preparation for a locomotive with the use of an electronic passport are developed in papers [5, 10, 12]. The mathematical model is developed in the paper and strategies for risk management in operation with the use of an electronic passport are proposed. An indicator characterizing the reliable performance of locomotives in operation is proposed to use the coefficient of route execution possibility. The interpolation formula for determining the coefficient of route execution possibility is obtained as a result of a full factorial experiment. Based on the statistical data processing it has been established that the use of an electronic passport of a locomotive in the pre-route preparation allows increasing the value of the coefficient of route execution possibility. The coefficient of route execution possibility is calculated by the formula (2). The electronic passport allows us to automate processing and analyze the results of technical diagnostics, as well as the development of a technological process for pre-route preparation. When applying an electronic passport of a locomotive, a decrease in the number of locomotive nodes failures en route is expected, since it excludes the possibility of sending a locomotive to a trip if the technical parameters of its nodes do not meet the requirements of the normative documentation.

$$C_{REP} = 1 - \prod_{i=1}^{n} \frac{P_{Ii} - P_{Mi}}{P_{Ii} - P_{Bi}}, \quad (2)$$

where C_{REP} − coefficient of route execution possibility; P_{Ii} − the initial value of the *i*-th determining technical parameter on the factory passport, or on acceptance tests; P_{Mi} − measured value of the *i*-th determining parameter during maintenance or pre-trip preparation; P_{Bi} − the limit value of the *i*-th determining parameter at which operation of the given equipment is not admissible.

For the design of the maintenance system [6], the authors use methods of reliability of a posteriori. Models can only be expressed on the basis of detailed knowledge concerning the behavior of a real existing set of objects that are operated. They have to generalize the results obtained and on other objects that were not directly subject to investigation.

Hitachi Company in [7] provides the developed latest ConSite Mine system which carries out remote round-the-clock control over vehicles and in real-time monitors their condition, as well as it conducts a predictive analysis of operating parameters using the Internet technology and artificial intelligence. On the basis of gathered information, it is possible to take measures necessary to prevent the breakdown of technology, including planning in advance of the maintenance and ordering spare parts, which allows minimizing downtimes of machines and reducing the cost of their operation. Thus, ConSite Mine improves fleet management and helps to provide a stable work of an enterprise with minimal operating costs. Data upon the technical condition of equipment, its operation are collected and displayed in real-time on the monitoring panel that is available in the personal online area of ConSite Mine system. This information can be saved in cloud service. Specialists of maintenance enterprises get access to it.

The author [8, 13] developed the model of the technical state for the traction rolling stock in the form of a three-circuit incident management system that is calculated by the formula (3). The model involves the "quality by design" principle using probabilistic-statistical methods and algorithms of international standards.

$$P_{inc} = \sum \left(\left(T_{tec} + T_{anl} \right) \cdot S_{idle} \right) + S_{work} + S_{rep} + S_{depot}, \quad (3)$$

where P_{inc} − the degree of impacts of incidents on the locomotives' technical state, T_{tec} − technological time spent on repairs; T_{anl} T_{anl} − administrative costs of time waiting for shunting work, free repair position, maintenance personnel, spare parts; S_{idle} − cost of locomotive downtime (lost profit); S_{work} − the cost of work (excluding the cost of spent spare parts and materials); S_{rep} − cost of spare parts and materials used in the repair; S_{depot} − cost of overhead costs for repairs.

The world leader in the transport sector Alstom Company with SimPlan Company develops digital decision support systems in the field of maintenance for the fleet of trains. Since the maintenance planning is influenced by a significant number of parameters, Alstom Company decided to perform simulation modelling of the entire maintenance system [9, 11].

Using relevant information that is updated daily, allows to reliably provide the maintenance system of trains. With the help of Anylogic Company, a digital twin in the existing train management system on the example of West Coast Main Line Railway in the UK was developed.

For modelling and planning of transportation, any most appropriate method of modelling or even a combination of methods is used. To create this model, the developers have chosen the method of the agent-based modelling, which allowed in detail to represent the railway network and its components: the fleet of trains, all maintenance depots, and stations, maintenance modes, diagrams reflecting the schedule of all trains.

At the core of the scheduler of the maintenance, which Alstom Company previously uses, there is a heuristic scheduling algorithm for the maintenance. When implementing the project, the company managed to introduce the same algorithm directly into the model. This is a great advantage, since when the model and the scheduler are connected directly, they are launched simultaneously, and obtained results are immediately used in the model.

4. Conclusions

In view of the above facts, it can be concluded that the problem of improving the locomotive fleet management system is relevant today. Most of the considered approaches are used to develop models of the locomotive fleet management system by methods of simulation modelling. The advantage of simulation modelling is the possibility to perform modelling the processes in the work of complex systems without the expenditure of time, funds and other material resources. One of the disadvantages of this method is the issue of the validity of obtained results in modelling complex technical systems.

The main tasks for improving the locomotive fleet management system are the choice of the criterion, according to which placing a locomotive is planned for repair when selecting it from a general locomotive fleet, development of a methodology for planning the loading of repair units taking into account the technical state of the locomotive fleet and the scope of planned repair works and improvement of the locomotives performance system.

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How Can the Mobility Campaigning Help to Promote the Sustainable Mobility: Case from City of Zilina

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Abstract

Many cities are trying to ensure the condition for sustainable mobility, but from the citizens perspective, there is resistance to accept the new rules and conditions mainly to car restrictions. The campaigning is important because the citizens do not always understand what the term sustainability means. The promotion of sustainable mobility can help cities and citizens understand what the are the goals of having the green and ecological transport systems. Therefore, it is required to convince the public of the potential impact of measures or to encouraging use of ecological modes of transport, e.g, cycling or public transport. This paper presents mobility campaigning conducted last year 2020 during European mobility week in the city of Zilina. It describes various types of events which serve to promote and encourage discussion about sustainable mobility with insights gathered during the events. The outputs of the campaign show that the active form of mobility promotion might lead to the active engagement of the citizens.
KEY WORDS: *mobility campaign, sustainability, ecological, transport systems*

1. Introduction

European Mobility Week (EMW) is held from 16th to 22nd September each year when the participating cities and various stakeholders promote sustainable mobility via various actions and events. There are certain events for the purpose of promote popularisation and they educate the public. In 2019 the 2,495 municipalities participated in this campaign and few of them Kruševac (Serbia) and Karditsa (Greece) were awarded as best practise cities in 2019. Local authorities together with main stakeholders, such as cycling lobbyists, NGOs and citizens are encouraged to use the main week to test the innovative planning measures, promote new infrastructure and technologies, measure air quality, and obtain feedback from the public [3]. Travel-awareness campaigns provide information and arguments for promoting sustainable transport behaviour. Citizens can divide promotional activities into those that provide information in which residents are only passive listeners. A total of 901 campaigns to promote sustainable mobility were registered in 2020 [22].

Recently, literature on how to stimulate sustainable mobility has flourished, especially in the context of urban areas [16]., as higher population density, congestion and pollution urgently need solutions. There are various studies focused on the promotion at various groups, e.g., visually impaired people [6, 7], children [11], public transport etc. Of course, there is no restriction of the period for the promotion of sustainable transport to just EMW – this can be campaigned anytime. The promotion had proved the positive effect to get more citizens behaving sustainable, e.g., bringing them to bicycle or just improving the conditions for them in particular place [19]. There are various schemes such as bike to work [20] and bike to school 28 which sustainably support the citizens. There are also studies [17] that compared cars and public transport usage and provided incentives for their users or evaluate travellers behaviour [3]. Another study [14] presented the disadvantages from the perspective of air pollution. Such a measure is widely adopted and has been tested in various cities, e.g. [26], [27]. The campaign can be focused on the road safety [1]. Another study [13] demonstrates that students prefer bicycles as a mode of transport, but students call for more cycle paths, additional parking spots or buses equipped with proper cycle carrying equipment. Students would welcome cheaper tickets if they use a bicycle or discounts on the purchase and maintenance of a bicycle.

In the presented study, the city of Zilina has participated in EMW since 2007 in cooperation with NGO MULICA (local cycling group) and other stakeholders (e.g DPMZ - city public transport company), and the University of Zilina. The goal of this paper was analyse the mobility campaigning linkage to citizens involvement.

2. Methodology

In order to achieve the goal of this paper, we wanted to analyse various types of promotional events and evaluate the citizens involvement. The scope was focused on the way how the citizens perceived such events and also evaluation of their active involvement in such event. A total of 5 different campaign were analysed.

The citizens engagement is already well known from public administration [4]. The scientists use various methods [8] to engage citizens. Some of these are based on surveys (online or personal), some are through the use of digital technologies (e.g., websites, smartphones, etc.). During EMW, the following events were presented:

- bicycle breakfast;
- bicycle forum;
- street closure;
- bicycle ride.

We have mainly focused on personal interaction with citizens. The interaction took place in various ways and approaches. We used the face to face interviews and discussion on the specific mobility issues (cycling, bikesharing, pedestrians). Another approach represented the statement of the problems from the citizens perspective and marking them on the city map. The most exciting way how to cope with specific situation, especially for cyclists, was the bicycle ride with on site visitation of problematic areas/bottlenecks.

Each event has been analysed and evaluate from the perspective of citizens involvement. The events have also another function to promote and explain what kind of measures city prepares to achieve sustainable mobility goals. The types of events and citizens involvement shows the following Table 1.

Table 1

Type of events and type of citizens involvement

Type of event	**Type of involvement**
Bicycle breakfast	Questionnaire, discussion, map
Street closure	Leaflets, posters, questionnaire, discussion, map
Bicycle ride	Active ride and discussion
Bicycle forum	Lecture, discussion, city map

The main organiser was NGO Mulica with the cooperation of the city of Zilina and the University of Zilina. The data used in this study served also as the new ideas in the process of urban and transport planning in Žilina (Fig. 1).

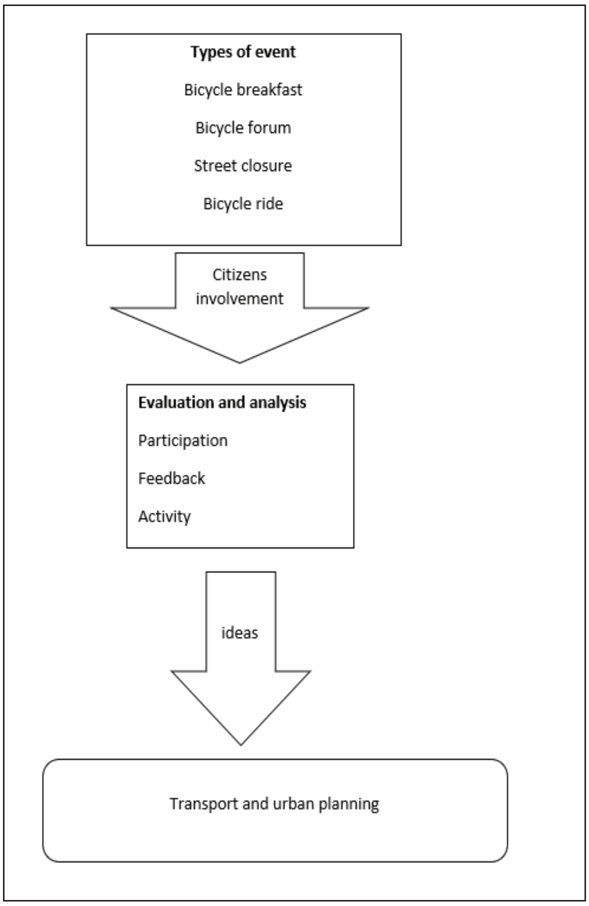


Fig. 1 The process of citizens involvement. Source: authors

3. Events During European Mobility Week

Bicycle breakfast – represents a special event focused on the cyclists. Totally 190 persons obtained the small takeaway as well as small refreshment's (tea, coffee, cake and apple). We also took the opportunity to ask them about the cycling issues (Fig. 2).

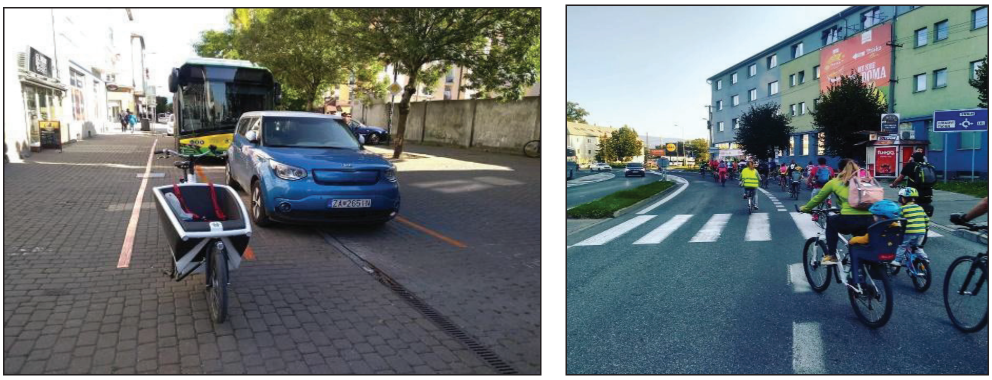
a b

Fig. 2 The bicycle breakfast on the street: a – discussion with cyclists; b – University bicycle day. Source: authors

The second bicycle breakfast was held at the University of Zilina and was primarily focused on the university employees and students. In addition, during the event, a small repair service was introduced with the possibility of checking bicycles. There were 26 participants.

Other events with participation included the **bicycle forum.** The forum aimed to present the current situation with cycling infrastructure and show the future to the public. Due to fat that the presenters were mainly city members, there were not so many complaints or comments. Most of citizens acted passively.

Street closure to car traffic. This event aimed to show different usage of the public space. The effect of closing a street to car traffic has already been presented in [12, 23]. This was applied not only to car parking and driving but also to socio-cultural events and economic perspective [10]. During this event, a presentation of preparing a new kind of bicycle advisory lane was delivered. Another benefit was the elimination of street pollution, mainly from car traffic [18]. We conceived of an engaging pop-up event by inviting citizens to bring their ideas and display them on the map. This example showed the critical spots on Zilina's transport infrastructure. During the day, various art performances have also been presented (dancing shows, concerts, etc.). Citizens could also play games such as street football and chess (Fig. 3 and 4. This event had very positive feedback, mainly from pedestrians.



a b

Fig. 3 a – the street with pop up advisory bike lane in Zilina; b – bicycle ride. Source: authors

a b

Fig. 4 a – the map on which the public could mark the most problematic spots; b – streets debate about the transport problems. Source: authors

On the contrary, some complaints rose from the side of restaurants and other facilities serviced by car. Although the facilities were informed about the temporary street closure, a small conflicts occurred due to limited car access of property owners and food-delivery drivers.

Bicycle cycle ride. It is a special event for cyclists aiming to show the massive presence of cyclists in the street together with cars in the traffic [21]. This kind of event also has educational features mainly for car drivers to see and understand that the public space is allowed for everyone, not only for cars. It also shows the possibility to encourage cyclists to ride in the traffic without fear. The new cycle path was tested during the ride, including examining an inappropriately designed part – a barrier with a bottleneck. Around eighty cyclists participated in the mass bicycle ride. This approach of an on-site visit allows us to understand the problem better and it is also a common method for other types of infrastructure [15].

4. Results and Discussion

The presented campaign events represent only a small amount of the potential promotion of sustainable mobility in the city. We have focused on those types of campaign with opportunity of citizen's active involvement. Such an approach is useful in attracting the citizen's attention to mobility problems and issues. Most of the cities in the world try to convince citizens to behave in a green or ecological manner. However, sometimes the cities are omitting the importance of the integration of citizens in the planning process. There are cities which have already worked in this area for a long period and they already have good results in this field (e.g., Copenhagen [24], Amsterdam [2] and Muenster [25]). The research was not focused on the quantitative aspects (how many people), but more on the qualitative aspects (are the citizens interested in such types of events or not).

During the events, we conducted personal face-to-face interviews with citizens who agreed to answer questions. There were forty semi-structured personal interviews, mostly with residents of the city of Zilina or its peripheral parts. We used a mixture of open-ended and closed-ended questions.

All participants were asked the same questions in the same order and an open question was asked at the end of the interview to enable further comment.

Data on the gender and age of respondents were collected. The questionnaire survey mainly involved young people and students of secondary education, university students, and working people. Participants were asked the following series of open qualitative questions about the nature of their interaction with mobility:

- What means of transport do you currently use most often for transport to work or to school?
- Under what conditions would you be willing to shift from individual car transport to a public transport system or another system (e.g., bike-sharing, P+R, B+R ...)?
- How do you evaluate the bike-sharing service in Zilina?
- In your opinion, what are the biggest shortcomings in terms of infrastructure in Žilina?
- Where would you welcome the new bike-sharing stations in Žilina?

In the following part of the research, questions related to the issue are processed graphically. Forty respondents took part in the questionnaire surveys. The questionnaire was filled in mostly by respondents from the age group of 16-25 years (of which there were six men and four women) and 26-65 years (of which there were thirteen men and seven women).

We also asked respondents about factors affecting their potential shift from individual car transport to the public transport system or to another system (e.g., bike sharing, P + R, B + R ...). In the area of public transport the comments were about the cheaper public transport, more frequent service of PT, better accessibility of stops and increase the speed of PT vehicle. Cyclists required more bicycle path and new bikesharing stations. About 12% of all respondents confirmed no way to switch from cars to ecological means of transport. Respondents evaluated the BikeKIA bike-sharing system service, which is the operation in Žilina since 2019. We also found out what the biggest criticism is in terms of mobility in the city of Zilina. As many as 80 % cited a lack of bike paths as a reason, 60% required more parking spaces. Other criticism is inadequate sidewalks and poor road conditions and also include – lack of bicycle stands, lack of bicycle shelters, insufficient road lights, lack of car parks of P+R, B+R systems.

Respondents were also able to comment on where they would welcome the new bike-sharing stations. Most new stations would be welcomed in urban areas such as Solinky, Závodie, Budatín, Vlčince and also at the railway station.

We noticed there are differences in citizens involvement. During the bicycle breakfast or bicycle ride, the citizens were more open to share their ideas, proposal or comments. During the bicycle forum, most of the citizens were passive, although they have the same opportunity to comment issues. One of the best concepts was marking the potential problems on the city map with explanation. The citizens welcome such involvement, because it was for first time to engage publicly for most of them. The comparison of citizens involvement shows Table 2. The low level of involvement refers to interaction below 20 persons, medium from 21 -50 persons and high more than 50 persons.

There is still room for improvement of citizens participation in transport planning, but what is required is to find a common communication channel between the municipality and the citizens. In this case, several events have been presented with underlying citizens active involvement. In future research, we would like to investigate other forms of citizen engagement in the process of transport planning and sustainable mobility. The study confirmed that the public are more likely to share their insights or thoughts if there is a small benefit, such as a bicycle breakfast or takeaway. Another sense confirms the fact that citizens believe that their ideas or thoughts would have an impact [8] on sustainable mobility.

Table 2

The level of involvement during events

Type of event	Formality	The level of involvement
Bicycle breakfast	informal	high
Street closure	informal	medium
Bicycle ride	informal	high
Bicycle forum	formal	low

There are several limitations to this study. The sample size of the interviewed citizens was small because not all citizens were willing to answer questions. We would also like to test more research questions related to street level pollution [20] and confront citizens' perspectives. It is also possible to use simulation methods in order to verify the planned measures [5] or focus on the road safety [9]. Until now, we have only tested limited methods of citizen engagement and in the future, we would also like to test new technologies, e.g. digital tools of citizens involvement. Some events, for example, the street closure, have to be planned very carefully, mainly with respect to property owners or service operators, to minimise potential conflicts on the street during temporary closures.

5. Conclusions

Planning sustainable mobility and realising the different measures within urban environments is a challenging task, primarily if the measures are targeted at the reduction of car usage. Within the policy framework, it is essential to also provide clear and understandable information for citizens to accept the proposed measures. This study revealed the various levels of engagement of citizens in the mobility planning issue. The street activities might help bring citizens together with responsible bodies into the process as partners. Therefore, this paper has presented the pop-up events in the city of Zilina in the scope of promoting sustainable mobility issue. We have discussed the various concepts of pop-up events to engage citizens.

The main task was to promote sustainable mobility issues to citizens and obtain feedback from them. Of course, residents mostly complain about aspects that they perceive negatively, especially in terms of everyday problems. Sometimes, they do not really understand what sustainable mobility is, and therefore, such events help explain them in an understandable way. Positive feedback from residents confirms that similar activities are perceived as an added value in planning and engaging residents in the planning process.

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Comparison of Unmanned Ground Vehicle Operating Time with Fuel Cell and Lithium Batteries

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Abstract

Unmanned technology is increasingly used in various areas of real life. Mobile robots are mainly used in applications where direct human action is problematic or in some cases extremely dangerous. Military use of this technology is the subject of growing interest. A major problem with these systems (regardless of their civilian or military use) is the source of power and the corresponding source of energy. If we consider a small, unmanned vehicle (able to enter the interior of buildings), we will choose an electric motor as a source of torque, for which the supply of electricity will most likely be a lithium battery. A battery provides the vehicle with a limited operating time, given by its capacity. In an effort to extend the operating time to the maximum, various technical solutions are being sought to eliminate the fundamental problem of the conventional battery - namely its insufficient energy density. Therefore, the fuel cell technology platform appears to be an interesting alternative. In our paper, we focus on a simulation comparison of the performance of a small 4-wheel unmanned vehicle with an in-wheel drive type.
KEY WORDS: *Unmanned Ground vehicle, LiIon accumulator, Fuel Cell*

1. Introduction

The subject of our interest is to compare the range of a small UGV, which in the first case uses a classic LiIon battery as a source of electricity and in the second case its alternative in the form of a fuel cell.

2. Vehicle Conventional Power Source

Electrochemical sources of electric current can be divided into three groups. All of these groups have in common that they convert the chemical energy of a fuel into electrical energy. The first group are batteries, the second group are accumulators, which can be recharged and reused after the consumption of reactants with the opposite current. The two groups have in common that the active chemicals are part of the electrodes and are able to supply electricity for a limited time, after which they need to be replaced or charged.

Nowadays commonly used lithium accumulators, uses a solid polymer as the electrolyte. The electrolyte is formed by a thin film of plastic, which does not conduct current, but allows the exchange of ions - electrically charged atoms. The polymer electrolyte replaces the traditional electrolyte-soaked porous separator. To reduce the internal resistance, a gel polymer is used, or a gel with which the polymer separator will be soaked.

The advantages are higher safety, durability and a thin profile of the batteries. The disadvantage is the low conductivity and thus the high internal resistance, which causes the battery to heat up when the current is released. Heating causes the packaging to inflate, which can damage it over time [1].

3. Fuel cEll

The third group of electrochemical sources are fuel cells, in which the reactants are fed directly to inert electrodes from the external environment. Theoretically, if the supply of fuel and oxidizer is ensured, the fuel cell is able to supply electricity continuously [2].

The chemical energy of the fuel is directly converted into electrical energy in the fuel cell. As this process does not involve a thermal-expansion process, we can talk about the so-called cold combustion [2].

The fuel cell consists of two electrodes between which there is an electrolyte. This electrolyte has special properties, namely that it is permeable to positive ions (protons) and impermeable to electrons. Gaseous hydrogen is fed to an electrode called an anode and, with the aid of a catalyst, is divided into an electron and a hydrogen proton. This process is shown in Fig. 1 [3].

$$2H_2 \rightarrow 4H^+ + 4e^- . \quad (1)$$

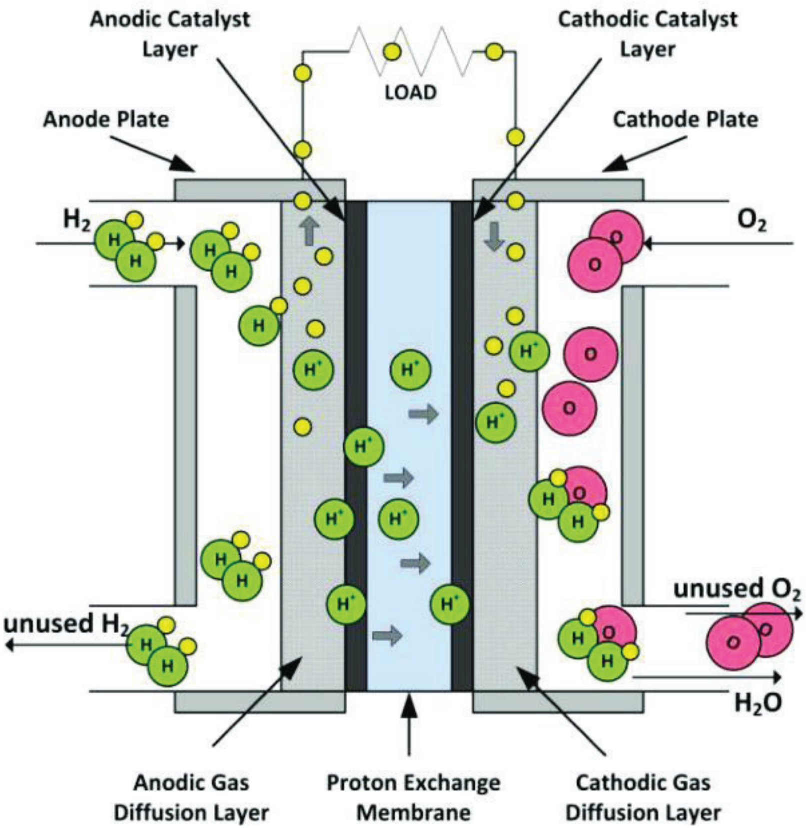

Fig. 1 Reactions in fuel cell [4]

Cathode reactions:

$$O_2 + 4H^+ + 4e^- \rightarrow H_2O\,. \tag{2}$$

The overall chemical reaction of a fuel cell can therefore be described:

$$2H_2 + O_2 \rightarrow 2H_2O\,. \tag{3}$$

Protons pass through the electrolyte to a second electrode called the cathode, while electrons pass through an external circuit, thus generating electrical energy. The hydrogen protons that have passed through the electrolyte, in combination with the electrons supplied by the external circuit and the oxygen supplied to the cathode, form water molecules [5].

PEM fuel cells, which mean polymer electrolyte membrane fuel cell, or proton exchange membrane use a thin (<50 μm) proton conductive polymer membrane (such as a perfluorosulfonated acid polymer) as the electrolyte. The catalyst is usually platinum supported on a carbon paper of about 0.3 mg/cm^2, or Pt-Ru alloys are used if the hydrogen fuel fed to the cell contains a minimum amount of CO. The operating temperature of these cells is usually from 60°C to 80°C. PEM fuel cells are the most likely type of fuel cells to be used in the automotive industry as well as in small stationary generators and portable applications [6].

4. Simulated Vehicle

Within the simulation, we will deal with a small electric unmanned vehicle with the following energy sources:

- LiIon accumulator;
- fuel cell with proton exchange membrane (PEMFC).

The presented UGV (with weight approx. 10 kg) has four wheels, each with a separate drive. The drive is a combination of a planetary gearbox and an electric motor. The planetary gearbox is advantageous in terms of its mounting in one axis with the motor. One drive set consists of a DC electric motor, a planetary gearbox and a wheel. The vehicle contains four these kits. Due to the small dimensions, low weight and simplicity of construction, driving the vehicle is solved by changing the speed of rotation of the individual wheels. Fig. 2 shows the UGV scheme. PG represents a planetary gearbox, EM represents an electric motor and PS represents a power source – LiIon accumulator or fuel cell.

The planetary gearbox consists of two identical planetary gears and acts as a reducer. The diagram of the gearbox is shown in Fig. 3.

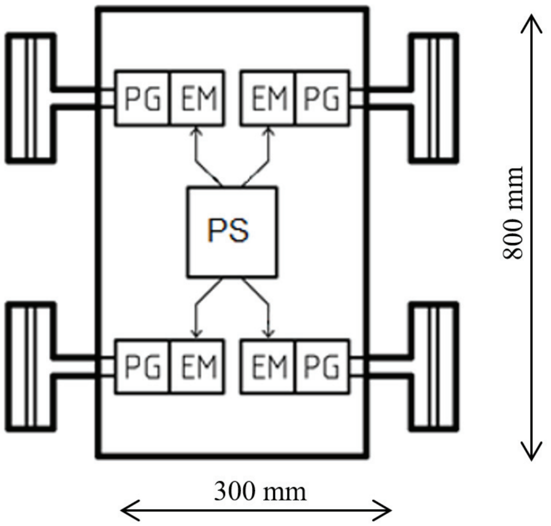

Fig. 2 Scheme of UGV (PG – planetary gear, EM – electromotor, PS – power source)

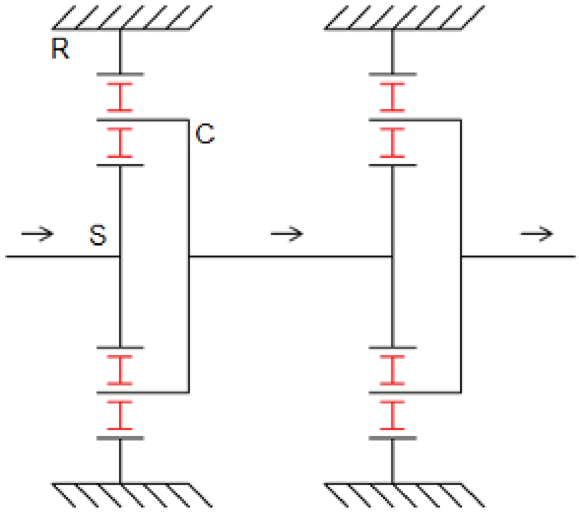

Fig. 3 Planetary gearbox (R – ring, C – carrier, S – Sun)

Simulated vehicle with LiIon accumulator is shown in Fig. 4, simulation with fuel cell as power source is shown on Fig. 5.

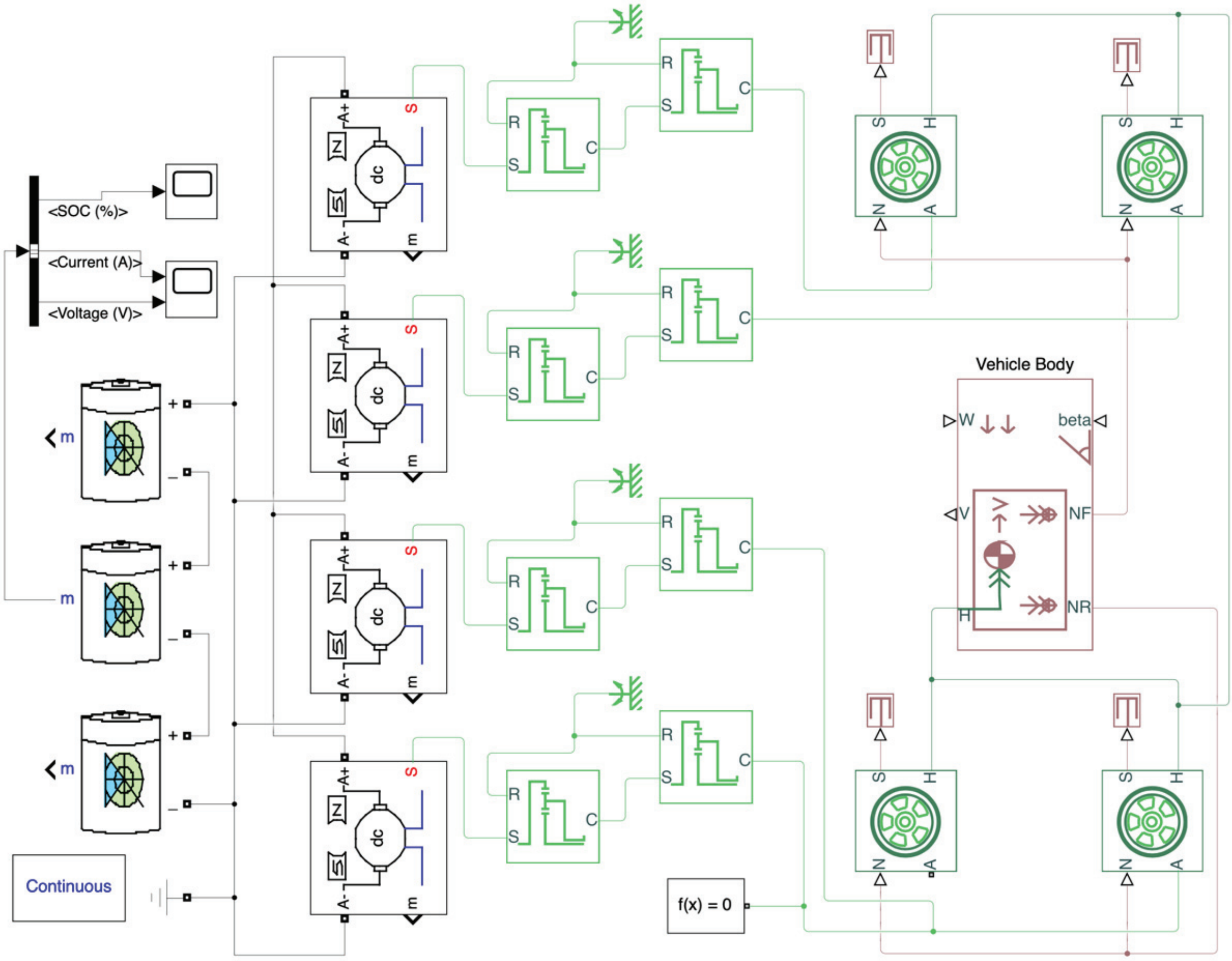

Fig. 4 MATLAB model of the UGV with LiIon accumulator

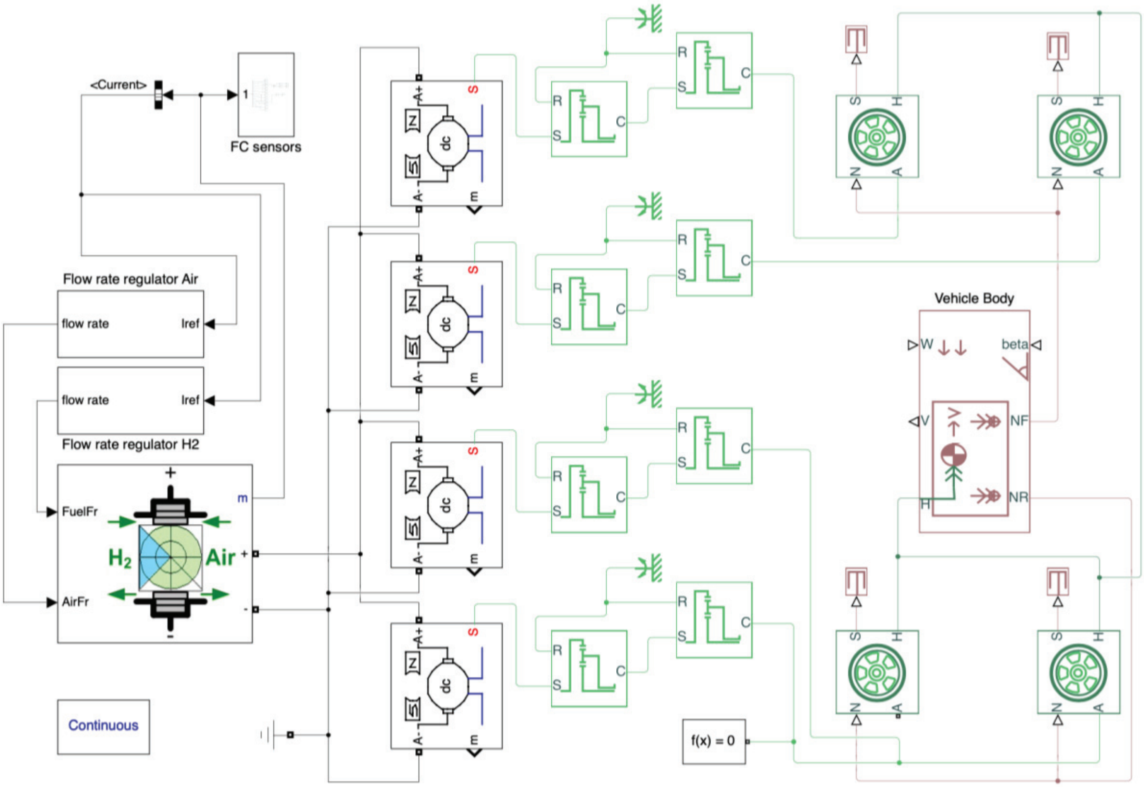

Fig. 5 MATLAB model of the UGV with fuel cells

Simulation results are shown in Fig. 6-9.

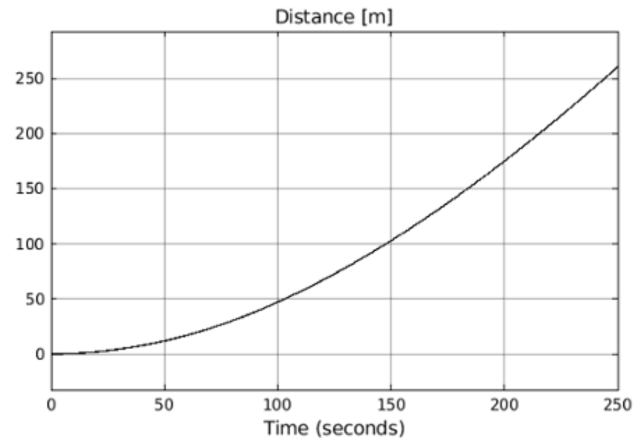

Fig. 6 Vehicle range with 3sLiIon 5Ah accumulator

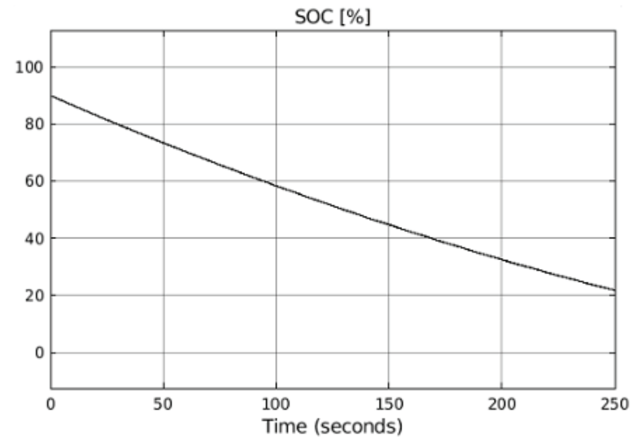

Fig. 7 Discharge curve of 3sLiIon 5Ah accumulator

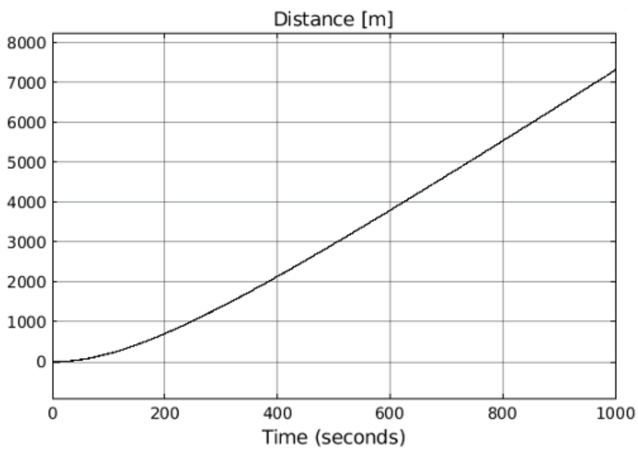

Fig. 8 Vehicle range with fuel cells

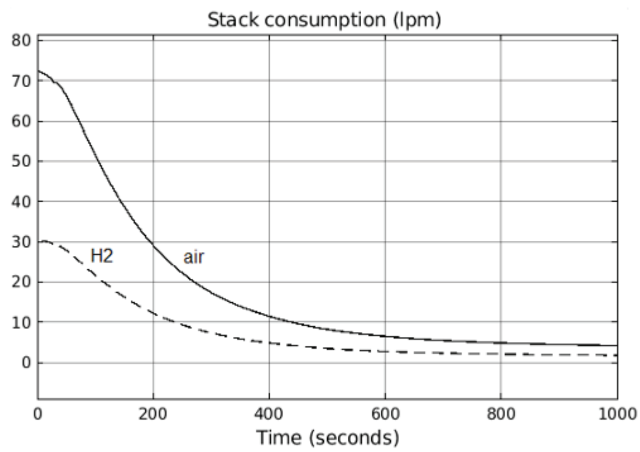

Fig. 9 Stack consumption of air and hydrogen

A vehicle which uses 3 LiIon batteries as the power source has an operating time of approximately 4 minutes. After this time the state of charge falls to 20 % and we can consider the vehicle as unusable. On the other side, vehicles with a power sources based on fuel cells, which has hydrogen tanks with a capacity of 118 liters will be operational for approximately 30 minutes.

5. Conclusions

The use of LiIon batteries for UGV propulsion is only justified for the smallest platforms. Vehicles that need to operate in a larger space must have a larger supply of energy. Solving this problem by increasing the number of LiIon batteries is not the right way for a small UGV (with small dimensions). The solution is offered by fuel cell technology.

Acknowledgements

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Proposal to Increase Safety at Railway Crossings in the Conditions of the Czech Republic

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Abstract

The article aims to find a rational solution in the field of increasing the safety of railway crossings in the Czech Republic. In the practical part, great emphasis is placed on assessing the current state of legislation. The identified discrepancies are resolved by adjusting the calculations of the view conditions and proposing changes to the erroneous provisions. The set of solutions consists in changing the way vertical and horizontal traffic signs are made and increasing the brightness of the warning lights. The task is to highlight and improve the visibility of crossings with regard to the safety of road users. All these modifications are designed to be applicable in as many cases as possible, while respecting economic indicators and requirements for technical feasibility.
KEY WORDS: *Railroad crossing, accident statistics, valid legislation, view triangle, railroad crossings security system, traffic signs, safety enhancement, rationalization*

1. Introduction

The Czech Republic belongs to countries with the highest railway density in Europe, with a total of 78,863 km2 and 9,408 km of railway lines [1]. The area of 1,300,000 km of railway networks highlights the necessity to build numerous multi-level intersections, with a total amount of 7,870 railway crossings [2, 3]. The high density of these intersecting lines (0.8 crossings per 1 km), their safety, technological and transport solutions are the central topic of this article [4]. All these junctions imply a risk of a road user crushing into a railway vehicle, a situation is not uncommon from the very beginning of railway transporting. The railway operators have always been on guard to prevent disastrous accidents by improving safety devices. A simple warning sign 'Watch for trains' and mechanical barriers have been supplemented by laser obstacle detectors to avoid collisions, which at the same time present the most up-to-date technology [5-8].

The article seeks a comprehensive solution to glaring inconsistencies between legislative, technical and public enlightenment-preventative measures on a representative sample of crossings within the Region of South Bohemia [9, 10] The locality is an optimal pick thanks to its geographic position, density of crossings and ongoing construction of the IV. Railway corridor. According to the statistics of The Railway Inspection Authority, the region also holds first ranks among the frequency of emergencies at the railway crossings [11].

2. Vertical and Horizontal Traffic Sings

The visibility of the obstacle itself is the central issue of this context. To deeper examine this hypothesis, we will have a look on crossing No. P5577 České Budějovice – Summerau ÖBB on 108,734th km in the vicinity of the stop of Kamenný Újezd (Figs. 1-2). The intersection has apparently failed to fully use all available railway signage [12-15].

The crossing is equipped with two light warning devices (LWD) AŽD 97 – PV with positive signalling. The warning lights do not come into operation until 80 km/h of critical running speed is achieved. The pictures show that an abandoned watchman's house prevents a good view of the railway from the left and a relay house hampers the outlook from the right. A local main road intersecting the railway is situated in the distance of 5.5 km from the axis of the outer track; however there is no warning sign indicating it. The driver coming from this direction and giving way can hardly see the sign or the track. He has to rely only on sound warning or reactions of road users coming from the main road. To ameliorate the current situation, the only plausible solution would be supplementing further warning devices, or erecting unpopular and in most cases useless signs č B 24a 'No right turn' and č B 24b 'No left turn' on the main road from the direction of Kamenný Újezd. The same would apply to the adjacent crossroad in the direction to a pub to the left behind the crossing. Apart from lacking warning signs and distance signal boards, the survey also revealed absence of other warnings such as horizontal traffic signage or fluorescent retroreflective backgrounds, crossbucks and signal devices [17, 18].

The crossing has recently witnessed a large number of collisions caused by the combination of its precarious positioning, insufficient signage and violation of traffic regulations (intentional or unintentional – in the event of drivers failing to notice the warning sign). It is surprising all the more because we deal with a relatively long, straight and clearly segment. However, the unhappy combination of the above-mentioned circumstances and LWD poses a high risk to road users. New blacktop on the roadway and modern construction of the crossing invite drivers to exceeding the speed limit so that many of them fail to slow down in due time. The motorists can thereby easily overlook the railway intersection which, on top of that, merges with its surroundings. The reaction time to the warning is therefore much longer. Practically, there is no possibility for the driver to spot the oncoming train. Neither the engine driver can clearly see the vehicle to avoid the collision by alerting sound signal 'Danger', or pulling the communication cord [19].

Fig. 1 Railway Crossing P5577, km 108,734, Stop Kamenný Újezd (source: author)

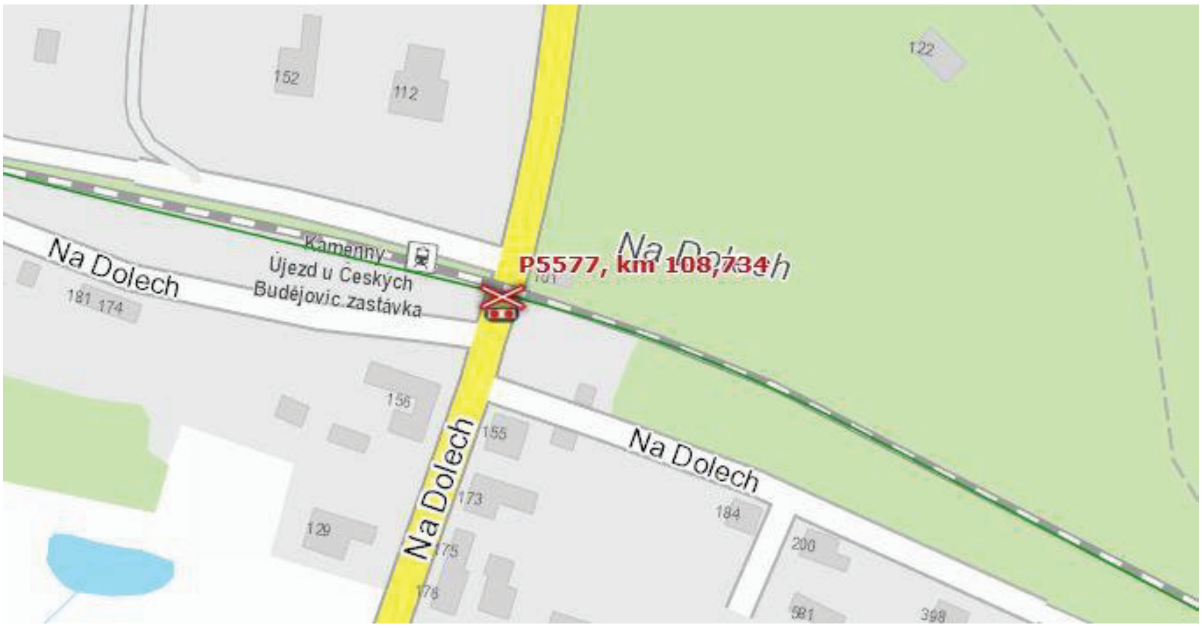
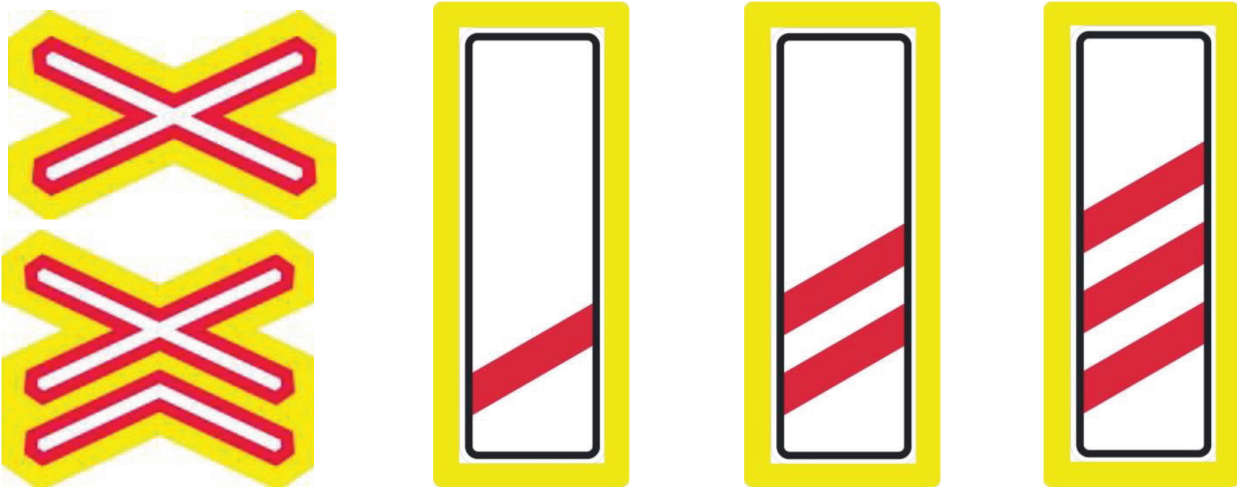


Fig. 2 Crossing P5577, situational scheme (source: [20])

The current state of the infrastructure and high traffic density calls for using all available facilities. Signal boards as the only distance warning signs are quite insufficient, not to mention their ineffective placement, poor technical condition, low amount or missing information about the number of tracks. The majority of other similar level crossings are unfortunately in the same poor conditions, which means that supplying more sophisticated safety equipment, for example crossing gates, would be very expensive and time-consuming. Our proposal thereby involves effective deployment of B 24a and B 24b signs on side roads and 'No turning' sign on the main road to guarantee greater safety. As has been mentioned above, these measures prevent longer vehicles from overlapping into the dangerous railway crossing. The next step includes negotiations with the road administration body and Police of the Czech Republic and providing vertical and horizontal signage with retroreflective fluorescent background.

Regulation No. 294/2015 Sb. as amended in No. 84/2016 Sb. and related technical conditions TP 65 directly stipulate the use and placement of traffic signs including their highlight in dangerous areas, such as this case. Technical conditions TP 133 lay down principles of horizontal signage. The combination of vertical and horizontal traffic signs without a sound signal given below is a perfect match for the general layout of the municipality.

In this case, the best solution is to use the following: retroreflective yellow-green fluorescent background for vertical traffic signs A 32a "Crossbuck for a single-track crossing", A 31a "Signal board (240 m), A 31b "Signal board (160 m), A 31c "Signal board (80 m) under Regulation No. 294/2015 Sb (Fig. 3). The detailed implementation and specific requirements are regulated in technical conditions TP 65. These stipulations limit using highlight "only to substantiated cases, as its excessive use would play down the seriousness of the imposed measures" – the argument which is fully respected in this article. Highlighting crossbucks has become a common practice within reconstructing or modernizing the current security system. However, the situation is completely different in the event of signal boards, which did not undergo any modification illustrated below in the Region of South Bohemia. Lenná et al (2013) argue that using the fluorescent background would be useful and highly effective on P5577 crossing and intersections with the similar lay-out. The price of such a non-standard upgrade goes about 5,000 CZK (depending on a producer).



a b c d

Fig. 3 Highlighted vertical traffic signs warning about a railway crossing (source: author): a − A 32a, A 32b – Crossbuck, single-track and multi-track lines; b − A 31c – Highlighted signal board (80 m); c − A 31b – Highlighted signal board (160 m); d − A 31a – Highlighted signal board (240 m)

Horizontal traffic signage has recently been promoted to a useful tool to warn drivers about imminent danger. This type of warning, however, must always be complemented by vertical traffic signs, as longitudinal lines are not clearly visible in winter months and may easily wear off from the passing traffic. Horizontal signs thereby need regular maintenance and service, which often take place no sooner than beyond the limit of its acceptable condition.

The Ministry of Transportation has recently recommended using V 5 'Stop line', which commonly marks a place where a vehicle should stop. However, its use often leads to a misinterpretation as indicated in Fig. 4. The illustration shows an inacceptable layout of V 1a 'Longitudinal solid line' continuing over the level crossing to both – left and right, which misleads the oncoming driver to continue driving. Sign V 5 is also wrongly placed as it is positioned in the axis vertical to the warning sign. Nevertheless, technical conditions recommend placing it within 4 metres from the signal board, with 2 metres as a minimum distance (TP 133, 2005). If a driver encounters such a chaotic situation, he cannot see the warning sign signal due to its narrow light beam. Thus, he exposes himself to unnecessary danger. The implementation of the signage should definitely comply with provisions in TP 133, with regard to local conditions.

Fig. 4 Ineffective implementation of horizontal traffic signage (source: author)

Failure to observe the regulations also results from highly unsuitable positioning of No. V 5 sign situated before the level intersection with crossbucks, supplemented by P 6 sign. Proved by the calculations, such an unhappy combination inevitably leads to increased danger. By pulling up a car at this point, Dp value (the length of the crossing measured in the axis of the road in metres) moves exactly by this distance. The equation shows that the minimum lookout field distance for the slowest vehicle Lp significantly extends. The road administration must thereby be informed to prevent this situation from happening by referring to a legally-effective regulation and technical conditions. This could be best done during traffic-safety events in collaboration with the Police of the Czech Republic.

The current wording of technical conditions providing for horizontal traffic signage offers a large scale of options how to make the traffic situation at the level crossing clearer; using a psychological-optical highlight effect involving a funnel-shaped arrangement of broken lines of 1-metre thickness vertical to the road axes in the distance of 5 metres from each other provides a fine example. No. V 15 sign 'Sign in a form of a notice' consists of a crossbuck including markings and design of combined letters allowed for special traffic situations. The size of the notice always depends on the speed limit allowed for the specific road. In this case, the speed in the municipality is restricted to 50km/h, which requires 2-metre letters and signs. The solution schemes below reflect the requirements for calmer traffic in the place concerned (Fig. 5).

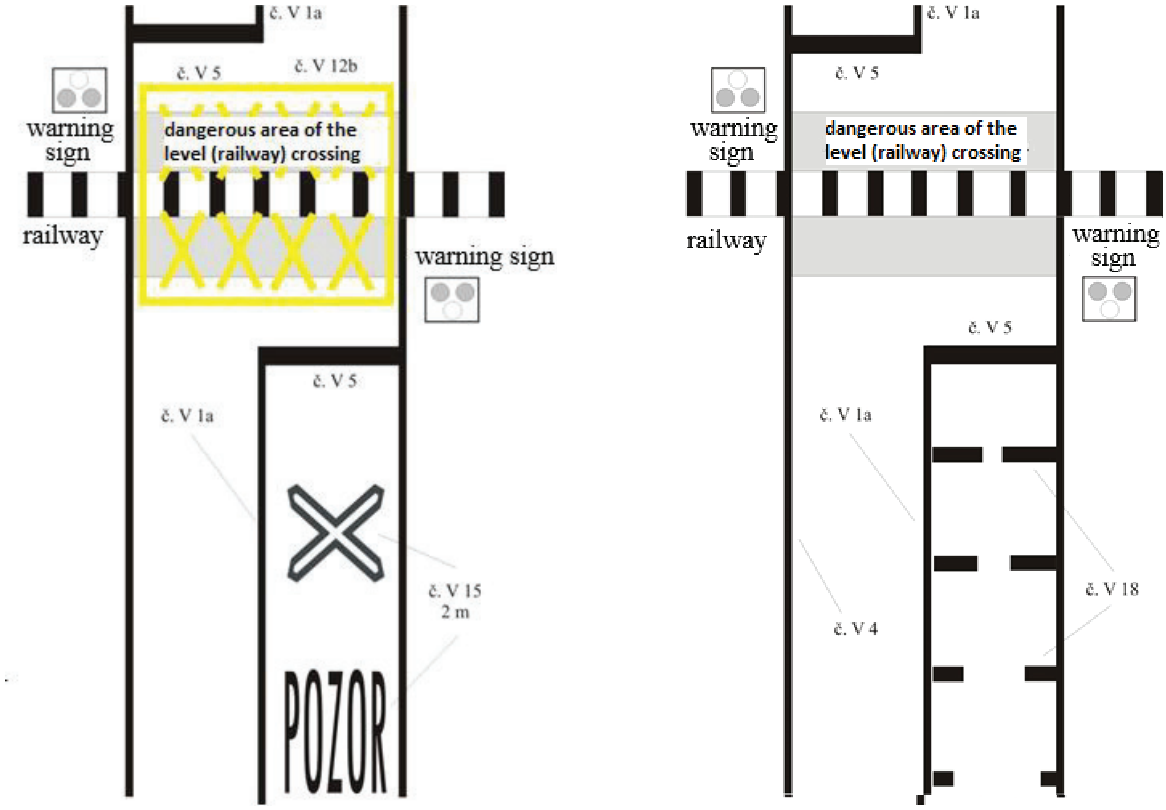


Fig. 5 A scheme of horizontal traffic signage at P5577 Crossing (source: [21], author's design)

The proposal on the left involves notices on the carriageway by combining letters and No. V15 crossbuck capped by stop line No. V5 within 4 metres before a signal board. The absence of No. B 24b 'No left turning' sign must be set off with No. V 12b yellow crossbucks between these two lines to ensure safety of vehicles coming from the direction of Kamenný Újezd. The crossbucks forbid a vehicle to pull up at such a place and prevents a situation when a vehicle turning to the side road just behind the level crossing stands in the dangerous area when giving way. Its driver must also ensure that he can manoeuvre his car through the dangerous segment without pulling up. Regarding a good view of the traffic on the main road, the action can easily be performed [22].

On the other hand, the scheme on the right counts on the optic highlight using optical-psychological disincentive. The imposed measures convey an impression of a narrowing road, persuading the driver to slow down. Although No. V 12b serves here the purpose well, No. B 24b 'No turning left' vertical traffic sign will better apply in this case. The implementation of the proposed measures is, however, subject to the consent of relevant administration bodies and approved project documentation.

3. Conclusions

Horizontal and vertical traffic signage suffers from a severe deficiency, which seriously endangers the passing traffic. Highlighting warning signs significantly reduces the risk of accidents. The proposed measures are thereby aimed at the maximum use of all available elements. Unfortunately, remedial actions already taken contain serious defects and as such are rather harmful. Selected railway crossings were subject to a detailed analysis regarding the identification of problematic places with a suggestion for correctional measures. The whole safety procedure is highly effective with a minimal effort and funds. Insufficient brightness of warning lights appeared to be a more complex issue. Their luminous intensity was compared with street traffic lights, observing the same parameters. The test revealed that highly luminous

LED diodes are the best alternative to complement the warning lights, as LWD are very ineffective and easily overlooked compared to other road signal boards. The effective legislation and everyday use casts doubts also upon the practicality of the white light signal, proving their application rather confusing and risky. Its cancellation would remove double speed restriction. The proposal also works on the assumption that it is the administrator who always takes the responsibility for the smooth operation of the device.

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Problems and Opportunities of Emission Reduction in Ports

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Abstract

Many ports are located near cities or even within limits of the cities. Large ships arrive and equipment, which is used in port area consume enormous amounts of fuel - have powerful engines, which generates big amounts of emissions. Much of the emissions is generated are borne by ports and cities themselves, and this has a negative impact on the environment and people. Reduce of emissions from shipping is provided in EU directives as well, as countries and cities are also trying to reduce emissions. The use of green and blue energy is one of the ways of reducing emissions generated in port areas. At the same time, there is no easy-to-use methods for determining the amount of emissions, which are generated.
This article presents methods for determining emissions from shipping (ships and port equipment) and provides a case study that attempts to demonstrate the acceptability of the proposed methods and the potential for reducing emissions by using LNG fuel for ships and in port facilities.
KEY WORDS: *shipping; ports; emissions from ships and port facilities, LNG fuels*

1. Introduction

Many ports are located close to living areas and emissions generated by ships and port facilities decrease living standards, make other environmental problems [1, 7]. At the same time, it is very difficult to receive correct data about the type and quantities of the emissions in particular places. The main emission generators in ports are ships and port equipment, which use a lot of fuel [2, 4]. For the decreasing of the emissions in ports and particular terminals, there are two main solutions: electrification of the ships and, especially, port equipment can dramatically decrease main emissions, and use more environmentally friendly fuels [3, 8, 11]. Investigation of the ships entering into port, stay and departures from the port, shows that good logistical organisation of ships entering in port and port operations of the ships can decrease fuel consumption and emissions up to 15 – 20% [5, 12, 16].

A nowadays international and national maritime organization looks for ways to decrease emissions from shipping and negative impact on environment, because maritime transport emits around 940 million tons of CO2 annually [6, 9, 10]. The negative impact of shipping on the environment is concentrated close to big ports like Shanghai, Rotterdam in Baltic Sea Gdansk, Klaipeda and others, as well on the main maritime ways, like Suez and Panama channels, approach channels or rivers to the big ports, like Elbe river, Yangtze river, Denmark straits and other areas [5, 7, 15].

Environmentally friendly fuels such as LNG can decrease emissions in all ways, for example, Sulphur oxides (SOx) and Particular Maters (PM), decrease CO2, NOx and CO emissions [11, 17]. Prepared emissions quantities evaluation and calculation methods were tested on full vision simulator and on the real ships on basis of fuel consumption, which resulted in good, correlation between theoretical and experimental results.

2. Emissions in Ports Situation and Literature Analysis

Emissions from shipping problem are recognized in many areas and it requests take measures to decrease emissions from ships and ports equipment [3, 7, 9]. It is estimated that the daily suboptimal operation of ships and port equipment increase energy consumption up to 15 – 18% [3, 7].

Conducted analysis of available literature shows that emissions decreasing for ships and port equipment could be on the basis using new environmentally friendly fuels and more widely using renewable energy sources [1, 2, 8, 13, 14].

Emission from ships and port facilities has a wide regulation framework. Stringent regulations were implemented by the IMO and the EU (i.e. within and beyond the SECA-limits) to reduce the sulphur emissions of ships and port equipment [5, 14]. IMO has tasked its members to achieve a 70% reduction in CO2 emissions by 2050, decarbonisation process is based on EU strategic documents, low-emission and zero-emission technologies in shipping [5, 9]. Furthermore, nitrogen emission control areas (NECA) in the Baltic Sea and the North Sea in 2021 are planned to be introduced [9, 10]. These and other restrictions significantly affect the functioning of shipping companies and seaports, as well as force them into actions measure to comply with environmental protection requirements [6, 17].

For the emissions analysis in ports were taken a few types and different parameters of ships and few types of terminals. Panamax and Post Panamax container carriers, tankers and bulk vessels were taken for the analysis. Selected type of the ships fuel consumption during entering in port from approach channel until terminal quay walls and from terminal to the open sea (outside of approach channel) was between 800 kg and up to 1200 kg on one way (approach or departure), during port operations fuel consumption mentioned ships were between 3000 kg and up to 4500 kg per day (24 hours).

3. Theoretical Basis for the Emission Evaluation and Calculation in Ports

Emission generation by ships engines and terminal equipment is based on engine's power, working time, and fuel consumption during ships entering into port, staying there and departure. At the same time, fuel consumption and engine power have strong relationship. Engine power can be calculated based on fuel consumption over a specific time, such as an hour and relative fuel consumption, as follows:

$$N = \frac{q_{kh} \cdot t}{q_k^{'}}, \tag{1}$$

where N − engine power, kW; q_{kh} − fuel consumption, kg; $q_k^{'}$ − relative fuel consumption, kg/kWh; t − engine operating (working) time, h.

At the same time, with the average engine power and fuel consumption and operating hours, the relative fuel consumption of the engine can be calculated as follows:

$$q_k^{'} = \frac{q_k \cdot t}{N}. \tag{2}$$

where q_k − amount of fuel consumed during time t, kg.

Ship engine power and ship speed are related in quadratic dependencies. In most of the cases, relative ship engine power and relative ship speeds can be used. For estimation of the relative engine power and the relative speed of the vessel, the graph obtained from the experimental results of more than 1000 vessels can be used.

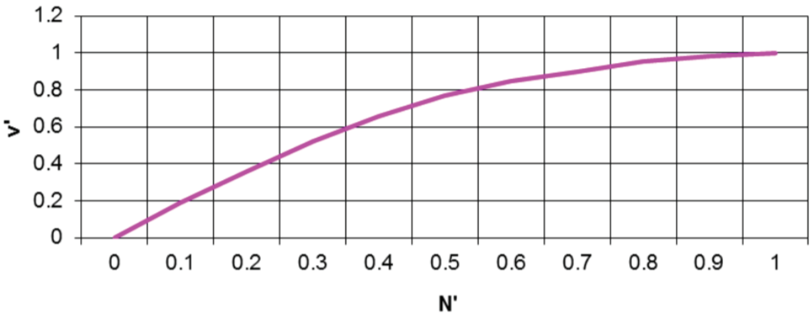

Fig. 1 Dependence of relative ship speed (v') on relative ship engine (N') ($v' = f(N')$)

The relative ship engine power N' and the relative ship speed (v') are calculated as follows:

$$N' = \frac{N}{N_n}; \tag{3}$$

$$v' = \frac{v}{v_0}, \tag{4}$$

where N_n − the rated power of the ship's main engine; v − ship's speed at ship engine power N; v_0 − the speed of the vessel at the rated power of the vessel's engine.

Due to the fact that ship's engines are powerful enough, ships consume a lot of fuel. Ships use a lot of fuel when sailing and use less fuel when standing in ports or an anchorages. The amount of fuel consumed by a ship is often calculated during the voyage or during another period. In general, the ship's fuel consumption during navigation (qLP) can be calculated as follows:

$$q_{LP} = q_L^{'} \cdot \sum N \cdot T_{PL}, \tag{5}$$

where $q_L^{'}$ − the relative fuel consumption of the ship during the voyage, for many ships the relative fuel consumption of the main and auxiliary engines ranges from 0.13 to 0.25 kg/kWh (more precise data can be taken from the engine specifications of a particular ship); $\sum N$ − total average power of main and auxiliary engines during navigation; T_{PL} − the ship's sailing time in hours, for example during the voyage, in a separate voyage period and so on.

Auxiliary engines and the ship's boiler are left switched on when the ship is in port or at berth in the port accesses. The amount of fuel consumed while a ship is in port or at port access (q_{SL}) can be calculated using the formula:

$$q_{SL} = q'_{SL} \cdot \sum N_{SL} \cdot T_{SL}\,, \tag{6}$$

where q'_{SL} − the relative fuel consumption of the ship during berthing in the port or at the port approaches, for most of the ships' auxiliary engines and the relative fuel consumption of the boiler ranges from 0.20 to 0.30 kg/kWh (more precise data can be taken from the ship engine specifications); $\sum N_{SL}$ - the total average power of the auxiliary engines and the boiler or boilers at the berth or port approaches; T_{SL} − the total average power of the auxiliary engines and the boiler or boilers at the berth or port approaches.

The amount of fuel used by terminal tractors per year at the terminal (q_{kV}) can be calculated using the formula:

$$q_{kV} = 365 \cdot 24 \cdot n_V \cdot q'_V \cdot k_{V,N} \cdot k_{V,T} \cdot N_V\,, \tag{7}$$

where n_V − number of terminal tractors in the terminal; q'_V − relative fuel consumption of terminal tractors, for most diesel engines of terminal tractors the relative fuel consumption is from 0.30 to 0.40 kg/kWh (more precise data can be taken from the specifications of specific tractor engines); $k_{V,N}$ − power utilization factor of terminal tractor engines; $k_{V,T}$ − time factor of use of terminal tractors; N_V − engine power of terminal tractors.

For the calculation of emissions, formulas are used, the components of which are: the amount of fuel consumed, the actual engine power used and the relative size of specific emissions. In this way, the carbon dioxide content is calculated using the following formula:

$$CO_2 = Q_k \cdot \Delta CO_2\,, \tag{8}$$

where Q_k − total fuel; ΔCO_2 - carbon dioxide factor, which is from 3.0 to 3.5 for petroleum products (diesel, heavy fuel oil), from 2.5 to 2.9 for LNG.

The sulfur oxide content can be calculated using the following formula:

$$SO_x = Q_k \cdot \Delta SO_x\,, \tag{9}$$

where ΔSO_x − the coefficient of sulfur oxides, which depends on the type of fuel: for petroleum products it is between 0.001 and 0.035, for LNG it is about 0.

The carbon monoxide content can be calculated using the following formula:

$$CO = N_{vid} \cdot \Delta CO \cdot \frac{t}{60}\,, \tag{10}$$

where N_{vid} − average engine power over a period of minutes (t); ΔCO − carbon monoxide factor, depending on the engine type.

The amount of nitrogen oxides generated can be calculated using the formula:

$$NO_x = N_{vid} \cdot \Delta NO_x \cdot \frac{t}{60}\,, \tag{11}$$

where ΔNO_x − nitric oxide factor depends on the engine type.

The amount of particulate matter (PM) generated can be calculated using the formula:

$$PM = N_{vid} \cdot \Delta PM \cdot \frac{t}{60}\,, \tag{12}$$

where ΔPM − particulate matter coefficient, depending on engine type and fuel type, for oil products it can be up to 10 g/kWh, for LNG fuel it is close to zero.

Presented theoretical basis for the emissions reductions in ports was used for the case study of container terminal.

4. Case Study of the Emissions in Port and Decrease

As the case study is taken container terminal, which have capacity of 1 mil TEU. Average containers quantity incoming and outgoing on a single container vessel is 4000 TEU. Number of the container vessels is 250 per year. Vessels speed in port are is 8 knots, sailing time in port area (entry into port, mooring, unmooring and departure) is 4 hours, ships main engine average power during sailing 5 MW, during loading operations in port axillary engine power 1,5 MW. Number of STS (shore to ship) is cranes 6. Number of RTG cranes -20, engine power 200 kW, number of terminal tugs – 25 and engine power 120 kW; other equipment number 20 with average engine power 110 kW, utilisation coefficient 0,7; power and time utilization factors of terminal equipment 0,7; the relative fuel consumption of the ship 0,18 kg/kWh; terminal equipment relative fuel consumption 0,25 kg/kWh. Ship and terminal equipment use diesel fuel and LNG.

On basis theoretical basis presented in section 3, were received next results: number of vessels per year 250; ships sailing time in port area per year 2000 h; ships staying in port about 5200 hours; diesel fuel quantity, which used ship and terminal equipment about 17900 t/year and LNG – about 15560 t/year.

Emissions, which generate ships and port equipment in case of used diesel fuel per year, looks as follows: CO2 – about 57236 t; SOx – about 18 t; CO – about 350 t; NOx – about 700 t; PM – about 35 t.

Emissions, which generate ships and port equipment in case of used LNG fuel per year, looks as follows: CO2 – about 34200 t; SOx – about 0 t; CO – about 210 t; NOx – about 200 t; PM – about 0 t.

It should be also mentioned that fuel type, like LNG, methanol, ammonia fuels and operation optimisation can decrease emissions volumes up to 30 % or even more.

5. Conclusions

In navigational channels, access to the ports and in ports decrease emissions from ships and port equipment is very important due to the big concentration of the ships and port equipment. Calculation possibilities of the emissions in ports and other intensive shipping areas are very important to decide measures which are necessary take to decrease the impact on environmental in such important areas.

The methodology for the emissions calculated presented in this article, where tested and shown possibilities used in intensive shipping areas that will be possible take precaution measures to decrease emissions based on new more environmentallly friendly fuels using, optimize port operations.

Operation optimization in ports terminals and using more environmentally friendly fuels, like LNG, can decrease CO2, NOx and CO emissions from ships and port equipment up to 30%, and SO_x and PM emissions up to 100%.

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Setting Dynamic Problem of Logistic Support of Building Objects by Material Resources Taking into Account Random Factors Affecting Transportation Timing

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Abstract

This article considers deterministic (e.g. the exact time at which to deliver the goods, dimensions and characteristics of the vehicle, route length, waiting time in line, loading and unloading time) and non-deterministic factors (e.g. transport breakdowns; accidents; weather conditions; the time that the vehicle is at the consumer's after unloading; downtime due to non-payment; breakdowns of machines and mechanisms; low-quality materials; delays in subcontractors) that affect the time of transportation and the time of the beginning of the use of material resources.
Having identified the main deterministic and non-deterministic factors, it was made the analysis of existing models for solving the problems of organizing the provision of construction facilities with material resources without delays in time. It was determined that the existing models could not fully solve the problems associated with the peculiarities of the construction industry. The following factors are not taken into account: random factors that affect transportation, which increases the maximum cost, the specifics of the construction industry, which leads to inconsistencies, and as a consequence, the false results of the objective function.
Schedules were drawn up for the supply of construction resources by the transport organization and the use of the resources mentioned by the construction organization, taking into account random factors that affect the time of transportation. By intersecting these two graphs, two main equations that affect the time of transportation and the time of commencement of material resources and the relationship between these equations were identified.
Based on those equations, two target functions were drawn up, one of which takes into account the additional costs of the transportation organization logistics and the time for waiting for transporting, the other takes into account the additional costs of the construction organization for delays in starting work.
KEY WORDS: *deterministic factors, non-deterministic factors, transport time*

1. Introduction

The specifics of construction, as an industry, include the need to supply building materials, structures, and finished products to the construction site. Depending on the type or type of object being built, there is a difference in building materials. For example, for the construction of bridges or high-rise constructions, from monolithic reinforced concrete, constant receipt of concrete mix or components for its manufacturing is required [11-12]. Such materials can also include supporting steel, metal structures or formwork for concreting. Delays in the supply of materials or structures for such facilities can cause downtime, leading to significant losses for the construction organization. Conversely, delays in obtaining materials and resources direct to transport costs due to delays.

As it is known from practice, very often there are situations when there is a delay in the transportation, in the supply of construction materials or the construction organization does not invest in time, due to which the additional costs are required to be determined, those depending on the delay time of the construction or transport organization [13].

These delays can be caused by various factors. In [1-3], deterministic and non-deterministic factors that may affect the time of transportation of construction materials, and as a consequence, affect the formation of the initial conditions of the task of organizing the provision of material resources of construction sites were considered.

Deterministic factors known before the start of transportation of building materials include [2-4, 15]: the exact time at which to deliver the goods, dimensions and characteristics of the vehicle, route length, waiting time in line, loading and unloading time.

Non-deterministic unpredictable factors include [2-4, 14]: transport breakdowns; accidents; weather conditions; the time that the vehicle is at the consumer's after unloading; downtime due to non-payment; studies of machines and mechanisms; low-quality materials; delays in subcontractors.

All these factors affect the conditions of transportation of construction materials and, as a consequence, the provision of construction facilities with material resources may lead to downtime on construction sites and non-compliance with contractual obligations and increase of construction time.

2. Main Part

In [5], linear models of supplying material resources to the point of consumption were presented. These tasks solve routine, simple tasks concerning the supply of materials, the optimal distribution of materials without residues and with maximum revenue. However, these models do not include random factors that affect transportation, which increases the full cost.

In [6], a linear model and algorithm for solving supplying construction materials to the construction site, taking into account random factors and characteristics that affect the transportation time and the final target function were developed. The disadvantage of this model is its bulkiness. This is due to the fact that in this algorithm there are five target functions, each of which corresponds to a specific situation, with a delay in delivery.

In works [7-10] the formulations of dynamic transport problems for the supply of materials taking into account the time characteristics, are presented. The disadvantage of the presented algorithms is that they do not take into account the specifics of the construction industry, which leads to inconsistencies, and as a consequence, the false results of the objective function.

To set a dynamic problem to provide construction sites with material resources, taking into account random factors that affect the time characteristics of transportation, we formulate the following initial conditions.

Suppose it is the starting point of the route of transportation of material resources, i.e. it is the loading point of transport. J is the endpoint of the route of transportation of material resources, i.e. it is the point of unloading of transport.

From here, we can conclude that the total ideal transport time is $t_{ij}(t)$ and the total ideal route length is $S_{ij}(S)$, where t and S are direct functions corresponding to the time and length of the route, respectively.

Then $\tau_{ij}(t)$ - ideally corresponds to the point of time of unloading of material resources and the point, respectively, the beginning of their use. In practice, these two points are different and will be able to change by random variables, depending on the above factors. We represent these quantities as $\pm\varphi_j(t)$ and $\pm\omega_j(t)$. Where $\pm\varphi_j(t)$ is a random time value of delay or early delivery of material resources, and $\pm\omega_j(t)$ is a random time value of delay or early start of consumption of material resources.

Taking into account that and setting the time characteristics that consider the influence of deterministic and non-deterministic factors on the time of transportation and use of building materials, we determine the points of time of unloading material resources and points of their use, taking the form $\tau_j(t) \pm \varphi_j(t)$ and $\tau_j(t) \pm \omega_j(t)$, respectively. Suppose that the time transportation schedule of material resources and time of the beginning of consumption take into account random factors (Fig. 1-2).

It should be noted [6] that based on the characteristics of the construction industry, it is necessary to specify the maximum (t_{max}) and minimum consumption time (t_{min}) of building materials because, for example, for concrete mix, it can not be brought before installed formwork and later required mobility of concrete mix.

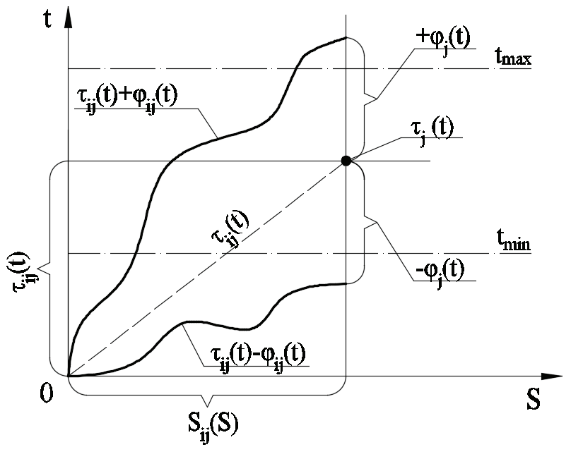

Fig. 1 Transportation schedule $\tau_{ij}(t) \pm \varphi_j(t)$

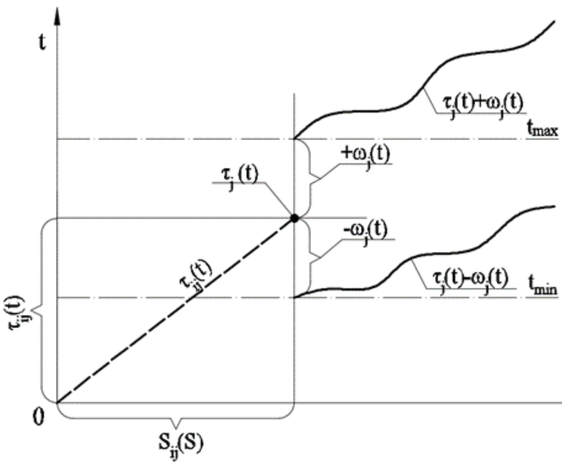

Fig. 2 Graph of usage $\tau_j(t) \pm \omega_j(t)$

Based on the given graphs $\tau_{ij}(t) \pm \varphi_j(t)$ and $\tau_j(t) \pm \omega_j(t)$ it can be concluded that under some conditions of the intersection of the two graphs, the losses from delay or early delivery of construction materials will be equal to zero. Also, under some conditions of the intersection of the two schedules, the losses from the early or late start of work will be zero. The intersection of the two graphs is shown in Fig. 3.

In [6], four possible cases of crossing the schedules of supply of construction materials and the beginning of the use of these materials were considered, namely:

1. Delayed delivery and the start of work ahead of schedule - maximum costs of the construction organization due to downtime crews;
2. Delivery of the previously specified term and the beginning of works later than the planned schedule - the maximum expenses of the transport organization because of transport delay;
3. Delivery of construction materials and the start of work with a delay - the costs are zero because the end of the

delivery schedule coincides with the plan of work;

4. Delivery of construction materials and the start of work before the specified date - the costs are zero, because the end of the delivery schedule coincides with the schedule of work.

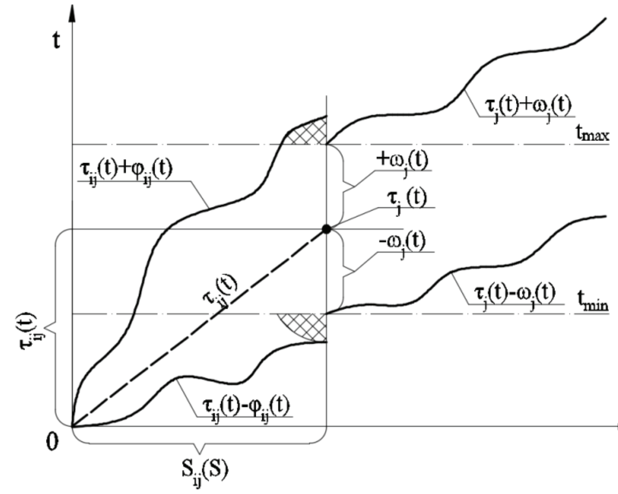

Fig. 3 Intersection of graphs $\tau_{ij}(t) \pm \varphi_j(t)$ and $\tau_j(t) \pm \omega_j(t)$

These intersections are also valid for the dynamic task of providing construction sites with material resources, but it should be noted that the supply schedule may go beyond (due to non-deterministic factors) the maximum (tmax) and minimum (tmin) time of use of these building materials.

If the condition $\tau_{ij}(t) \pm \varphi_j(t)$>tmax is met, the losses are borne not only by the construction organization due to idle crews but also by the transport organization, as there is a high probability of loss of the necessary parameters of material resources.

If the condition $\tau_{ij}(t) \pm \varphi_j(t) <$ tmin is met, then the losses are borne only by the transport organization because the transport with construction materials arrived earlier, before the preparatory scheduled time.

Having considered possible intersections of schedules of delivery of building materials and the beginning of the use of this material, we will define three potential cases of additional expenses depending on time of a delay:

1. If $\varphi_j(t) = \omega_j(t)$ (1) or $-\varphi_j(t) = -\omega_j(t)$ (2) - there are no additional costs, i.e. they are zero, because the delay or advance of delivery and consumption is equal to one one;

2. If $\varphi_j(t) < \omega_j(t)$ (3) or $-\varphi_j(t) > -\omega_j(t)$ (4) - the costs for waiting at the transport organization will approach the maximum because in this case the start time is later during the delivery of construction materials;

3. If $\varphi_j(t) > \omega_j(t)$ (5) or $-\varphi_j(t) < -\omega_j(t)$ (6) - the costs of delaying the start of work in the construction organization will approach the maximum because the delivery time of construction materials is delayed according to the time of the beginning of works.

Consider Eqs. (1) and (2). If we move the right part of the equation to the left and equate the values to zero, we obtain the same Eq. (7):

$$\varphi_j(t) - \omega_j(t) = 0. \tag{7}$$

We can state that with the difference between the delay of delivery time and the delay of consumption time, the cost of these delays will be zero.

Consider Eqs. (3-6). We get rid of the minus sign in Eqs. (4) and (6) by dividing them by -1, and we obtain Eqs. (3) and (5), respectively, i.e., the value of Eq. (3) corresponds to Eq. (4), and Eq. 5) corresponds to Eq. (6).

After analyzing Eqs. (1-6), we can conclude that there are two main variables of equations, namely, (3) and (5), based on which we make two objective functions to determine the cost of transportation and use of building materials, taking into account possible non-deterministic factors, affecting the time of transportation and start of use, and as a consequence, additional costs (option with the loss of material of required indicators, in this case, is not considered):

$$L_1(x) = c_1 \cdot n + c_2 \cdot t_{ij} + \int_{\omega_j}^{\varphi_j} c_2 \cdot tdt + c_3 \cdot t_{j,j+1} \rightarrow min\,; \tag{8}$$

$$L_2(x) = c_1 \cdot n + c_2 \cdot t_{ij} + c_3 \cdot t_{j,j+1} + \int_{\varphi_j}^{\omega_j} c_3 \cdot tdt \rightarrow min\,, \tag{9}$$

where c_1 – the cost of building materials; n – the number of building materials supplied; c_2 – the cost of transportation per unit time; t_{ij} – transportation time; c_3 – the cost of wages to employees of the construction company per unit time; $t_{j,j+1}$ – the time during which the construction organization performs this type of work.

In order to determine the variables $\varphi_j(t)$ and $\omega_j(t)$, it is necessary to establish the actual values of delivery time of construction materials (t_{fact1}) and the actual start time of works (t_{fact2}), where using formulas 10 and 11 to set variable time values:

$$\varphi_j(t) = t_{fact1}-\tau_j(t); \quad (10)$$

$$\omega_j(t) = t_{fact2}-\tau_j(t). \quad (11)$$

Based on the equations of the objective function, we make an algorithm for solving a dynamic problem of providing construction sites with material resources, taking into account random factors that affect the time characteristics of transportation and use of resources and which will consist of the following steps:

1. We define the initial data (quantity of construction materials supplied; cost of construction materials; cost of transportation per unit time; planned time of transportation; wage costs of employees of the construction organization per unit time; time for which the construction organization performs this type of work, maximum and minimum delivery time and start time);
2. We define the deviation in time from the planned delivery time and start time;
3. We compare the obtained values of deviation from the planned delivery time and the planned start time. Depending on the predominant value, we define which organization bears the additional costs;
4. Using specific formulas of the objective function, we define the quantitative value of additional costs borne by the transport or construction organization.

The block diagram of the algorithm for solving the dynamic problem of providing construction sites with material resources, taking into account random factors that affect the time characteristics of transportation in a dynamic setting, is shown in Fig. 4.

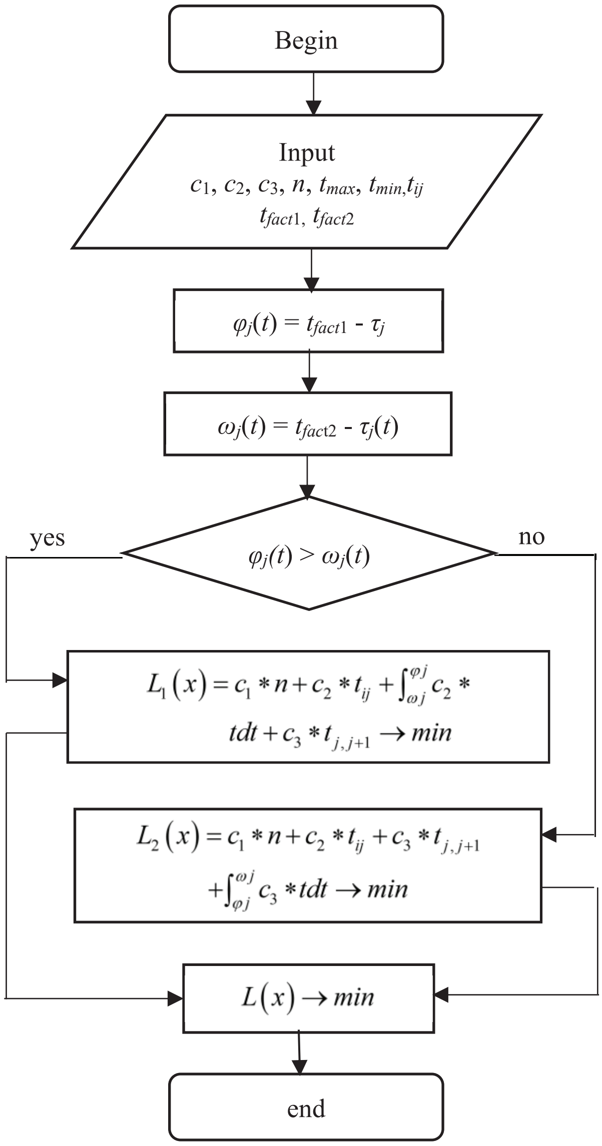

Fig. 4 Block diagram of the algorithm for solving the dynamic problem of providing construction sites with material resources, taking into account random factors that affect the time characteristics of transportation and the beginning of the use of resources

3. Conclusions

Two target functions were drawn up, one of which takes into account the additional costs of the transportation organization logistics and the time for waiting for transporting, the other takes into account the additional costs of the construction organization for delays in starting work.

After analyzing the target functions, the algorithm for solving a dynamic problem of providing construction sites with material resources was developed, taking into account random factors that affect the time sites with material resources was compiled, taking into account random factors that affect the time characteristics of transportation and the beginning of resource use, which can determine the additional costs of both transportation and construction organizations.

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Proposals for Improving Mobility in the City of Pardubice and its Surroundings Through Selected Measures

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Abstract

Currently, the main topic of public transport entities is the effort to make this service more attractive. As a result of the COVID-19 pandemic, there have been significant declines in passenger transport due to the forced decline in mobility. It is still appropriate to look for various solutions and measures to bring public transport back to the forefront of means of transport within the city. The authors of the article, using various measures and solutions, which they deal with in their dissertations, propose to improve mobility by public transport within the city of Pardubice and its surroundings. The proposals will be addressed, for example, in terms of synergies between urban public and regional / suburban transport (eg integrated transport systems), preferential measures for urban public transport vehicles on local roads, or synergies between urban public and individual transport (eg. parking systems). The aim of the article is, in addition to the mentioned proposals, also to point out weaknesses in the determined infrastructure.
KEY WORDS: *synergy between means of transport, public transport preferency, city mobility, park and ride systems, Pardubice region*

1. Introduction

The city of Pardubice is located 100 km east of Prague. It is a city with over 90,000 inhabitants. Together with Hradec Králové and Chrudim, it forms a polycentric East Bohemian agglomeration. A railway transit corridor of European importance passes through Pardubice, namely the East Mediterranean Corridor and the Rhine-Danube Corridor. As part of road transport, Pardubice is connected to a high-capacity road of the motorway type leading to Hradec Králové, where it is then connected to the motorway network. There is also an international airport in Pardubice (IATA: PED, ICAO: LKPD). It is therefore clear that this is an important transport point from the position of the Czech Republic, which is clearly reflected in the traffic load, which is caused both by transit traffic and as a destination for transport routes.

2. Current Status

Between 2017 and 2018, a survey of traffic behavior was conducted in Pardubice, which was attended by 1,004 households, of which 606 were households from the surrounding municipalities. This survey showed that 52% of all journeys made by car in Pardubice are made by residents of the surrounding municipalities who commute to Pardubice [1].

Fig. 1 Representation of traffic intensity in Pardubice [2]

Another interesting view is based on traffic intensities on roads leading to Pardubice available from the national census of traffic carried out by a state organization – Ředitelství silnic a dálnice. Fig. 1 shows the traffic intensities in Pardubice in 2010 (situation on the left) and in 2016 (situation on the right). At first glance, it is clear from the picture that between the mentioned years there was an increase in traffic intensity on almost all roads.

For better orientation, Table 1 is attached below, which shows the absolute data from the mentioned roads.

Table 1

Traffic intensities on roads leading to Pardubice expressed in absolute values [2]

2010					2016					
Road	From direction	Intensity in 24h	Φ I in 1h	Φ I in 1min	Road	From direction	Intensity in 24h	Φ I in 1h	Φ I in 1min	Δ I in 24h
I/2	Přelouč	11 363	473	8	I/2	Přelouč	11 464	478	8	101
I/36	Sezemice	9 480	395	7	I/36	Sezemice	8 455	418	7	-1 025
I/37	Chrudim	10 000	417	7	I/37	Chrudim	15 548	648	11	5 548
I/37	Hradec Králové	10 800	450	8	I/37	Hradec Králové	16 794	700	12	5 994
II/211	Lázně Bohdaneč	6 685	279	5	II/211	Lázně Bohdaneč	10 015	417	7	3 330
II/322	Dašice	4 684	195	3	II/322	Dašice	4 671	195	3	-13
II/324	Chrudim	1 376	57	1	II/324	Chrudim	4 441	185	3	3 065
II/324	Hradec Králové	6 023	251	4	II/324	Hradec Králové	5 824	243	4	-199
II/355	Hrochův Týnec	1 641	68	1	II/355	Hrochův Týnec	2 288	235	4	647
III/2985	Ráby	3 472	145	2	III/2985	Ráby	3 181	133	2	-291
III/3239	Dolany	1 269	53	1	III/3239	Dolany	1 486	62	1	217
III/32226	Dubany	2 686	112	2	III/32226	Dubany	3 712	155	3	1 026
III/34026	Chrudim	4 979	207	3	III/34026	Chrudim	5 841	243	4	862

From the above, there was an increase of more than 5.5 thousand cars per day on 2 1st class roads, which represents an increase of about 4 cars in 1 minute. Further on 2 roads II. class, there was an increase of more than 3,000 cars in 24 hours, which represents an increase of about 2 cars in 1 minute. Although there was a decrease on 4 sections, it is only possible to work seriously with the section on the I/36 road, where there was a decrease of a thousand cars per day. Other regression sections should be taken with a grain of salt, as there has been a change in the level of statistical error.

It is therefore a clear fact that the burden on the city's transport infrastructure continues to grow. This trend was further helped by the ongoing COVID-19 pandemic, where according to current surveys, people do not like public transport passengers because they are concerned that they will become infected with COVID-19. This statement is confirmed by a study carried out in the Polish city of Gdańsk, which found that only 74% of people would return to public transport after the end of the pandemic [3]. In Pardubice itself, there was an increase in car journeys of up to 10% [4] during the first wave (March-June 2020) of the pandemic. Due to the fact that currently there is only one intercepted parking lot in Pardubice, which is oriented only for access from the south to the city, it can not be used to collect traffic that goes to the city, which worsens the traffic situation in the center cities and thus creating increasing pressure on transport infrastructure at ease. Its location in the former TGM barracks is shown in Fig. 2.

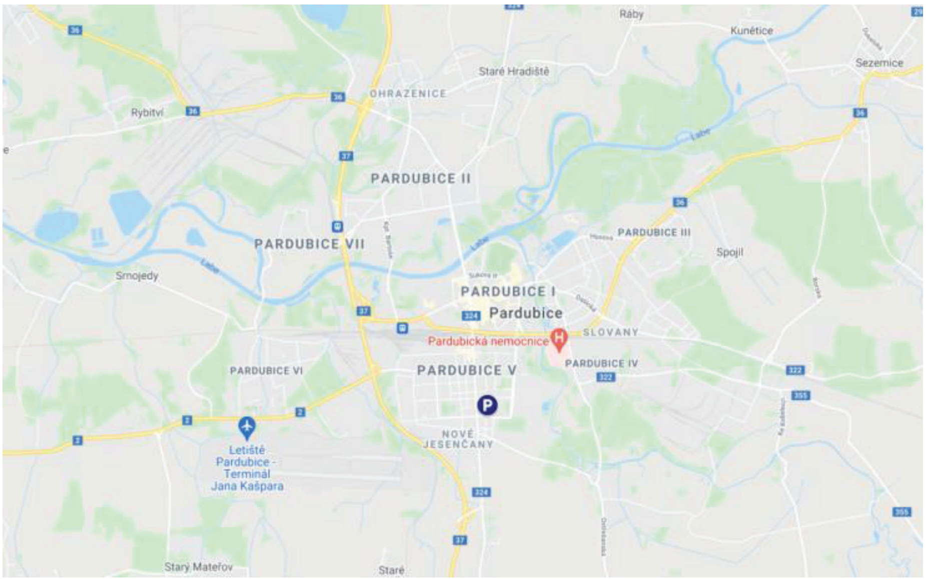

Fig. 2 Location of the P + R car park. Source: authors based on Google Maps

Fig. 2 shows that the location of the current parking lot is not very attractive. First, it is not close to any train station or bus station. The advantage is certainly its price, which is in the price of 5 CZK (0.19 €, or $ 0.23) for 24 hours of parking, and that the parking lot is open non-stop. However, a clear disadvantage is its coverage by public transport, where there are 2 public transport stops in its immediate vicinity, but as Table 2 shows, their coverage is not very attractive. And although at first glance it may seem that there are a large number of lines and there could be synergies resulting from the interleaving of these lines, the reality is that in a large number of cases there is more of a parallel run.

Table 2

Period for individual lines serving the parking lot [5]

	Stop	Zborovské náměstí						
	Distance from P+R	250 m						
	Line	1	6		7		18	27
	Direction	Masarykovo náměstí	Rosice	Dukla	Globus	Dukla	Rybitví	Zdravotní škola
Workday	Period (04-09)	15 min	-	-	8-23 min	30 min	60 min	30 min
	Period (09-13)	15 min	15 min	15 min	30 min	30 min	60 min	30 min
	Period (13-19)	15 min	10 min	10 min	30 min	30 min	60 min	30 min
	Period (19-24)	30 min	-	-	30 min	20-40 min	60 min	-
	Period (24-04)	-	-	-	-	-	-	-
Weekend	Period (04-09)	30 min	-	-	30 min	60 min	60-120 min	-
	Period (09-13)	30 min	20 min	20 min	30 min	30 min	60-120 min	-
	Period (13-19)	30 min	20 min	20 min	30 min	30 min	60-120 min	-
	Period (19-24)	30 min	-	-	30 min	30 min	60-120 min	-
	Period (24-04)	-	-	-	-	-	-	-

	Stop	U Kapitána				
	Distance from P+R	200 m				
	Line	6		10	27	98
	Direction	Rosice	Dukla	Univerzita	Zdravotní škola	Staré Čívice
Workday	Period (04-09)	-	-	10-30 min	30 min	-
	Period (09-13)	15 min	15 min	30-60 min	30 min	-
	Period (13-19)	10 min	10 min	20 min	30 min	-
	Period (19-24)	-	-	60 min	-	-
	Period (24-04)	-	-	-	-	60
Weekend	Period (04-09)	-	-	30-60 min	-	-
	Period (09-13)	20 min	20 min	30-90 min	-	-
	Period (13-19)	20 min	20 min	60 min	-	-
	Period (19-24)	-	-	30-60 min	-	-
	Period (24-04)	-	-	-	-	60

3. Proposed Measures

For the reasons described in the last chapter, it is clear that Pardubice needs to effectively manage the growing number of journeys made by individual car transport, a higher number of intercepting parking lots, which could take all directions. Subsequently, it would be necessary to ensure a smooth and carefree transfer to public transport or public transport (ITS – Itengrated transpot systém), which would operate in a meaningful period throughout the day, so that it can not only satisfy regular commuters, but also passengers who arrived occasionally, whether for cultural events, by plane or by long distance train. Another need is then to ensure tariff interconnection and convenience.

Location of P + R car parks

P + R car parks should be created at the entrance points to the city, where they will not only offer an easy transfer to public transport, but also, if possible, to rail transport. Furthermore, they should be located near industrial zones, so that they can play the role of parking lots for employees of major companies in the city.

In this particular case, it is proposed to build a parking lot on the road I/2 in the area of Technopark Pardubice, where it is possible to connect not only with the industrial area, but also to create a railway connection to passenger trains in the route Kolín - Pardubice - Česká Třebová. On the road I/36 from the direction of Sezemice, the Dubina shopping center seems to be a suitable option, where it is possible to combine parking in the parking lot with shopping, so that the journey is more pleasant for the passenger. On the road I/37 from the direction of Hradec Králové, it seems to be an ideal possibility to build a parking lot near Stéblová, where there would be synergy with the road II/324 and the creation of a railway connection to passenger trains Pardubice - Hradec Králové - Jaroměř. From the direction of Chrudim, a catchment car park should be built in the north of the village of Dražkovice, thanks to which there would be synergy with roads II/324 and III/34026. The parking lot for the road II/211 is ideal to build near the village of Lázně Bohdaneč, thanks to which not only will there be a collection point for Pardubice, which can be served by a trolleybus line, but also the spa town and the Semtín industrial zone. The last interception parking lot should be built in the Černá za Bory industrial zone, so that traffic intensities are collected from roads II/322 and II/355. Their location is then shown in the map shown in Fig. 3. Fig. 3 shows the proposed P + R car park in red, the current P + R car park is shown in blue.

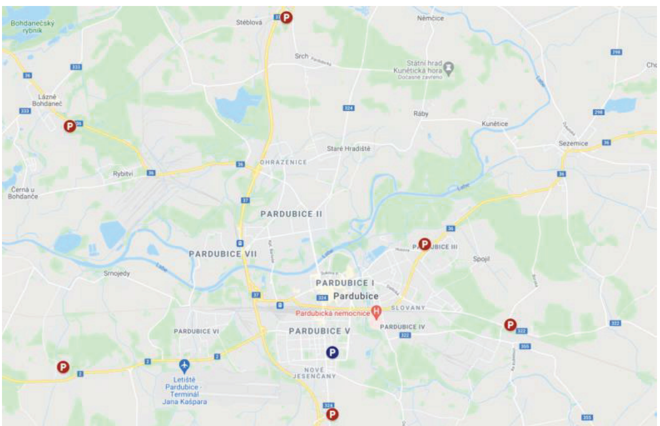

Fig. 3 Proposed location of the P + R car park. [Source: Authors based on Google Maps]

Preference for public transport vehicles

However, in order for the implementation of intercepting car parks for the purpose of possible transfer of customers to public transport vehicles to be important, the quality of services of this type of transport must be adequate and competitive. Public transport preferences are understood as direct preferences (construction modifications in the road / physical measures, priority of vehicles on traffic lights or various changes in traffic regimes, etc.) but also indirect preferences. This consists of issues of transport quality, quality connection offer, ITS creation, interception parking systems and many others, while sufficient synergies should be made between the two types of this preference [9, 10].

Within the city of Pardubice, from the point of view of public transport preferences, there is something to work on. Apart from the approximately 100-meter section near the Main Railway Station, public transport vehicles are not preferred to individual traffic by reserved lanes; they do not have an absolute or conditional preference in the places of traffic lights, and controllers have solid phases. The only reserved lane within the city is shown in Fig. 4.

Fig. 4 Reserved lane for public transport vehicles in Palackého třída street [Source: Mapy.cz.]

There are several intersections of local roads, where in order to improve and increase the competitiveness of public transport on the basis of data on the intensity of road vehicles, it would be appropriate to establish priority for the approaching public transport vehicle at least by conditional display of the signal free in the appropriate direction. The principle of this preference is the synergy between a stable device at a given junction (controllers, contact contacts, detection devices in communication) and between a mobile device in a vehicle (GPS). The controller of the given traffic light will thus evaluate the approaching public transport vehicle at the appropriate moment and provide it with a free signal, if it is appropriate at the given moment. In the case of the so-called absolute preference, this happens regardless of the surrounding situation. Selected systems for the priority of public transport vehicles evaluate whether to provide absolute priority for vehicles also depending on the delay of the connection. If it travels with a delay, it will be given a free signal at the expense of other collision directions, if it travels with a lead, other directions will be preferred [9]. This measure would contribute to higher reliability and increase of cruising speed at the intersection of road II/324 in Hradecká street with Bělěhradská and Studentská streets, as well as at the intersection of Hradecká and Sukova třída, Hradecká / 17. listopadu with Palackého třída / Míru street, Palackého třída with K Polabinám street and last but not least, for example, at the intersection of Palackého třída and Hlaváčova streets (especially in the direction of the center).

In connection with the solution of the priority of public transport vehicles at intersections with SSZ, it would be appropriate to implement reserved lanes, as the most economically acceptable preferential measure in the event that it is not necessary to make construction modifications to the road. Dedicated lane for public transport vehicles (or for cyclists, taxi vehicles and integrated rescue system) is one of the most used preferential measures for public transport vehicles, however, its implementation (either valid continuously or only during rush hour) significantly reduces the capacity of the road . Again, it is offered to use the road traffic intensity scheme shown above. Here, however, it is necessary to take into account that the strict implementation of a reserved lane in a place with a higher intensity of road traffic and the associated higher probability of congestion may move congestion and given high traffic intensity to other places where this problem was not before this change. and, in general, the situation related to the intensity of road traffic throughout the city may worsen. It is therefore necessary to consider the implementation of a dedicated lane. Within the solved city of Pardubice, this measure is offered to be implemented in Hradecká Street in front of the intersection with Suk Street in the direction of the center, or in front of the intersection with Bělehradská Street in the direction of the center. In the case of a sufficient width of the local road, the same measure could be implemented in essentially the entire length of Palackého třída Street. Another problematic area is the I/37 road at the Paramo overpass, where several public transport bus lines run and where their travel speed and reliability would also be increased by a dedicated lane. However, even here, this measure could also lead to a significant slowdown in traffic flow in general, and this measure could induce further congestion and slowdowns elsewhere in the city. According to the study in sources [6] and [7], it would be possible to implement the so-called intermittent bus lane (IBL) in this section. The principle of this measure is that there is a signal directly in the road, which signals the approaching public transport vehicle and warns the PMV (private motor vehicle) driver that he must not use the reserved lane at this time. The public transport vehicle thus passes smoothly through this lane as if it were a normal reserved lane described above. At the moment when there is no public transport vehicle, nor is it close to the given section, it is possible to use the given lane also with individual transport vehicles. This measure does not significantly reduce the capacity of the road, as a permanently reserved lane. The condition for the implementation of this measure is that there are at least two lanes in one direction of the road.

According to the study in Article [8], the implementation of this measure is suitable if the given parameters are met, namely the intensity of traffic in 60 minutes and the number of public transport vehicles in 60 minutes. The following Table 3 shows the appropriate values found in the study [8] for the implementation of this compromise preferential measure. The traffic intensity of the Paramo overpass on the road I/37 according to the source [2] is 2,110 vehicles/hour in the peak period. The number of public transport connections in the direction of the center (Hlavní nádraží) is at the highest value of 10 connections per hour during the peak period.

Table 3

Critical values for suitability for implementation IBL (intermittent bus lane) [8]

Critical traffic volume, veh/h for two lanes	Volume of the buses, buses/h	Velocity of the buses, km/h	Velocity of the cars, km/h
2700	2	21,4	34,1
2550	4	21,3	35,1
2550	6	21,3	33,2
2400	8	21,0	33,7
2250	10	21,5	35,1
2100	12	21,5	36,5
1950	16	21,5	37,4
1500	20	21,4	40,9

In addition, the connections of all lines led by this road have very close time positions (departures in the direction of the center, for example 16:01, 16:04, 16:17, 16:24, 16:34, 16:34, 16:44), which is for this preferential measures in relation to the capacity of the communication are ideal. For an average of 10 minutes, this intermittent dedicated lane functions like a regular PMV lane. In other parts of the city, where there are more public transport connections per hour, it is more appropriate to implement a regular permanently reserved lane.

Regarding the issue of indirect public transport preference instruments, it is necessary to find such measures so that we can drag potential PMV drivers into public transport vehicles. There are certainly various electronic applications for ticket purchases, interactive connection finders with information on the nearest connection, barrier-free vehicles, acceptable fares but also connections to other public transport subsystems, for example through integrated transport systems, mentioned in the following paragraph.

Coordination with public transport and ITS

In order for the measures proposed above to work well and contribute to increasing mobility, but at the same time not burdening the current PMV infrastructure, interconnections with public transport within the region are necessary. The Pardubice Region operates an integrated IREDO transport system, which includes public regular bus transport as well as regional (partly long-distance) railway transport. However, from the passenger's point of view and the issues addressed in the article, this system has several problems, of which the main ones are: non-existent transfer ticket (except for the use of IREDO chip card and ticket with designated transfers in rail transport) and cities in the region, including the city of Pardubice [11].

In the places of the newly designed P + R interceptor car parks, there should be a mutually convenient transfer between public line bus transport (or railway transport) and public transport, of course with a link to the existence of the P + R system.

The fact that similar transfer terminals with links to more modes of transport and the P + R system is also shown in the example of the South Bohemian Region, where the non-existence of such terminals in this region is pointed out and the concept of these new nodes is presented, the construction of which would competitiveness and attractiveness of public transport in the region [12].

In the area of Technopark Pardubice in Staré Čívice, it would be a matter of connecting bus lines from the southwestern direction (especially from the town of Heřmanův Městec) and relevant public transport lines Pardubice (lines no. 14, 23 and 25), or in the future construction of a railway station nearby. In the area of the Dubina shopping center, these would be bus lines from the north-western direction, especially from Holice and public transport lines Pardubice 5, 9, 11 and 13. At the Stéblová parking lot, there would be mainly connections between the P + R system and regional railway transport, then in connection with bus lines serving the surrounding villages, or Hradec Králové. At Dražkovice, south of the city, bus lines would be connected mainly from the south, ie from the town of Chrudim and the current public transport line Pardubice No. 18. Here, in the future, one could consider extending some other public transport line due to better transport services (eg. line No. 1 from the Jesničánky stop). In the Lázně Bohdaneč locality, after the construction of a catchment car park, this system would be connected in its vicinity with regular transport in the direction from the northwest (eg from the town of Chlumec nad Cidlinou) and the Pardubice public transport trolleybus line No. 3. The last of the localities, ie Černá za Bory then offers connections with bus lines from the southeast (especially from the town of Hrochův Týnec), public transport lines Pardubice No. 12 and 28 and also regional rail transport. These interconnections are summarized in the following Table 4.

Table 4

Links to the proposed parking lots

location	P+R system	IREDO lines (direction)	public transport lines	railway station
Technopark Pardubice	yes	Heřmanův Městec	14, 23, 25	yes *(in future)*
Dubina	yes	Holice	5, 9, 11, 13	no
Stéblová	yes	Hradec Králové	no	yes
Dražkovice	yes	Chrudim	18, 1 *(in future)*	no
Lázně Bohdaneč	yes	Chlumec nad Cidlinou	3	no
Černá za Bory	yes	Hrochův Týnec	12, 28	yes

The essence is therefore to be able to achieve connections and convenient transfers in one place. Therefore, there should be a public bus stop in the vicinity of the proposed car parks and also a public transport or train stop. Passengers will thus be able to comfortably use public transport across all available subsystems so that they can get to the desired place in the city as quickly and conveniently as possible. This option can then be implemented in two ways:

1. The passenger travels to the city center or another important place in the city (eg Central Station, Hospital, University…). In this case, the passenger uses the P + R system and continues on "accelerated" lines directly to the desired destination. These "accelerated" lines are existing bus lines from the region, which stop in the city only at major stops. These passengers thus significantly reduce their travel time, even in coordination with the proposed preferential measures in the city.
2. The passenger travels to an existing public transport stop (outside major destinations), or transfers to another public transport line. In this case, the passenger will use the P + R system and continue on "slow" lines. These "slow" lines form the existing public transport lines, which serve all road stops. These passengers can thus comfortably get to their destination, and even here, in connection with the proposed preferential measures, travel time can be shortened.

In both cases, due to the reduction of PMV in the city, the traffic situation is improved and congestion is reduced. However, it is necessary in this case to link the current integrated transport system IREDO with the Pardubice public transport tariff and to create a transfer ticket for all passengers. It is also offered to connect the IREDO system and the public transport tariff with payment for the use of the P + R car park. Therefore, a solution is offered to mutually recognize chip payment cards (ie the possibility to use the IREDO chip card and the Pardubice public transport system and, conversely, to use the Pardubice card for payments in IREDO lines) or to make all payments by payment cards uniformly. In connection with the modernization of the Pardubice public transport check-in system, where it is possible to use a payment card, an IN card of Czech Railways or an IREDO chip card in addition to the Pardubice card, the above options could become real [13].

In the case of creation, resp. modifications to existing systems, it would be appropriate to offer passengers who use one of the intercepting car parks a corresponding fare discount in order to be even more motivated to use the system.

4. Conclusions

The article dealt with specific measures to increase mobility within the city of Pardubice and the surrounding area. Specific measures have been proposed, namely the design of new interception car parks of the P + R type in selected localities on the main access routes to the city. However, these newly designed car parks would not be able to fulfill their purpose without follow-up measures. These include coordination with public transport in the region, including tariff interconnections, as well as in other preferential measures (especially for public transport) in the city itself.

Many cities around the world are addressing the challenges of population mobility, public transport and PMV, and there are many tools and ways to regulate or improve the situation in cities. This paper presents some of these measures applied to the specific example of the city of Pardubice.

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Overview of Safety Aspect into Ports: Port Tug Impact Research

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Abstract

To ensure safety in a port big role takes port tugs which made major important jobs such as escorting vessels, assist for big vessels to help them maneuvering during entering into port and leaving it, help during mooring and unmooring operations, breaking ice in port channel, works in firefighting and rescue operations. In many case quantities of necessary tugs or tugs power decisions are made from experience and is not optimal. This paper present research of port tugs impact for port navigation safety results, while traying to optimize in exact case necessary number of tugs and tugs power depending on vessels parameters and external conditions to use ship handling mathematical models. Finally, conclusion and recommendations presented in the end of article.
KEY WORDS: *port tugs, safety in a port, navigation safety*

1. Introduction

Shipping is one of the most growing sectors of transport in the world in the past years. Maritime transport accounts for 80% of the world's total freight traffic, while the Baltic Sea accounts for about 15% of the world's shipping capacity [1, 2]. There are about 2,000 ships regularly sailing in the Baltic Sea at any time, and about 3,500 to 5,000 ships entry to the Baltic Sea regularly each month when the destination is one of the Baltic Sea ports [3, 4]. 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 [5]. 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 [6]. Disasters in ports or at the open sea cause significant financial and environmental damages, so ship accident prevention studies are a very popular objects for researchers from all over the world. Shipping in the Baltic Sea is very intensive and at the same time the risk of disasters at sea and in ports is very high. The majority of ships in the Baltic Sea are passenger and passenger cargo ships such as Ro-Ro and RO-PAX type, and about 22% of all ships are oil and chemical tankers [3]. The most common shipping incidents places are port accesses areas and the ports themselves, accounting for 59.9% of all disasters, and the most common incidents are ship grounding, ship collisions and equipment damage, which account for a total of 55% of disasters [3, 7-10]. It is very important to ensure navigational safety at port accesses areas and in the ports themselves in order to prevent recurring accidents that cause material damage and ecological consequences. In my article i will represent the influence of tugs on maritime and navigational safety in ports, and the application of mathematical models in selecting the optimal number of tugs to ensure safety operation in ports.

2. Situation Analysis and Literature Overview

Most port tug researches in the world can divide into a few popular branches: problems related to maximum size vessels safety maneuvering in ports, calculations and problems of port infrastructure limits to accommodate maximum size vessel and port tug influence into safety assistance for this type vessels; calculations of vessel and port tug movement behavior in various conditions, the optimal number of tug research; various studies about tug maneuvering, hull shape and propulsion properties related with most efficient solutions to ensure maximum performance, decarbonization and environment friendly decisions. 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 and D. Paulauskas [11]. Research of vessel maneuvering properties and relations with ports infrastructure limit parameters represent D. Paulauskas where he makes conclusions of the importance of port tug while accommodating maximum size vessels into port [12]. VLCC, VLCS and UCLS vessels maneuvering into ports wide represent researches from all over the word. Authors L. Kang, S. Gao, and Q. Meng represent in the articles detail analysis of towing capacity based on modeling results [13]. A. Toma, V. Oncica and D. Atodiresei study vessel behavior while making a turn with port tug assistance. In most cases, the ship's trajectory during the turn is not an ideal circle due to the acting external hydrodynamic forces, changes in depth, distance from the shoreline, wind. The study examines the actual movement of the vessel when the tug is acting on a transverse or stationary vessel [14]. Concerning the safety of towing, a slack towline condition on tug-towed ship motions interaction during turning is an important to 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 [15]. Authors N. M. Quy, K. Łazuga, L. Gucma, J. K. Vrijling, and P. H. A. J. M. van Gelder in the paper presents generalized models of ships maneuvering. Those models are needed for a better understanding of the safe navigation process in ports areas and its approaches and for risk analysis when no full information about the ship's behavior is available [16]. Many authors present various problems of technical characteristics of port tugs. It's widely analyzed by the finite element method and simulation models looking to the most optimal hull shapes or solving propulsion, maneuverability problems in various operating conditions. Port tugs often operate at both low and high speeds. The widely applied RANS method for calculating the hydrodynamic forces acting on a tug allows estimating the forces generated by the port tug hull, which are generated during the steering and braking action [17]. A variety of finite element methods can be used to determine the maneuverability characteristics of a tug operating at different modes, as well as at different hydrodynamic conditions, by comparing them with real test experimental data. The ability for ship designers and engineers to get recommendations regarding tug control, efficiency and safe at an earlier design stage is a key factor in the optimal tug design process and can help to build the most efficient vessels [18-22].

3. Theoretical Basis for the Tugs Using in Ports

To calculate the minimum required quantity of port tugs during mooring and unmooring operations where hydrodynamic forces affecting vessel and part of this forces can be compensated by vessel screw and steering complexes another part can be compensated by a port tug. To evaluate the minimum quantity of port tug and minimum required to power all acting forces must be analyzed. Generally all forces can be expressed by the following equations [23]:

$$m\frac{dv_x}{dt} + R_x + P_x + F_{xa} + F_{xsr} + F_{xs} + F_{xv} + F_x = 0\,; \tag{1}$$

$$m\frac{dv_y}{dt} + R_y + P_y + F_{ya} + F_{ysr} + F_{ys} + F_{yv} + N_y = 0\,; \tag{2}$$

$$M_{in} + M_R + M_p + M_a + M_{sr} + M_s + M_v + M_N = 0\,. \tag{3}$$

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 [23]:

$$M_v' = F_v \cdot sin\,\beta \cdot l_1'\,. \tag{4}$$

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:

$$M_v = F_v \cdot cos\,\alpha \cdot sin\,\beta \cdot l_1'\,, \tag{6}$$

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 (Figs. 1-3).

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 [24]:

$$x_0 = L\left(0,4 + 11,5\frac{T_{lg} + T_{lp}}{L} - 0,004 \cdot \alpha_r^0\right), \tag{7}$$

where L ship's length between perpendiculars; T_{lg} − ship's bow draft; T_{lg} − ship's aft draft; α_r^0 − rudder turn angle in degrees.

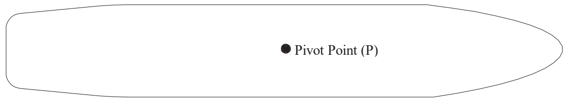

Fig. 1 The location of the pivot point of the ship in the stop position

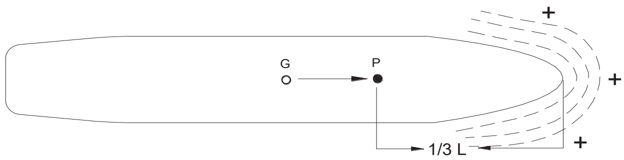

Fig. 2 The location of the pivot point when the ship moves ahead

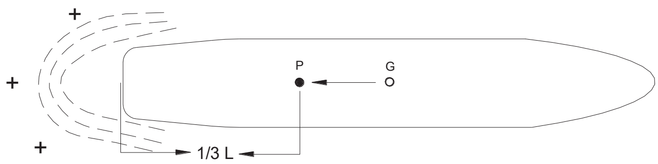

Fig. 3 The location of the pivot point when the ship moves astern

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. Case Study of the Using Tugs in Ports

Simulation of vessel blackout situation in a Klaipeda port channel represent us how is important tug assistant to prevent accidents. Location of experiment is Klaipeda Port. Experiment was made by "Simflex Navigator" simulator. Scenario was recovery from real situation when bulk carrier vessel after blackout was grounded into port channel bank. Target of experiment is to get information if tug can handle vessel in critical situation to prevent accident and losses and calculation methodology of minimum tug quantity demand in various operations calculations.

Table 1

Experiment vessel's parameters

	Length	Breadth	Drought	Bollard pull
Bulker	218	32	12	
Port Tug	32	14.5	5.5	60 T

Fig. 4 Experimental vessels visualization bulker (left) and port tug (right)

Cargo carriers takes 48% of total ship operated into in the Baltic sea generally we can divide into few main types: general and bulk carrier [3]. This type of vessel mostly standard has 2 stroke diesel engine and 1 propeller propulsion. In many case maneuverability of this type vessels in difficult situations is complicated due to general construction and shape of the vessels (Fig. 4) (Table 1).

Table 2

Weather and environment conditions

Clearance	Wind speed	Wind direction
2 m	10 m/s	269°

Conditions of experiment we can describe as most common and usual in Klaipėdas region (Table 2) [25]. Due to real accident any anomaly weather unnoticed and unrecorded.

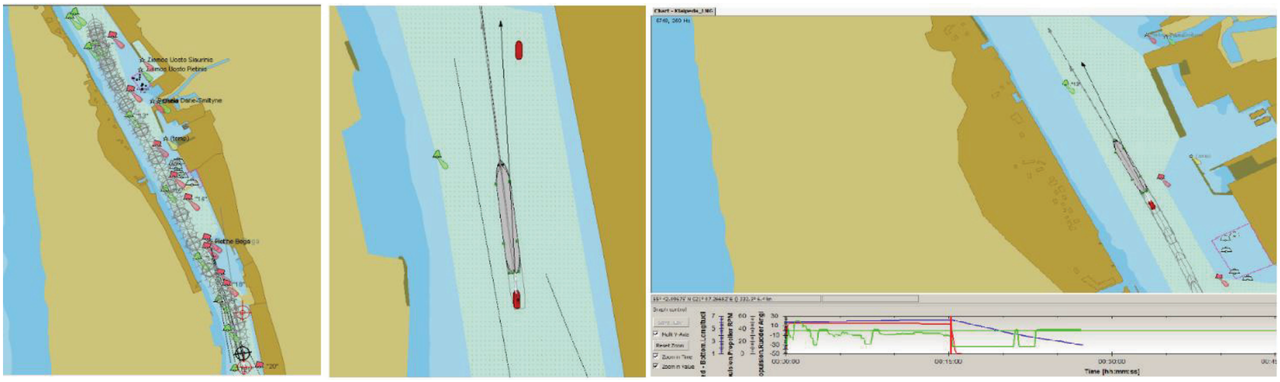

Fig. 5 Vessel trajectory in the port from different views

First picture from left is full vessel trajectory in the port, middle picture vessel with town line connected port tug in stern before blackout, right picture vessel trajectory at blackout moment (Fig. 5).

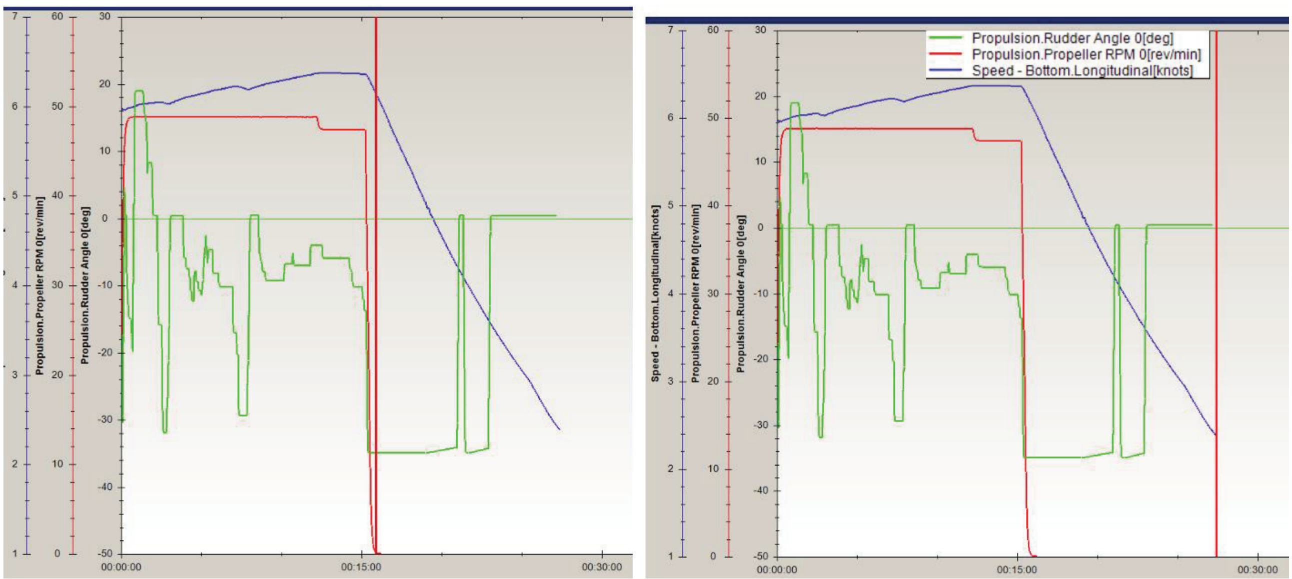

Fig. 6 Vessel parameter before (left pic.) blackout situation and after when operation was done (right pic.)

Red line shows blackout moment when engine stops and vessel starts losing speed and was control only by rudder while tug join to operation. Moment from blackout until vessel safety stop into rotating pool area (Fig. 6 right picture). Vertical red line marks operation end. Both graphics (Fig. 6) represent mane vessel parameters during whole real-time simulation.

Vessel and tug position trajectory show that tug assist gives result and vessel avoid grounding situation (Fig. 7 left picture). Vessel reach port channel rotating pool and here vessel can safety anchor while waiting from assistance from another tug for mooring by the nearest free jetty. The critical situation is managed and the vessel is safe from grounding or other unexpected accidents (Fig. 7 right picture).

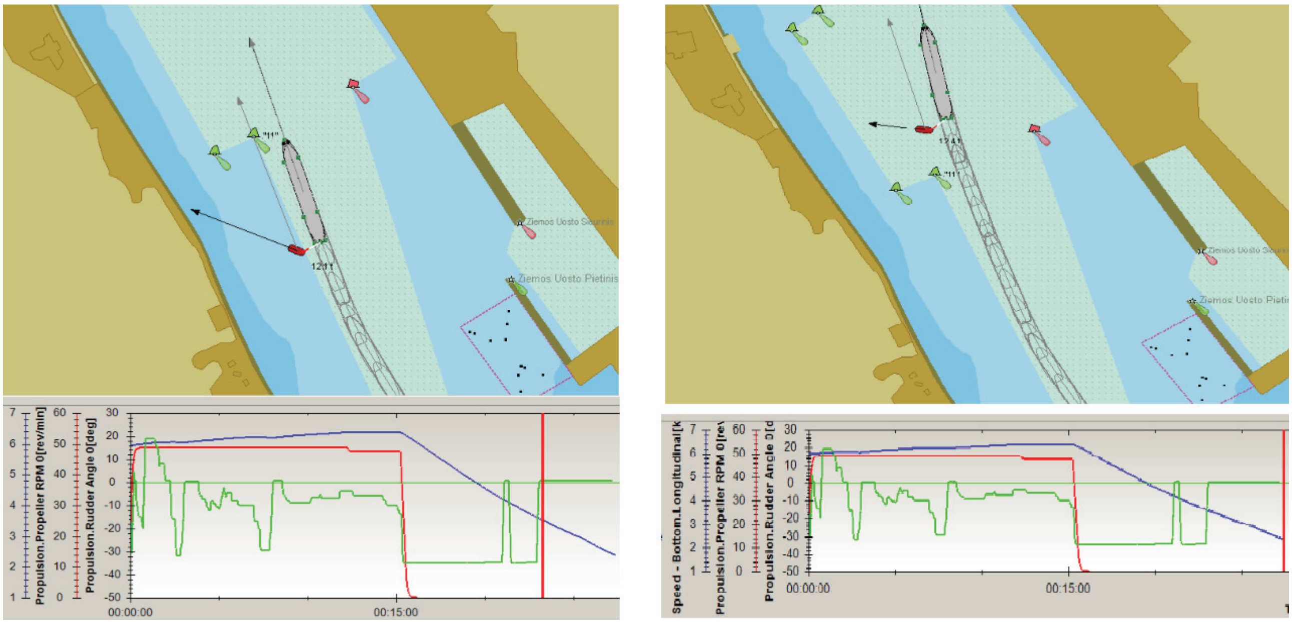

Fig. 7 Vessel and tug trajectory just before entering (left pic.) into the vessel turning point of the equator and just after vessel safety reach destination (right pic.)

5. Conclussions

Port tugs takes a big part to ensure navigation safety in ports and port access areas. As this paper represents in many cases port tugs can prevent accidents and can help in a critical situations to avoid disasters and losses. The mathematical models can help port authorities, tug towing companies, ship owners better prepare for the towing operation, better evaluate risk factories to avoid accidents and have an optimum number of port tugs to make towing operation most possibly efficient considering with vessel size, weather and hydrodynamic conditions. The environmental aspect of decarbonization and economical factories, as well as scheduling problem, could be another important future studies topic to have a right number of port tugs at the right time we can significantly reduce CO emission. When we have optimum number and optimum power tugs we can ensure the shortest operation time. This scenario also can help to reduce expenses for ship owners while we have an optimum operation with reduced operation time. This economic – environments aspect needs deeper studies and can be represented in the near future research.

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The Importance of the Mobile Space Testing Facility "METAMORPHOSIS" Prototype Development

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Abstract

EU space industry develops slower, then the USA, Canada or Japan. One of the reasons of such lag is testing, cause according to standards, without validation and verification in the operational conditions you can offer on the space market only ideas, but not goods, that's why fast-growing space market leads to growing demands in the test facilities. Only 43 facilities in the EU comply with the ECSS requirements. Only ~20 of them are accessible. They are stationary test centres-it means, that research organizations (RO) need to pay for tests, specimen shipment, insurance and team business trips. To access public facilities, they must have some joint project with the public entities, who have long-term plans regarding their facilities. Private facilities are expensive and booked for years ahead. This paper introduces a mobile space testing facility - the truck-and-trailer based facility and approach that will offer space test service, will assist RO to develop test plans, make test predictions, prepare and perform tests, recognize and analyse the results, prepare test reports in accordance with standards. The idea of the projects has been originally launched by SIA CVS in the frame of HORIZON 2020 and had been awarded with the Seal of Excellence from the EC. The solution includes trailer based space simulating facility with clean room for specimen preparation, space environmental simulating facility and the operation room for test data collection. The approach to the testing facility requires solving many engineering problems: the problem of multi systems integration, the problem of quick deployment after transportation, the problem of maintaining technical characteristics under the influence of vibration and shock loads during intermodal transportation etc. CVS invited Riga Technical University Institute of Aeronautics to develop the METAMORPHOSIS prototype and increase its TRL from 3 to 5-6.
KEY WORDS*: space environmental simulation, spacecraft testing, space market products preparation.*

1. Introduction

Since 2005, the turnover of space industry has doubled in 2016 and reached 339 billion USD [1] grouse up to 414.75 billion USD in 2018 [2] Some forecast shows, that global space economy turnover will rich 1 trillion USD in 2040 [3].

The share of private companies doubled too, and reached > 76% [4]

This is mainly due to the expansion of knowledge and available training in satellite building – hardly any university with relevant curricula misses a chance to build a small satellite, and their students develop spin-off companies in small payload (satellite) market. The global space market is getting "younger" - such tendencies are typical for the USA and Canada, where the share of start-ups and young companies occupies up to a quarter of the private market. Powerful young companies from Brazil, Mexico, India, Australia and Japan have appeared on the global market.

European Community is investing great share of the EU budget into space programs as one of its priorities, but unfortunately, in the EU the process of involving young companies in the space market is relatively slow. Main reasons causing this fact are lack of competency in system engineering, validation, verification, testing and integration, as well as lack of testing infrastructure allowing to proof the space readiness of products and lack of relevant skills of companies' specialists.

When the space segment part design starts the problem appears - will the product operate in outer space? To get a positive answer to this question, a new product must be validated and verified in the space environmental conditions at each stage of the development. That's why if you have no tests, your product has no development, no future and on the space market you can sell only an idea.

2. "Metamorphosis" is the Way Out

The space environmental testing facility is very expensive (hundreds thousands or millions EUR), so the only way for young companies and low budget high schools to proof their products is to use public facilities or rental facilities.

In 2017 Latvian R&D company SIA "CRYOGENIC AND VACUUM SYSTEMS" (hereinafter CVS) offered to the European Commission project "Mobile space testing facility on demand "Metamorphosis", as alternative providing affordable access for space testing. This project received the Horizon 2020 grant under SME Instrument Programme Phase I.

During execution of this project CVS conducted the survey among 600+ European space industry enterprises and marker analyse on this base.

The survey showed, that only 43 space environment testing facilities in the EU comply with the ECSS/NASA standards requirements for Space Environmental Testing. Only 20 of them (13 publics and 7 private) are accessible for outside company. All of them are stationary test centres - it means, that you need to pay not only for tests, but for spacemen shipment, insurance and team business trip.

To access public facilities, you must have some joint project with the public entities, who have long-term plans regarding their facilities. Private facilities are expensive and booked for years ahead.

The survey also showed that 101 company are interested in mobile space testing service and 43 companies are ready to order such service immediately.

For the development of METAMORPHOSIS project (Phase II) CVS was awarded with the Seal of Excellence Certificate of the European Commission 26.08.2018.

Mobile space testing facility will be the truck-and-trailer based facility and will provide almost all required by ESA ECSS and NASA standards tests possibilities – it will be possible develop test plans, make test predictions, prepare and perform tests, recognize and analyse the results, prepare test reports in accordance with ECSS/NASA standards requirements.

To move up the project progress it need to develop the METAMORPHOSYS prototype and increase it TRL from 3 to 5-6. That's why CVS invited Riga Technical University, who have experience in aerospace engineering and intermodal transport to be a partner in ERDF project "Prototype development of transportable in multimodal traffic mobile space testing facility "Metamorphosis".

3. Short Technical Description of Future Facility on TRL 9

The proposed solution includes trailer-based space simulating facility with clean-room for specimens' preparations, space environmental simulator, place for test data acquisition.

Upon customer request on facility can be mounted Sun radiation simulator, UV radiation simulator, X-ray band simulator and Van Allen belts simulators.

The facility finally will be accompanied with the Virtual Laboratory allowing to simulate all the thermal, ray tracing, gas dynamics factors during the test. The Virtual Lab will be the flexible instrument for predicting, planning and optimizing the real test.

Technical requirements and conditions for testing preparation, holding, their results analyses and processing are regulated by ESA ECSS and NASA standards, among them the most important are ESA ECSS-10-03C Testing [5] and NASA GSFC-STD-7000 General Environmental Verification Standard [6], ISO 17851:2016 Space systems - Space environment simulation for material tests - General principles and criteria [7].

Due to the abovementioned requirements, finally at the TRL-9, the mobile space testing facility "Metamorphosis" will be able to ensure customers the capability of passing the following types of tests for their specimens:

– Thermal vacuum tests, including specimen thermal stating, thermal cycling and thermal balance test;
– Pneumatically test, including leak definitions with helium alongside with residual gas analyses upon request;
– Electric space segment equipment test in environmental conditions;
– Extra-terrestrial Solar irradiance specimen stability tests;
– Extra-terrestrial Solar particle and UV radiation tests;
– Van-Allen belts simulation.

Also the facility should provide the thermal vacuum outgazing of the specimen.

The specimen thermal load simulation, Solar radiation simulation, high vacuum and black space energy disappearance ability will provide high quality space environmental simulation in accordance with common criteria of high fidelity outer space simulation are declared in [8].

Such tests capability list is mostly enough to provide validation & verification procedure, certification, qualification and acceptance of the majority of space segment components, instruments, systems and satellites at all.

General approaches to designing space simulators are outlined in [9] and [12]. Our team understand it, and have own experience of stationary space simulators design and development [14], [16], but here we have extraordinary task and challenge – to make transportable and stable working facility, which is always before was stationary, because it is very sensitive and "gentle" instrument.

Preliminary test facility view is shown in Fig. 1

According our estimation, based on the survey results, and EU Traffic Laws, the facility vacuum chamber must be positioned horizontally, will have diameter approximately 2,26 m, length approx. 3,5 m. The chamber must have a cover in top. The chamber should be manufactured from appropriate stainless steel. Such space simulating facility let to test space products with dimensions less, then 1,3 m × 1,3 m × 2,0 m. The vacuum vessel should be heat transfer protected because the inner temperature may change in the range $-2 \cdot 10^2$ °C to $+2 \cdot 10^2$ °C, and simulator casing should be about +20°C.

A significant advantage of the proposed solution is the creation of a solar radiation simulator, which provides high reliability of reproducing the spectral and other physical characteristics of solar radiation outside the Earth's atmosphere.

Fig. 1 Preliminary view of the mobile space testing facility “Metamorphosis”

The power of the solar radiation simulator should be sufficient to create a luminous flux into 1 solar constant (1367 W / m2) on the surface of the test object.

Earth's infrared radiation will be reproduced using black body assemblies based on quartz infrared lamps built into their re-emitting screens with a high degree of blackness. The power of the simulator of the heat flux of the earth should provide its density of 900 W / m2 on the surface of the test object.

The heat flux simulators must provide the maximal heating temperature of the test specimen surface up to +300°C.

Energy dissipation ability of the outer space will be simulated through the “Metamorphosis” cryogenic system. It includes cryogenic tank, liquid nitrogen recirculation system and liquid nitrogen shields, which are located inside vacuum vessel around the tested instrument.

Vacuum in the “Metamorphosis” facility is produced using dual stage low pressure pumping system, designed without oil lubrication. Modern digital vacuum transducers are used in the pressure feedback loop for pressure control mode.

More technical details of finalised “Metamorphosis” facility on the TRL-9 you can find in [17].

Mobile approach to testing facility requires solving many engineering problems. In addition to the problem of multi systems integration, there are the problem of quick deployment after transportation and the problem of maintaining technical characteristics under the influence of vibration and shock loads during intermodal transport.

The facility cost evaluation with full set of need systems is more, then 12 M EUR, that’s why it is so important to develop the low cost prototype, identify all the design and development challenges and constrains and find the way how to make state-of-the-art “Metamorphosis” facility for space industry development.

4. Approach to Reduce the Prototype Systems Composition, Which Will Allow to Develop the System to Highest TRL. Onstrains and Challenges

Finally, on the TRL 7-9 stage, the centre the space testing facility “Metamorphosis” occurs the universal multi-functional space environmental simulator, which, based on the required tests list, must consist of the below mentioned instruments:

– High vacuum vessel;
– Infrared flux system;
– Liquid nitrogen outer space dissipation ability imitator;
– Air evacuating system;
– Extra-terrestrial Solar irradiance imitator (optical, working in IR, visible and near UV bands);
– UV simulating system;
– X-rays simulator;
– Van-Allen Belts imitator (α, β, p+);
– Chamber gas determination system;
– Auxiliary instruments.

Now, during the implementation of the ERDF project № 1.1.1.1/18/A/133 “Prototype development of transportable in multimodal traffic mobile space testing facility “Metamorphosis”, our main aim is to recognise and define main design and manufacturing challenges, research the way out and proof it by production and testing the facility prototype.

That’s why, due to the project budget limitation constrain, on the TRL-6 prototype stage we have no possibility to provide all above listed systems and subsystems composition to the space environmental simulator prototype.

During the engineering analysis we made were defined the systems of space environmental simulator, which technologically have similar design approaches and put it into analysis list. We detected their design challenges and constrains and reflect each problem in analysis list. Then, compared noted problems, we decided which system from the list will mostly reflect the problems of all listed systems.

I.e. Approaches to radiation effects simulating are outlined in [10] and [11]. Generally, Van-Allen Belts simulating system includes electron beam gun with electron optic scanning system, helium ion generator, hydrogen ion generator and ion accelerator with ion optic scanning system. X-ray simulating system contain high power X-ray tube with focusing optics and actuators. UV simulating system contains high power UV LED source and UV optics.

But here, from the point of view of intermodal transported system design challenges and constrains, they are high vacuum instruments, mounting on the flanges of the space environmental simulator or inside it's vacuum chamber. All they have high power (for cathodes) and high voltage electrical feedthroughs, cooling feedthroughs, high vacuum assemblies, seals, bellows, massive details connected with vacuum chamber etc.

That's why if we will design and make properly high and fore vacuum systems (seals, bellows, heavy parts mounting which will be high-vacuum stable in intermodal transport) and will provide stable working of such sensitive and massive instrument, like turbo molecular pump in shock and vibration conditions of intermodal transportation of prototype and validate it during tests – it means that we find solutions for all problems, concerning vacuum design of the whole future facility on TRL 7-9.

If we will proof the good job of electrical feedthroughs in power supply to the heaters (high power) of the heat flow simulation system and in sensors signal transferee in control system (also making some experiments with high voltage) – it means, that we have proper solutions for TRL 7-9.

If our cryogenic shrouds, thermal bridges, cryogenic insulation, cryogenic liquid feedthroughs, pipelines etc. will have good test results in the prototype, we will use the same approaches in the main facility. Our team have good experience in space simulator cryogenic systems design and developing [15] and we hope our "Metamorphosis" cryogenic system design will be on the high level too.

On the base of the analysis results it was decided, that following systems list with the limited systems quantity, will not worse the results of prototyping, but will provide us to pass the budget constrains:

– Vacuum chamber (high vacuum vessel);
– Heat flow simulator;
– Solar radiation simulating system;
– Cryogenic system;
– Vacuum system;
– Control and measurement system;
– Supply system.

Also we understand, that for prototype design we can define user sectors as cube sat producers. It requires to think over simulator adaptation to cube sat test requirements, which assumed in [13].

5. Results and Discussion

After preliminary engineering analysis, a wide range of strengthens and stability calculations alongside vacuum and thermodynamic calculations were made.

On the basis of these calculations it was decided to develop the prototype, suitable for real multimodal testing, based in light track or minivan.

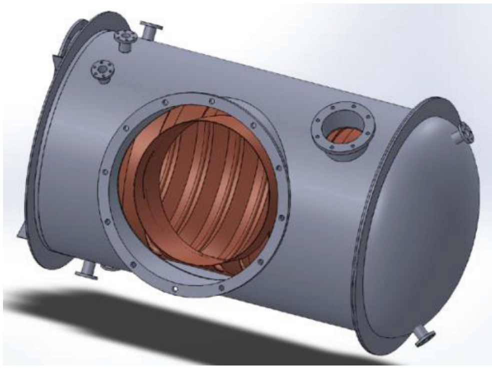

Fig. 2 Prototype vacuum chamber with installed cryogenic shrouds

We determined the prototype dimensions – it will have vacuum chamber with an inner diameter of 500 mm and a cylindrical part length of 780 mm.

Also we calculated the cryogenic shrouds, made their preliminary design, including pipelines, supports, thermal bridges calculation, designed the cryogenic system scheme, defined valves, cryogenic tank and other system components technical requirements.

The draft design view of vacuum chamber with cryogenic shrouds is shown in Fig. 2.

On the base of the vacuum chamber concept we started to design supporting system, amortization bellows and concept of turbo molecular pump assembly which should provide high stability and reliability of turbo molecular pump and high vacuum gate assembly work, without decreasing of vacuum grade and pumping speed.

The preliminary design of vacuum chamber structure with high vacuum manifold and anti-vibration bellow is shown in Fig. 3.

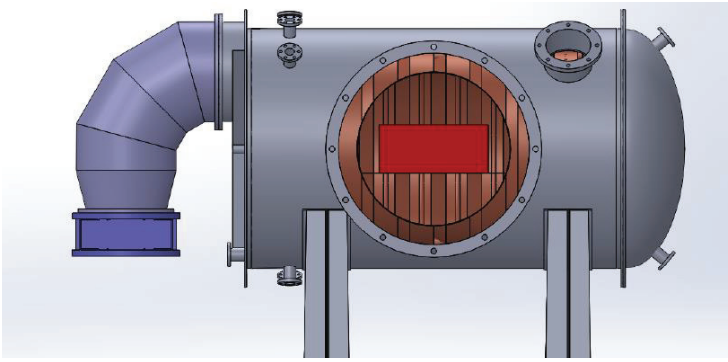

Fig. 3 Prototype chamber with high vacuum manifold and upper part of the supporting system

6. Conclusions

The design of “Metamorphosis” space environment simulator needs a lot of state-of-art engineering solutions, even it is small range prototype.

Problems of tightness and stable operation of high mass flanges, vacuum pumps and gates, electric and optical feedthroughs, hangers and support problems, vibration insulation and stabilisations of vacuum equipment, cryogenic pipelines, valves, tanks, stability and thermal conductivity problems of internal pipelines and vessels supports of cryogenic superinsulation systems should be made.

After preliminary engineering analysis, wide range strengthens and stability calculations alongside with vacuum and thermodynamic calculations were made.

The prototype dimensions were determined - vacuum chamber with inner diameter 500 mm and cylindrical part length 780 mm.

Acknowledgements

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The Role of Logistics in Managing the Costs of Civil Passenger Traffic

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Abstract

Motor transport civil passenger traffic has several advantages over the other types of public transport: maneuverability, time-saving, convenient connections. Therefore, it is important to focus on the need to develop this type of passenger traffic. At the same time, in Ukraine, most motor transport enterprises engaged in civil passenger traffic incur significant losses, which requires solving the problem of cost optimization and increasing income to ensure the profitability of services provided by them. The search for the options to increase the profitability of the enterprise is based on the use of analysis of the profitability of each route of passenger traffic and the factors that affect it. One of the important factors of effective work is the management of operating costs of the motor transport enterprise. However, this management will not be rational if the importance of logistics in this process is not recognized, which focuses on finding the most cost-effective process of passenger transportation. The relationship between cost management and logistics is clear and requires the direct use of logistics data to reduce passenger costs. The optimization of routes, in addition to reducing costs, will cut down on the cost of travel, which will increase the demand for road transportation and a corresponding increase in income. Calculating traffic for each route will help identify less cost-effective traffic to review its profitability. The implementation of passenger classification in terms of logistics will make it possible to track not only their number but also the group parameters of transported passengers and take into account their needs. The perspective directions of development of the transport infrastructure in the field of passenger transportation are determined. The analysis of passenger traffic volumes in Ukraine is carried out to identify the trends of this indicator change.
KEY WORDS: *accounting, costs, income, logistics, transport logistics, passenger transportation, management*

1. Introduction

The role of urban passenger transport in the development of the city is very important, as many factors depend on its quality: timely traffic does not lead to traffic jams, which is an urgent problem for most cities of Ukraine, and its solution plays an important both economical and environmental role. Besides, regular traffic makes it possible to avoid heavy congestion in public transport vehicles, which will not only increase its comfort but also contribute to a good anti-epidemiological situation due to the existing Covid-19 pandemic. Moreover, a well-established system of urban transport will facilitate the formation of a positive financial result of the enterprise. It should be noted that mostly the enterprise profitability is considered in terms of getting a profit by the enterprise owner but in the authors' opinion, the success of the enterprise should be considered in a many-sided way, as it means additional jobs and the replenishment of state and local budgets through paying taxes by both employees and the enterprise. That is, a successful company is of great importance not only for its owner or investors but also for the state as a whole. Enterprise profitability depends on many factors, but the main ones include the management of enterprise costs and, accordingly, the role of logistics in this process. That is why it is important to consider the issues that are made actual before writing this article.

2. Expediency

Urban logistics is a new mechanism for managing the flow of entities in the municipal area [7]. The main activities that characterize the essence, content, and purpose of transport logistics, its tasks, and objectives in the system of economic and management sciences [8] should be regarded as the function of transport logistics.

The importance of the role of logistics in urban passenger transport lies in optimizing passenger traffic, as a qualitative criterion for the profitability of a motor transport enterprise is the payback of transportation, which is a problem now, as the cost of transportation in some cases is higher than the fare. Thus, a crucial task is to analyze the profitability of each route. That is, the role of logistics in cost management needs considering.

The success of passenger traffic, or rather transportation of passengers from the point of boarding to the destination point depends on the correct transport network in the city, the economic feasibility of drawing up a scheme of each mode of public transport with the establishment of an optimal interval of the vehicle. After all, the correct decision-making directly affects the number of costs for passenger transportation, which makes it possible to economically influence the formation of financial results of enterprises that provide such services. To optimize costs, it is necessary to consider the relationship between cost management and logistics (Fig. 1).

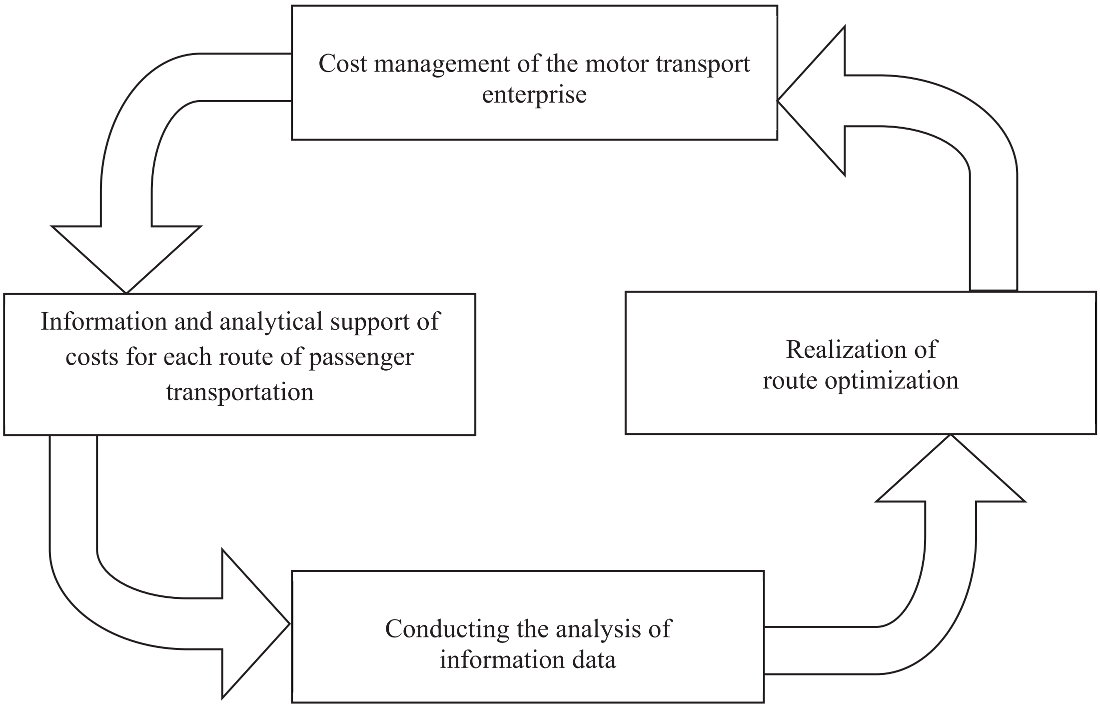

Fig. 1 Relationship between cost management and logistics

As it can be seen, the relationship is clear and requires the direct handling of logistics data to reduce the cost of transporting passengers in general.

It should be noted that the route optimization ought to meet the following objectives:

- reducing the travel time on the road;
- increasing the comfort and service of transportation;
- establishing an acceptable interval of traffic;
- competent construction of the route as part of the transport network.

All these measures will help reduce the cost of transporting passengers, which in turn will cut down the cost of travel and will have a positive impact on the demand for road transport and increase its profitability. To make effective management decisions, it is necessary to make a calculation of traffic on each route. This measure will help identify less cost-effective transportation to review its profitability.

Particular attention should be paid to the reliability and accuracy of the data obtained from the survey of passenger traffic. Thus, the transition to electronic fare payment in urban transport in Ukraine is still going on, so the information on passenger traffic is quite approximate. The electronic fare payment records the exact number of passengers on the route, travel time, and trip duration. However, in the authors' opinion, it would have significant informational essence if the fare cards were sold to passengers based on their classification in terms of logistics (Fig. 2).

This classification will allow tracking not only the number but also the analytical characteristics of passengers, taking into account their division by territorial, age, and economic characteristics and will better understand the needs of transport users to improve the operation of a motor transport enterprise and make adjustments to the existing routes.

The future development of transport should be based on a number of the following directions:

1. Improving the energy efficiency of vehicles of all modes of transport; development and application of ecological types of fuel and power plants.
2. Optimizing the functioning of multimodal logistics schemes, in particular through the wider use of modes of transport that are more resource-efficient, where other technological innovations may be insufficient.
3. More efficient use of transport and infrastructure due to improved transportation management and information systems, advanced logistics, and market measures [1].

The logistics management system needs information support for cost estimation, which is formed by the accounting system under each possible option of transportation, which allows optimizing the route and choosing the best mode of vehicle and transportation conditions [2]. After all, the main task of transport logistics is to choose the most cost-effective process of passenger transportation. It is important to provide information on management accounting in the analytical context based on the analysis of the traffic of different passenger categories as well as boarding and disembarking processes at stops. To reflect the trends in the development of passenger traffic, the authors will analyze the volume of this traffic (Table 1).

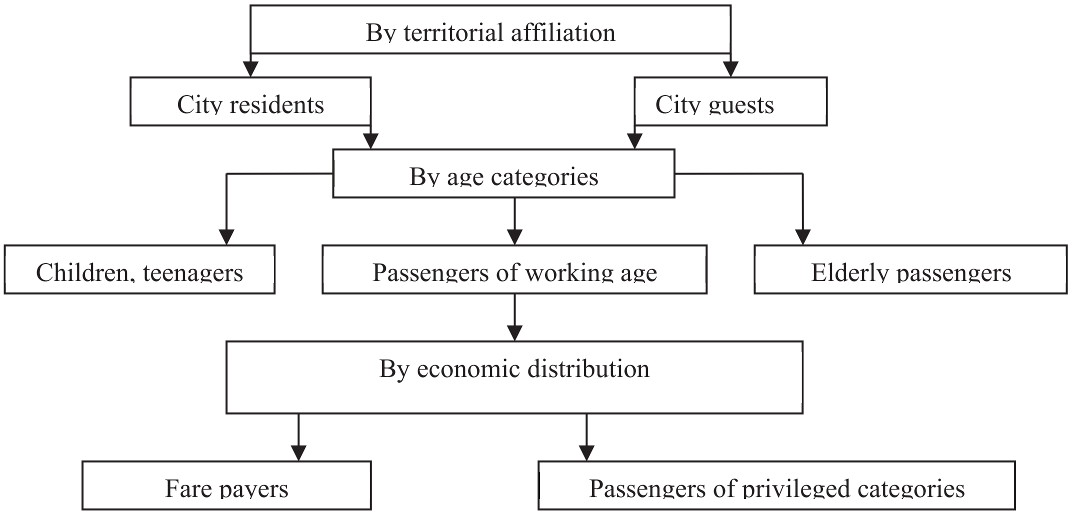

Fig. 2 Classification of passengers in terms of logistics

Table 1

Volumes of passenger traffic and performed passenger-kilometers in Ukraine from 2015 to 2019 [3]

Years	Volumes of passengers in urban traffic, mln.	Performed passenger-kilometers, mln	Chain growth rates,%
2015	1666.5	34.6	-
2016	1494.2	34.6	89.7
2017	1501.6	35.5	100.5
2018	1436.5	34.6	95.7
2019	1367.5	33.9	95.2

The graphical dynamics of passenger traffic in Ukraine from 2015 to 2019 is shown in Fig. 3.

As it can be seen, the volumes of passenger traffic are declining, despite the improvement of this indicator in 2017 compared to 2016. The volume of traffic decreased much in 2018-2019. This fact indicates that motor transport enterprises are operating at a loss, which means that the cost of transporting passengers is greater than the income received from them.

Today, among Ukrainian motor transport enterprises there is a tendency to choose an innovative project depending on the indicators that determine its cost. For enterprises, the priority is the project that allows increasing income rather than reducing costs from the provision of passenger services [4]. That is, it is important to develop the logistics of civil traffic not only in terms of finding ways to reduce costs and optimize them in the field of road transportation but also from the standpoint of finding options to increase the enterprise profitability. This fact primarily concerns increasing the competitiveness of bus transportation.

From the passenger's point of view, the efficiency of city civil traffic is defined by service reliability, trip comfort, and an affordable tariff. The problem of finding a compromise is manifested in the choice of the vehicle and route [5]. The logistics management of passenger traffic significantly changes the traditional nature of economic and organizational relations between different modes of transport. The most fundamental change that logistics brings in the management of passenger traffic is to ensure the efficiency of complex transport services by different modes of transport with a focus on high-end results [6]. Such a complex combination of public transport will lead to more efficient operation in general and of motor transport in particular.

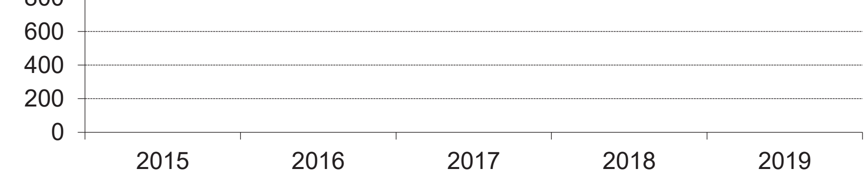

Fig. 3 Graphic display of passenger traffic in Ukraine from 2015 to 2019

3. Conclusions

After analyzing this material, it can be concluded that the management of costs for urban passenger transportation is extremely important. However, without the use of logistics, such management will not be complete and effective. Everybody can achieve the desired result − cost optimization and profitability of the motor transport enterprise only thanks to a competent approach to the smooth operation of vehicles, starting with the appropriate construction of a transport network and ending with the traffic comfort.

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Methodology of Identification and Protection of Soft Targets of Transport Infrastructure – initial study

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Abstract

This article is focused on the methodology of identification and protection of soft targets of the transport system. In our research, we try to find new possibilities of protection of the soft targets. The first step is identifying which objects, places or events are the soft targets and calculating their vulnerability in the other action. We create our methodology for the calculation of the vulnerability of the soft targets, especially the transport system. Nowadays, the methodology is in the beginning and we describe the initial study. This article defines the soft targets, shows statistics of attacks, and presents our methodology and results.
KEY WORDS: *Soft targets; Identification; Protection; Methodology; Transport infrastructure*

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, shows that the danger is all around us, and we must prepare for this. Our research takes around four years

In our life, we move to many different places. Many of them are Soft targets that can be the target of violent attacks [1]. It does not have to be just terrorist attacks but also revenge, violent crime, extremism, organized crime, etc. In several years ago, we started with research about soft targets and their protection.

In this article, we present our methodology, which is focused on the transport system. In the beginning, we define the soft targets and show statistics (number of attacks, type of targets, modus operandi). Then we describe our methodology for the identification and protection of soft targets.

2. Soft Targets

“As "Soft Targets” can be referred to those objects, (open) spaces, or events characterized by the accumulation of a large number of people, the absence or low level of security measures against violent assaults and their omission among critical infrastructure and hard target objects.” [2].

These objects, spaces, and events are the targets of terrorist attacks and other violent attacks in Europe since 2014. This year, the Islamic State declared a caliphate and started with the terrorist attacks on the whole world [3]. For Europe, the attacks are something new and alarming. The last significant attacks were in 2004 and 2005 in Madrid and London. Al-Káida caused these attacks. From 2014, the terrorist attacks were very frequent, as you can see in Fig. 1.

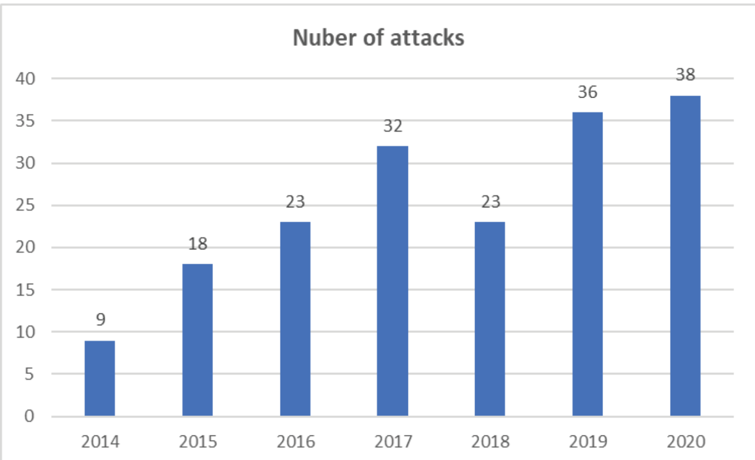

Fig. 1 Number of attacks 2014 – 2020 [4]

For our research, we create our database of violent attacks (DoVA) [4]. We are limited to Europe, the European part of Russia, and Turkey from 2014 to the present (2021). This information is critical because they help us understand attackers – motivation, modus operandi, etc.

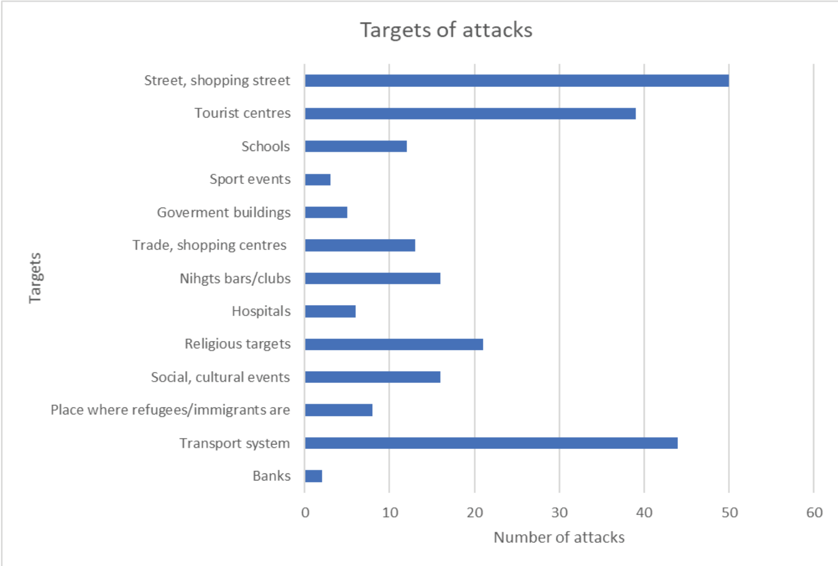

Fig. 2 Number of attacks 2014 – 2020 [4]

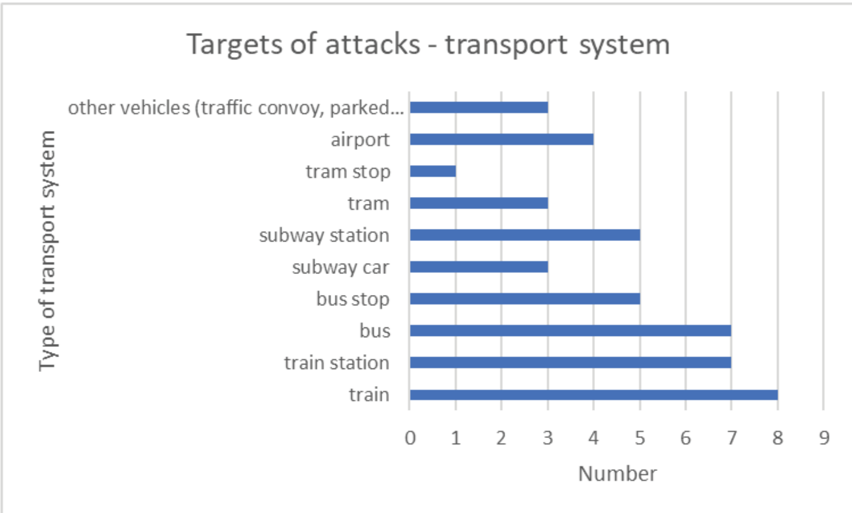

Fig. 3 Number of attacks 2014 – 2020 [4]

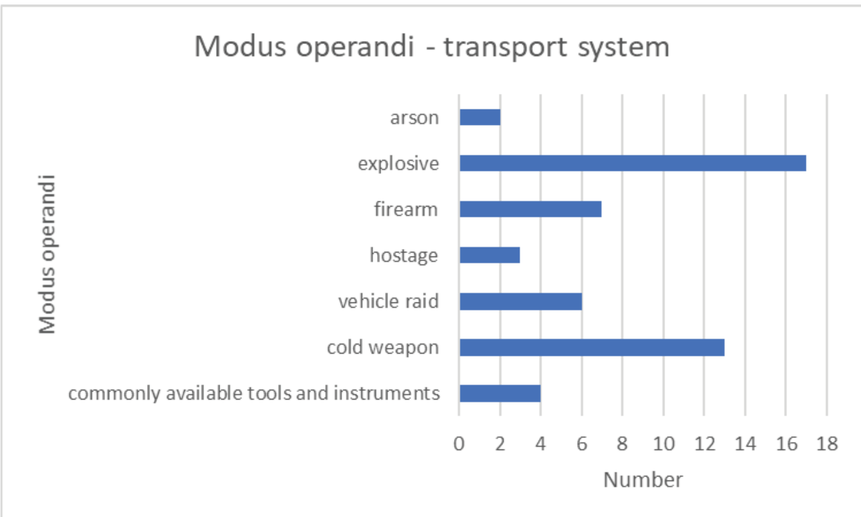

Fig. 4 Number of attacks 2014 – 2020 [4]

In the figures (Figs. 2-4), we can see that the transport system is often the target of the attacks. This is the reason why we must try to improve the planning and realization of security measures.

3. Methodology of Identification and Protection of Soft Targets of Transport Infrastructure

The process of the identification and the protection of the soft targets for transport infrastructure, and thus assessing the risk of these infrastructure systems, consists of the following steps:

- Assessment of the identification aspect;
- Assessment of the analytical aspect;
- Assessment of the application aspect.

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 (1).

$$R = \frac{1}{n}\sum_{i=1}^{n} D_i = \frac{A_{id} + A_{an} + A_{ap}}{3}, \qquad (1)$$

where R – risk (vulnerability) of the soft targets of the transport infrastructure target; D_i – i-th determinant R; n – number of determinants; A_{id} – identification aspect; A_{an} – analytical aspect; A_{ap} – application aspect.

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.

3.1. Assessment of the Identification Aspect of the Soft Target of Transport Infrastructure

Given the nature of the soft targets as an important infrastructure system, the identification aspect will to some extent, reflect the logic of identifying and marking critical infrastructure elements in terms of the cross-sectional nature of the proposed criteria. In this context, three categories of criteria are identified:

I. Number of transport connections per day;
II. Number of passengers/people per day;
III. Number of passengers/people per hour.

According to relation, the calculation of the risk identification aspect of the soft target of the transport infrastructure is the weighted average of the individual variables defined below, according to relation (2).

$$A_{id} = \sum_{j=1}^{m} P_j v_j = P_{sd} v_{sd} + P_{ld} v_{ld} + P_{lh} v_{lh}, \qquad (2)$$

where A_{id} − risk identification aspect of the soft target of the transport infrastructure; P_j = j-th variable A_{id}; v_j − normalized weighting coefficient of the j-th variable A_{id}; m − number of variables A_{id}; P_{sd} − coefficient expressing the number of connections per day; P_{ld} − coefficient expressing the number of passengers/people per day; P_{lh} − coefficient expressing the number of passengers per hour.

Table 1

Standard weighting coefficients for calculating the risk identification aspect of the soft target of transport infrastructure

	v_{sd}	v_{ld}	v_{lh}	$\sum$
v_j	0,20	0,35	0,45	1,0

The determination of weighting coefficients (Table 1) and their subsequent normalization was carried out on the basis of expert evaluation of expected future users of the method (subjects of selected territorial units) using the Analytic Hierarchy Process method [5], which is based on pairwise comparison of variants supporting evaluation of criteria hierarchies.

Determination of values of variables P_{sd} – coefficient expressing the number of connections per day; P_{ld} – coefficient expressing the number of passengers/people per day; P_{lh} – coefficient expressing the number of passengers per hour uses binary logic (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).

P_{sd} – in case of a positive answer the value 0 is set, in case of a negative value 1

P_{ld} – in case of a positive answer the value 0 is set, in case of a negative value 1

P_{lh} – in case of a positive answer the value 0 is set, in case of a negative value 1

Table 2

Assessment of the risk identification aspect of the soft target of transport infrastructure

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)?	
2.	**Coefficient expressing the number of passengers/people per day (P_{ld})**	
2.1	Does the total daily number of passengers exceed 5000/day?	
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?	

Assessment of the risk identification aspect of the soft target of transport infrastructure (Table 3):
<1; 0,5> = large identification aspect;
<0,499; 0,250> = average identification aspect;
<0,249; 0> = small identification aspect.

3.2. Assessment of the Analytical Aspect of the Risk (Vulnerability) of the Soft Target of Transport Infrastructure

The calculation of the analytical aspect of the risk of the soft target of transport infrastructure is the weighted average of the individual variables defined below, according to the relation (3).

$$A_{an} = \sum_{j=1}^{m} P_j v_j = K_{ih} v_{ih} + K_{ia} v_{ia} + K_{ar} v_{ar} + K_{pr} v_{pr} + K_{dz} v_{dz} + K_{ro} v_{ro} + K_{fo} v_{fo} + K_{po} v_{po} \,, \qquad (3)$$

where A_{an} – analytical aspect of the risk of the soft target of the transport infrastructure; P_j – j-th variable $\mathrm{A_{an}}$; v_j – normalized weighting coefficient of the j-th variable A_{an}; m – number of variables $\mathrm{A_{an}}$; K_{ih} – threat identification coefficient; K_{ia} – asset identification coefficient; K_{ar} – risk analysis coefficient; K_{pr} – risk prioritization coefficient; K_{dz} – object security documentation coefficient; K_{ro} – coefficient of regime and organizational measures; K_{fo} – physical guard coefficient; K_{po} – insurance coefficient.

K_{ih} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{ia} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{ar} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{pr} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{dz} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{ro} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{fo} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{po} – in case of a positive answer the value 0 is set, in case of a negative value 1

Table 3

Standard weighting coefficients for calculating of the analytical aspect of the risk (vulnerability) of the soft target of transport infrastructure

	v_{sb}	v_{bm}	v_{so}	v_{bs}	v_{oz}	v_{sv}	v_{kb}	v_{rb}	$\sum$
v_j	0.10	0,10	0,15	0,10	0,10	0,20	0,15	0,10	1,0

The determination of weighting coefficients (Table 3) and their subsequent normalization was carried out by the same method as in the case of calculating the identification aspect of the riskiness of the soft target of the transport infrastructure.

Assessment of the analytical aspect of the risk (vulnerability) of the soft target of transport infrastructure (Table 4):
<1; 0,5> = large analytical aspect;
<0,499; 0,250> = average analytical aspect;
<0,249; 0> = small analytical aspect.

Table 4

Assessment of the analytical aspect of the risk (vulnerability) of the soft target of transport infrastructure

ID	Controlled area	YES/NO
1.	**Threat identification coefficient (K_{ih})**	
1.1	Does the soft target's owner identify and categorize threats?	
2.	**Asset identification coefficient (K_{ia})**	
2.1	Does the soft target's owner identify and categorize assets?	
3.	**Risk analysis coefficient (K_{ar})**	
3.1	Is the method and process of risk analysis described and implemented?	
4.	**Risk prioritization coefficient (K_{pr})**	
4.1	Are the risks, as an output of the risk analysis, prioritized?	
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?	
6.	**Coefficient of regime and organizational measures (K_{ro})**	
6.1	Are regime and organizational measures set by the soft target's owner?	
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?	
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?	

3.3. Assessment of the Application Aspect of the Risk of the Soft Target of Transport Infrastructure

According to the relation, the calculation of the application aspect of the transport infrastructure soft target is a weighted average of the individual variables defined below, according to the relation (4).

$$A_{ap} = \sum_{j=1}^{m} P_j v_j = K_{sb}v_{sb} + K_{bm}v_{bm} + K_{so}v_{so} + K_{bs}v_{bs} + K_{oz}v_{oz} + K_{sv}v_{sv} + K_{kb}v_{kb} + K_{rb}v_{rb} \quad (4)$$

where A_{ap} – application aspect of the softness of the transport infrastructure soft target; P_j – j-th variable A_{ap}; v_j – normalized weighting coefficient of the j-th variable A_{ap}; m – number of variables A_{ap}; K_{sb} – safety management structure coefficient; K_{bm} – security manager coefficient; K_{so} – object manager coefficient; K_{bs} – security services outsourcing coefficient; K_{oz} – coefficient of employee responsibility; K_{sv} – coefficient of training and education; K_{kb} – safety control factor; K_{rb} – security incident / incident resolution coefficient.

K_{sb} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{bm} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{so} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{bs} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{oz} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{sv} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{kb} – in case of a positive answer the value 0 is set, in case of a negative value 1
K_{rb} – in case of a positive answer the value 0 is set, in case of a negative value 1

Table 5

Standard weighting coefficients for calculating of the application aspect of the risk of the soft target of transport infrastructure

	v_{sb}	v_{bm}	v_{so}	v_{bs}	v_{oz}	v_{sv}	v_{kb}	v_{rb}	$\sum$
v_j	0.10	0,15	0,05	0,15	0,10	0,15	0,10	0,20	1,0

The determination of weighting coefficients (Table 5) and their subsequent normalization was carried out by the same method as in the case of calculating the identification aspect of the riskiness of the soft target of the transport infrastructure.

Assessment of the application aspect of the risk of the soft target of transport infrastructure (Table 6):

<1; 0,5> = large application aspect;
<0,499; 0,250> = average application aspect;
<0,249; 0> = small application aspect.

Table 6

Assessment of the application aspect of the risk of the soft target of transport infrastructure

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?	
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?	
3.	**Object manager coefficient (K_{so})**	
3.1	Are facility managers appointed within the soft target's owner?	
4.	**Security Services Outsourcing Coefficient (K_{bs})**	
4.1	Are the soft target's owner's security services outsourced?	
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?	
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?	
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?	
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?	

4. Conclusions

In this article, we present our research focused on Soft targets. We find the possibilities for their protection. This article is focused on the methodology of identification and protection of soft targets of the transport system. The whole process is very easy because we wanted to create the tool for all people, not only for experts.

In the first section of this article, we defined the Soft targets. In the other part, we showed statistics because it is very important to know how big the danger is. The most important section was about the methodology of identification and protection of soft targets. We were focused on the transport system, but it is possible to use this tool for other categories of Soft targets (after adjustment).

Acknowledgement

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Tram Resilient Wheel Analysis within Frequency Domain

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Abstract

Noise generated in the wheel-road contact patch is one of the main sources of noise in case of the road traffic. The significant share of it comes from the phenomena occurring in tram wheel-rail systems. Due to the complex nature of the mechanism of noise generation works on the analysis are still ongoing since the 70s of the last century.

This paper presents the results of calculations of two different models of a tram wheel equipped with a resilient layer isolating the wheel rim from the wheel disk. One of them represents a new wheel and the other a wheel after a long-term operation. In the first model the rim, disc and pressure ring are completely attached to rubber layer and the initial mounting stress of this layer is implemented. In the second model there is no initial stress and slips between elastic layer and the rim and the disk are possible to recreate the results of exploitation.

The analysis of the noise generation in the frequency range up to 5 kHz was based on the use of the finite element method, considering the three-dimensional model. Harmonic forces in three main directions, equal to 10 kN each, were applied to the tread. The eigenvalues with corresponding eigenforms were calculated. Special attention was paid to Frequency Response Function for of the wheel vibration at a point situated on the wheel flange.

Basing on the analysis we can conclude that a long-time operation of a wheel increases the vibration amplitudes of the wheel in the rolling noise frequency range. Additionally, it causes an increase in the number of eigenmodes of the system. At the same time, the decoupling of vibration of the elements of the wheel may occur. The shift of the eigenfrequencies towards the lower frequencies range is also observed.

KEY WORDS: *tram wheel, resilient layer, frequency*

1. Introduction

Wheel dynamics in high frequencies is inseparably linked to the study of noise generated by means of transport.

As an example, we would like to cite a few facts:

- European Environmental Agency estimates that c.a. 120 millions of people in UE (over 30% of entire population) are exposed to the noise caused by road traffic of sound level over 55 Ldn dB (Ldn - day-night average sound level).
- Over 50 millions of people are exposed to noise of over 65 Ldn dB.
- It is estimated that 10% of UE population is subject to noise related to rail traffic of sound level of 55 LAeq dB (LAeq - equivalent continuous sound level).
- Two main noise sources in case of the road traffic are engines operation and noise generated in the wheel-road contact patch.
- A significant share in the latter one has the noise generated by phenomena occurring in a tram wheel-rail system.

The literature on the generation of noise in a wheel-rail system is very extensive and cited in this study certainly does not exhaust the subject. The mechanism of noise generation is extremely complex and for this reason the works on the analysis, which have started in the 70s of the last century, is still ongoing and they are far to be complete.

The theoretical studies on such construction are based on circular plates and curved rods dynamics. As examples of the early works on this subject may be mentioned articles [1-4, 6, 8, 14], and this issue is still popular e.g. [5, 7, 15].

Currently used tram wheels are equipped with resilient layer, which isolates the wheel rim from the wheel disc. Its main aim of use is the reduction of the impact of unsprung mass on the track. Also the use of a resilient layer should bring about a reduction of noise in wheel - rail system due to the fact that the material, from which the layer is made, has greater vibration damping ability than steel.

It is worth to mention that the use of resilient layer can lead to difficulties connected with its behavior after long term operation. The operation can result with the occurrence of slips between the elastic pad and the wheel rim and wheel disc. So it is reasonable to analyze the comparison of dynamics of the “new” resilient wheel model (slips are not allowed), called further – Model “1” and wheel where slips are allowed. Such a model is called Model “2”.

Analysis is performed in the frequency range up to 5 kHz covering rolling noise and partly squealing noise range of tram wheel vibration.

This study, on high-frequency noise generation, is based on the use of the finite element method, and it takes into account the three-dimensional model. The key works in this field were the works [8-13].

2. The Models

To position among other design solutions examined in this article models let us first refer to the typical techniques used to reduce noise in the wheel-rail system.

Generally, the process of a noise generation reduction is carried out by means of three methods:

- Installation of dynamic dampers;
- Installation of damping layer onto the wheel;
- Application of an elastic layer between disc and rim.

The solution of the noise damping system, studied in this article, is contained in the last mentioned technique.

The basic assumptions adopted by us for the construction of the model (Fig. 1) are as follows:

Both wheel models have V-shaped layers (chevron shaped cross-section);

The chevron angle is equal to 60° for M**odel „1"**;

The initial stress of the elastic layer responds deformation equal to 0.5 mm in cases of M**odel „1"**;

The resulting stresses obtained in the static analysis were recorded as initial state for further analysis;

The wheel hub is clamped;

The rim, disc and pressure ring are completely attached to rubber layer for Model „1";

There is no initial stress of the elastic layer for **Model „2"**;

There are possible slips between the elastic layer and the rim for Model „2".

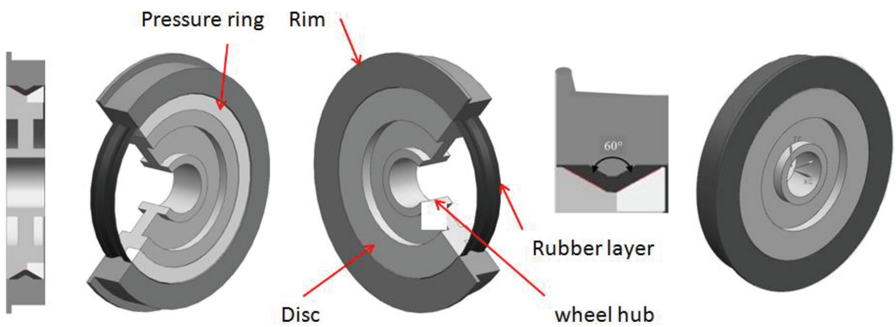


Fig. 1 Wheel model with V-shaped elastic layer

The models consist of four elements and one distinguished element – the hub where boundary condition is applied.

It is easy to see that the adopted models are a significant simplification of existing structures.

Therefore, the results obtained here should be regarded as showing the behavior of the system qualitatively.

Calculations were performed examining the eigenfrequencies and eigenforms in the range up to 5 kHz. Besides that, the special attention was paid to the Frequency Response Function (FRF) of the wheel vibration at a point situated on the wheel flange (Fig. 2)

Fig. 2 Point for FRF results calculation

Considering the forces acting on the wheel, its FRF was examined. The FRF results were calculated for the point which is situated on the flange top.

Harmonic forces are applied to the tread (Fig. 3). Values of applied forces were equal to 10 kN.

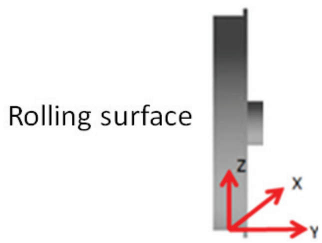


Fig. 3 Forces application for FRF calculation

The longitudinal, lateral and vertical forces were taken into account during numerical tests.

3. Calculations Results

In this section are presented eigenfrequencies and eigenforms of studied model and results connected with FRF values.

3.1 Model „1" Results Analysis

We have found thirteen eigenmodes which demonstrate typical shape for axially symmetric objects within studied frequency range.

Results regarding to eigenforms and eigenvalues are listed in Fig. 4.

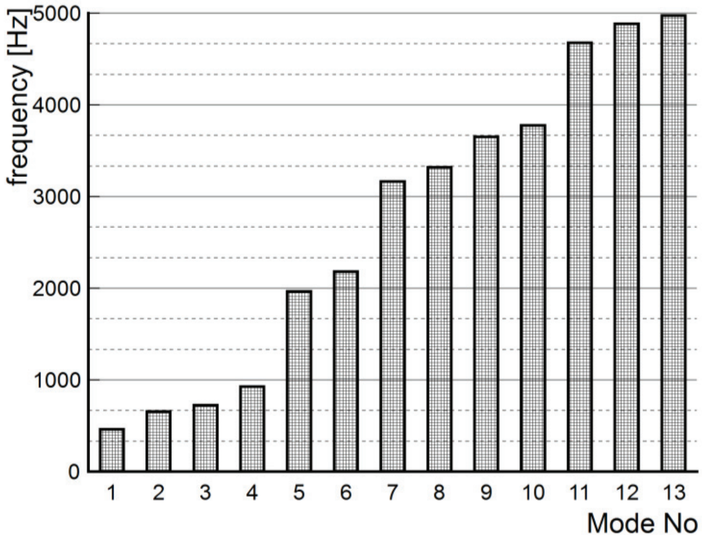


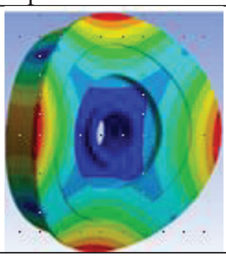
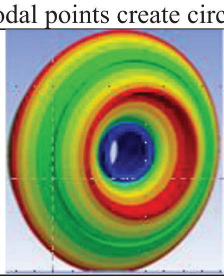
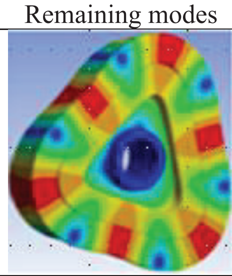
Fig. 4 Eigenmodes of Model „1"

Modes no. 1, 4, 6, 9 are the eigenmodes when nodal points create diameters, in modes 2, 3, 8, 12 the nodal points create circles.

The examples of resilient wheel modes are contained in Table 1.

Table 1

The examples of resilient wheel modes

Nodal points create diameters	Nodal points create circles	Remaining modes
		

Modes, where nodal points create circles or diameters, correspond to the wheel motion in perpendicular direction to the wheel plane and the motion is in both directions for remaining modes that is in the wheel plane and in the perpendicular plane.

In pictures of Table 2 the color navy blue denotes the smallest displacements and deep red – the biggest displacements.

3.2 Model „2" Results Analysis

Model „2" is identical to Model „1" as far as their geometry and inertial parameters are concerned. The difference is that Model „2" does not include initial strain of the layer and slips between elements are possible. This model can be regarded as a marginal condition being the result of exploitation.

The analysis of this model showed that there is much more eigenmodes in the frequency range under test than in Model „1". Those modes are listed in Fig. 5.

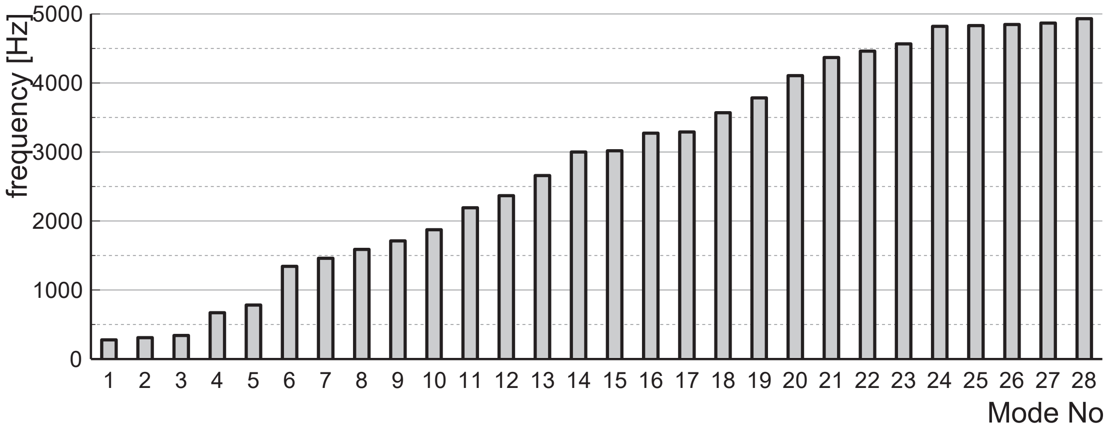


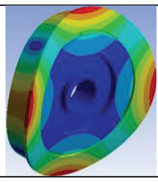
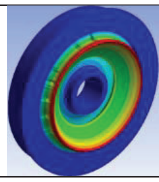
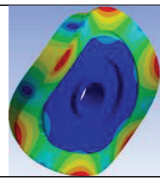
Fig. 5 Eigenmodes of Model „2"

When analyzing the results obtained, it can be stated that in the examined frequency range Model "1" possess 13 eigenmodes, whereas for Model "2" number of eigenmodes increased. It can be noticed that for many modes of Model "2" there is no coupling between the disc and the rim vibrations. In the case of Model "1" all of the eigenmodes show coupling between the rim and disc, whereas the coupled modes for Model "2" are: 1, 4, 9, 24, 26 (according to Fig. 5). Coupling occurs for the modes creating diameters. For the rest of the modes, vibrations of disc and rim are decoupled.

Examples of eigenmodes are contained in Table 2.

Table 2

Examples of eigenmodes

Eigenmodes when disc and rim are coupled			Eigenmodes representing disc vibration while wheel rim acts as rigid body			Eigenmodes representing rim vibration while wheel disc acts as rigid body		
Mode No	Frequency [Hz]	Eigenmode	Mode No	Frequency [Hz]	Eigenmode	Mode No	Frequency [Hz]	Eigenmode
4	671		25	4830		9	1711	

We can see that for modes when node points form one and two diameters, the corresponding to them frequencies are shifted to lower values.

3.3 Comparison of FRF results

Due to the fact that Model "2" can be treated as a wheel model (Model "1") after long exploitation the analysis of FRF at the point located on the flange is carried out by comparing the results obtained for Model "1" and Model "2". The comparison covers Frequency Response Functions calculated for vertical, lateral and longitudinal direction. Harmonic force is applied to the wheel tread.

The graphs are presented in decibel scale i.e. dB = $10\log_{10}(W/W_{ref})$, where $W_{ref} = 10^{-9}$ m.

Fig. 6 shows FRF for application of longitudinal force in directions x.

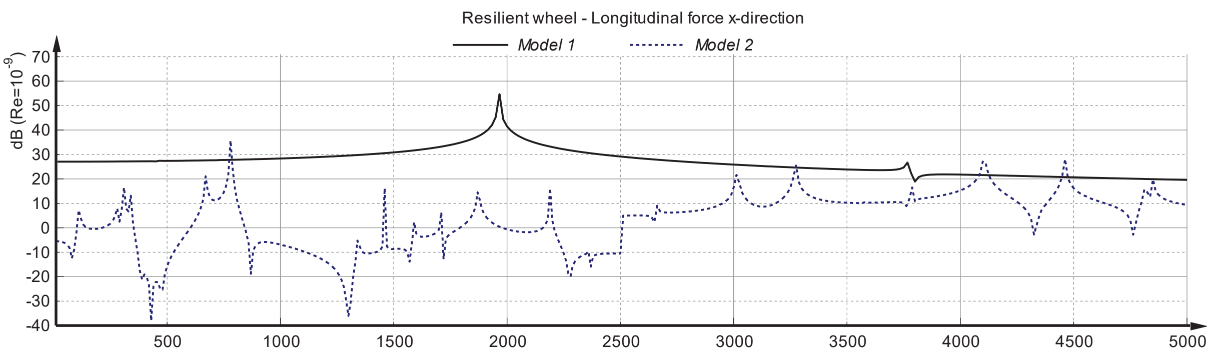


Fig. 6 Comparison of FRF calculated for longitudinal direction, longitudinal harmonic force applied to the wheel tread

The lack of initial elastic layer strain causes huge differences between obtained results. They are especially evident for displacement in longitudinal direction.

Fig. 7 shows FRF for application of lateral force in directions *y*.

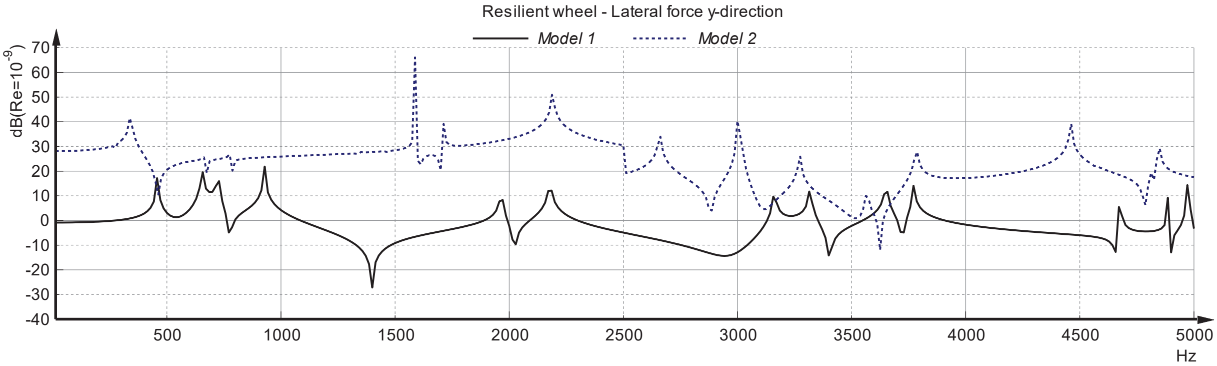


Fig. 7 Comparison of FRF calculated for lateral direction, lateral harmonic force applied to the wheel tread.

Fig. 8 shows FRF in directions z respectively for application of vertical force.

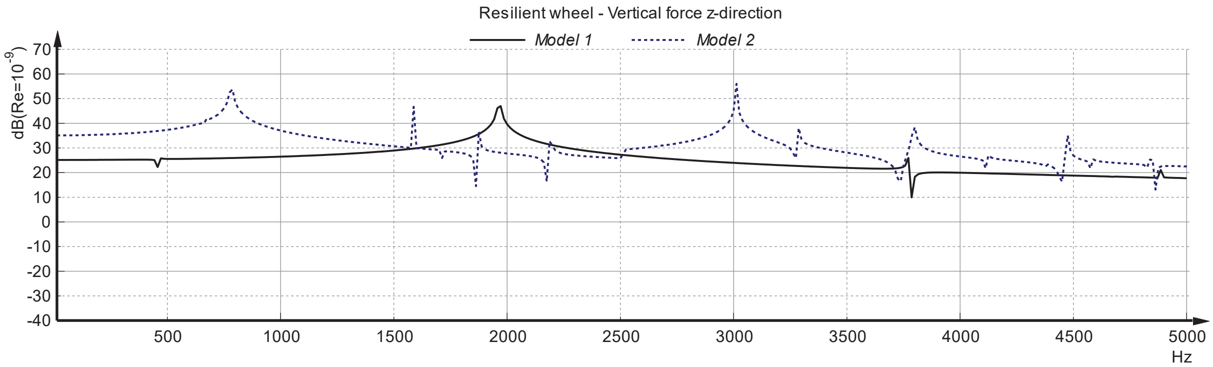


Fig. 8 Comparison of FRF calculated for vertical direction, vertical harmonic force applied to the wheel tread

Both for y and z direction there are significant differences in FRF values.

4. Conclusions

This article presents the results of calculations of two models of tram wheels. Models in terms of geometry and inertia parameters do not differ one from another. One of the models did not take into account the initial mounting stress and allowed a relative slip between the structure elements. This model can be considered a model of a wheel after a long time of an operation.

Basing on the analysis, it is concluded, that simultaneously with the operating time of the wheel, increases the number of eigenmodes of the system in the range of rolling noise. At the same time, the decoupling of vibration of the elements of the wheel may occur. It is observed also the shift of the eigenfrequencies towards the lower frequencies range.

Analyzing the results obtained for FRF, if the system is excited by the longitudinal force, we can see, that the largest differences in model responses, are visible for the circumferential direction. When the system is excited by the force perpendicular to the wheel plane, significant differences in FRF values occur for the y and z directions. For this case, the displacement of the point at which the FRF is tested is much higher for the Model “2”. When the system is excited by vertical force, the largest differences in FRF values occur in the longitudinal direction.

Taking into account the complex arrangement of forces acting on the wheel during a ride, we can conclude that a long time operation of a wheel increases the vibration amplitudes of the wheel in the rolling noise frequency range. At the same time, additional frequencies may appear in the system.

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Increasing of Business Competitiveness of Bus Transport Companies Through the Blue Oceans Strategy in Slovakia

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Abstract

This article deals with the issue of strategic management in bus transport companies in Slovakia. It briefly explains why it is important for companies to focus on new strategies, not the old ones. From new strategies, the article is focused on the blue ocean strategy and presents its essence, keystones, and recommendations. In connection with this strategy, the authors also explain the concept of the red ocean strategy. The aim of this paper is to find out whether companies in the Zilina region use some principles of the blue ocean strategy, and thus increase their competitiveness in the market, and to explain the necessity of this increase through the mentioned strategy by the Covid-19 crisis. A questionnaire survey method was used to achieve the aim of the paper. The results indicate that only a small percentage of the interviewed companies use any of the principles of the blue ocean strategy, the old strategies are more preferred in generally. E. g. focus on the quality of products / services, and innovations, which are, according to the blue ocean strategy, a very important factor of success and competitive advantage, ranked only third. After the questionnaire survey the authors used a structured interview to find out whether companies that use the blue ocean strategy are successfully operating in Slovakia as well. It turned out that the interviewed company really cared about all the principles of the blue ocean strategy. The results of this thesis are therefore recommendations that bus transport companies should focus on in the field of strategic management in order to be more successful in the market of transport services.
Key words: *strategy, bus transport companies, success*

1. Introduction

Competitiveness is a term that expresses the ability of a company to withstand competition with the same or similar focus on the domestic or foreign market. According to the OECD, business competitiveness refers to the ability to generate relatively high levels of income from production factors (inputs), but also their use at a sustainable level [5]. Business competitiveness is a complex concept that can be interpreted in different ways, e. g. as an indicator of a company´s ability to provide goods and services in a place and at a time that customers can buy them at prices that are better than those at which other competing companies offer goods or services [22]. Today, it is obvious that if a company wants to be successful and develop, it must have a quality strategy in place as part of the strategic management of the company. This also applies to bus transport companies, which currently must adapt to the new situation caused by the COVID-19 health crisis. Business strategies generally address how a company will compete in the market and gain a competitive advantage over competitors [21].

2. Blue ocean Strategies as a Tool of Competitiveness Improvement

Competitiveness is a key term in the world, where the market power is primary determined by economic results. Competitiveness determines the ability to conquer new markets, corner other market players, attract investment and grow. It usually means the ability of a company to successfully withstand competition with the same or similar focus on the domestic or foreign market. According to other sources, it means the ability of companies, industries, regions, nations, or multinationals to generate relatively high levels of income from production factors and their use at a sustainable level in the current competitive environment [22].

The Dictionary characterizes the word strategy as "the doctrine of the preparation and conduct of a major war operation; the science of fighting; the art of leading a team in order to achieve great common goals; the long-term intention of the action to achieve a certain goal. This word is derived from the Greek word "strategos", which means a general. In a broader context, it originally referred to the art and science of conducting military operations [18].

One of the oldest definitions of the term "strategy" is given by A. Chandler, who defined it in his book "Strategy and Structure. Chapters in the History of American Enterprise" firstly published in 1962. Chandler (1962) sees the strategy as the determination of basic long-term goals of a company, ways of achieving them and allocation of resources necessary for the realization of these goals. However, this characteristic is very broad, taking the strategy as a set of goals, means and resources [3].

According to Quinn (1980) the strategy is a model or a plan, which integrates the main goals of a company, politics and activities into a coherent whole [17].

Mintzberg (1991) looks at the strategy from a newer, more unconventional point of view. He defines it as a template or formula in a stream of decisions or actions [15]. Jakubikova (2008) characterizes strategic management as a dynamic process of creation and implementation of development plans, which are of fundamental importance for the development of any company [7]. It includes activities aimed at maintaining a long-term consistency between the company´s mission, long-term goals, and available resources, as well as between the company and the environment in which the company operates by creating a vision, mission, corporate goals, growth strategies, and portfolio for the whole company.

According to Trebuňa (2019), there are two approaches to typologies of business strategies [21]. The first, contingent approach, does not recommend well-defined and clearly formulated strategies for specific situations. For example, Hofer (1975) in Towards a Contingency Theory of Business Strategy concludes that the most important variable in determining a strategy is the phase of the product life cycle [6]. The second approach, generic, assumes that some strategies are almost always appropriate, regardless of the specific situation. The most famous of these was revealed by Michael Porter. We know them as Porter´s competitive strategies. William K. Hall, Raymond E. Miles, Charles C. Snow and Nelson Valverde also devoted generic typologies. An alternative typology of generic strategies was proposed by Henry Mintzberg [21].

There is a lot of talk at the moment about strategies and the need to change them. The fact that competition in existing sectors is still intensifying and thus increasing pressure on costs and profit margins has only conditioned the emergence of new strategies. The need for some global trends, which are evolving very fast, has also added to this need. This is how a new strategy, called the blue ocean strategy, was somehow created.

The creators of the blue ocean strategy are W. Chan Kim and Renée Mauborgne, professors of strategy at INSEAD, the second largest university of economics in the world [8, 9]. This theory was presented in the book Strategy of the Blue Ocean. The blue ocean strategy is based on more than 15 years of research, data from more than a century, and various articles focusing on various aspects of the subject matter. The ideas, tools and system frameworks of this strategy have been tested in business practice in Europe, the United States and Asia.

The blue ocean strategy is an alternative management approach that changes the traditional view on strategy management. It is a phenomenon that has become a very popular way of managing a company in the last decade, not only in the world of business [13]. The strategy is always based on value innovation. It has been used and it is also possible to apply in various industries, which is why we recommend it for attention in the field of public transport services in Slovakia.

The blue ocean strategy is often compared with other strategies, however the most often is contrasted with the competitive strategies of Porter. Burke, Van Stel and Thurik (2009) compared not only the theories, but also a practice [1]. The successful use of the blue ocean strategy in the telecommunications sector, in particular mobile phones, is evidenced by the study from 2010 [2]. Author Shi-Chi Chang applies the strategy to a company from Taiwan, which was the largest supplier of chips for the production of mobile phones in China [4]. This study once again demonstrates the important role that value innovation plays. In 2012, three Slovenian authors - Jaka Lindič, Mojca Bavdaž and Helena Kovačič, decided to prove that using the blue ocean strategy can support economic growth [11]. Their assumption was confirmed. Burke, Van Stel and Thurik (2016) returned to the comparison of the blue ocean strategy with the Porter´s competitive strategies in 2016 once more, however they paid attention to retail. They carried out their research in Denmark, and the analysis of the data obtained reaffirmed that the blue ocean strategy was successful in every sector.

The study of Lohtander et al. (2017) confirmed that the application of the blue ocean strategy supported the market position of companies operating in the environmental and ecological field [12]. The principles of this strategy were used in the field of agriculture to fight against unemployment, low investment activities and missing know-how in chosen areas of Poland and Ukraine. According to this, Zalizko (2017) suggested to apply the strategy into practice to utilize the agriculture potential and strengths of these countries [23].

One of the newest studies dealing with the issue of the blue ocean strategy is the study by Namboodiri, Banenerjee and Dasgupta [16]. The study offers many examples directly from the practice, e. g. Apple, Google or Amazon.com. The authors Oivind and Slatten (2019) analysed the Blue Ocean strategy from the point of view of management fashion theory [19]. From this point of view, they elaborated the history, development, characteristics, and supply side and demand side of the blue ocean strategy. Their research has shown that although the strategy can be applied in many sectors and has become a real phenomenon in the last decade, it also has problem areas that still need to be picked up.

As we have stated before, the blue ocean strategy is applicable in different fields. With the principles and tools of the blue ocean strategy, one can emerge from the "red ocean", where fierce competition is raging, and enter the undisturbed "blue ocean", which has a market space characterized by new demand, strong growth and profits. The strategic management of many companies is guided by the competition. However, the blue ocean strategy points out that focusing on competition often keeps companies firmly entrenched in the red ocean environment.

The goal of this strategy is to allow any company regardless of its size, field of operation, history etc. to create own "blue ocean" and such a way to maximize own opportunities and minimize risks. Based on the results of many studies it is obvious that companies, which successfully applied this strategy into practice, used three elements that are considered main advantages of the strategy, namely:

- focus – based on the precise definition of values that are essential for the company,
- divergence – an ability to create a different value of products or services in comparison to the company´s competitors,
- tagline – an impressive and concise slogan that is easy to remember and, in addition to its clear message, truthfully presents the company´s offer [10].

The strategy uses many analytical tools and frameworks. One of the most important is so-called 4-actions framework. This talks about what needs to be discarded when creating new value (those factors that have long formed the basis of the competitive struggle of companies in the industry, but is no longer the case today), limited, uplifted, and created. When a company applies this systemic framework to the image of the industry´s strategy, it gets a new perspective on traditional realities.

The fact that innovation is a very important topic that greatly affects the company´s results [20], perhaps we do not even have to say. But when we talk about the blue ocean strategy, we come up with the term "value innovation". Authors of the modern literature on strategic management have already understood that this innovation is the key to creating a sustainable competitive advantage [14].

If the company wants to be successful in the process of applying and using the blue ocean strategy, it must consider the pillar idea of this strategy that is called as "value innovation". In that case, the company does not focus on fighting the competition, but tries to take them out of the game by providing customers, as well as their company, with a leap in value. This way, the company can easily create an uncompetitive market space.

Value innovation only occurs if companies can combine innovation with the utility value, price, and cost. It is created in an area in which the company´s active measures have a positive effect on costs, but also on the value offer intended for customers. Cost savings result from the removal or reduction of factors that form the basis of competition in the industry. The value for customers is enhanced by creating features that the industry has never offered. Costs continue to decline over time as the economic benefits of high sales volumes begin to prevail.

Value innovation requires companies to target the whole system and processes on achieving leaps and bounds of value for customers. Value innovations are characteristic that the source of value for the customer becomes the product, experience in co-creating value and the total costs to satisfy the customer´s need (Vlček, 2011). According to the new concept, therefore, both the company and the customer participate in the creation of added value. An example is the YouTube channel, which created a web portal for the presentation of personal videos to users, which means that it involved them in creating a database that can be shared by all users (Košturiak, Chaľ, 2008). Another example is MediaTek – the company, which has uncompromisingly dominated the Chinese microchip market for phones. According to the study by Chang [4], this company applied successfully the principles of the Blue Ocean strategy and established itself as a market leader.

3. Possibilities of Applying the Blue Ocean Strategies in bus Transport Companies in Slovakia

We carried out an analysis of applying the blue ocean strategy in Slovakia using a questionnaire survey during May - December 2020. The questionnaire was sent online via the Google Forms platform to companies in the Zilina region. The reason was the fact that this region belongs to the important economic regions of Slovakia and has a well-developed industry. It is a region with great investment potential. The construction industry has a strong position in this area. Among other things, the region has a rich cultural and historical potential, which means that there are also many tourism companies. The Zilina region also has good economic results. It has almost 50% of the economically active population and the rate of economic activity reaches 59.1%. The unemployment rate is 4.09% (as of 31. March 2020) a as the only one, together with the Kosice region, they have recently recorded a decrease of rate of unemployment.

Overall, we sent 168 questionnaires without any specifications of the target companies. We primary tried to find out how many companies knew the blue ocean strategy as well as how many of them applied it principles in the practice. However, the return on the questionnaires was relatively low (22%); we assume due to the pandemic situation. The questionnaires were mostly filled in by owners (43.2%) or managers (37.8%). We consider the fact that owners and managers answered the questionnaire to be very favourable, as we assume that these persons are familiar with the company´s strategy and thereby can best respond to the questions asked.

Our assumption that most companies do not know the term "blue ocean strategy" even though this strategy has been a "global phenomenon" since 2005, was confirmed (58.3% of companies do not know this strategy). However, the result does not automatically mean that the companies do not apply some principles of this strategy in the practice. It has often happened that companies use some principles of strategy without knowing exactly what the strategy is called. On the other hand, respondents who have seen that they know the strategy do not automatically have to use it immediately in a practise.

Other results of our research show that more than half of companies (53%) copy or rather copy own competitors. This is probably due to the industry in which the company operates. For example, in accommodation services or construction, the services / products do not differ much, so it may seem that companies imitate the competitors. At this point, it is important to focus on innovation and added value, so that companies do not focus on competitors, imitating them, but try to get it out of the game with new and interesting ideas. Almost 40% of respondents do not think that they imitate their rivals, so we assume that these companies may apply basic principles of the blue ocean strategy focusing on innovation processes and on increasing the value for customers by which they try to differ from the competitors. The rest of interviewed companies were unable to comment on this issue.

Based on the results of our questionnaire survey, we state that companies in Zilina region focus primarily on product quality. Innovations are ranked third, but we believe that they are not crucial for entrepreneurs in every area.

As we have stated before, the questionnaire survey was not focused on a specific industry, since we are an opinion that the blue ocean strategy is applicable in each industry. It is the reason that why we also conducted a structured interview with the strategic managers of two selected bus transport companies. Our questions focused on important factors that, from the point of view of these managers, are necessary in implementing the blue oceans strategy. We have found that in bus transport companies, according to their strategic managers, it is necessary to focus on four areas, namely learning and growth area, area of internal business processes, area of customer satisfaction, and area of financial results.

From the point of managers, within the ***learning and growth area***, it is important to focus on rising and upgrading of professional skills of employees. They also state that information system and internal communication play also important role of this area.

Internal business processes are irreplaceable in bus transport companies. Their quality is evidenced by the "quality" of schedules and, ultimately, by the satisfaction, quality, and speed of transport of passengers (customers). Satisfaction is now also defined by the cleanliness of buses, bus stops and their sufficient disinfection. Customers also perceive the comfort of transport according to the occupancy of the lines. They are not willing to travel in crowded buses. For this reason, increased demands are placed on the number of bus lines, their cleanliness and equipment. They also prefer the ability to minimize contact with other people. To buy a ticket online etc. are important for them as well. All this now needs should be considered in customer care.

It is important that customer satisfaction is subsequently translated into an increased number of passengers. In this way, it will then be reflected in the financial results of bus transport companies. This kind of companies have special features and loss from own operation they cover by state budget contributions. However, the current pandemic situation increases the demands on the state budget, and for this reason it is important for both bus transport companies and the state that more and more customers use public transport, thus minimizing losses in the provision of services in the public interest.

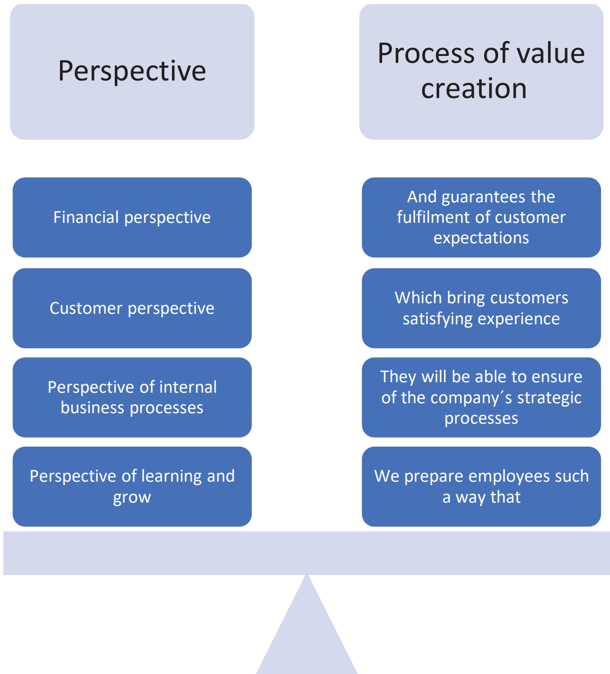

Fig. 1 Model of a strategic map of Blue Oceans strategy for bus transport companies

Based on a structured interview with the managers of bus transport companies, we created a general draft of a strategic map that is depicted in Fig. 1.

Companies may utilize these factors (4-actions framework) in the process of value creation. When a company applies the systemic framework of 4-actions framework to the image of the strategy of bus transport bus companies, it gets a new perspective on traditional realities, which it can then use to its advantage. It is up to the management of these companies to use this to their advantage.

4. Conclusions

The current trend of the market economy is dynamic and unpredictable, however a well-going economy has been braked by the Covid-19 crisis. What the future development will be in the current situation is very difficult to predict. However, it is necessary to find new solutions that will lead to a change in the system we are used to and it will be necessary to "start" new demand and supply. Bus transport companies are facing a new situation and the blue ocean strategy can help them in this case.

As part of the paper, we conducted a survey among companies in the Zilina region. This survey focused on knowledge of the blue ocean strategies but did not consider the specifics of bus transport. The paper also includes the results of the structured interview of strategic managers of bus transport companies. The aim of the paper was to point out the need to increase competitiveness through the blue ocean strategy. We found out that companies in Slovakia do not use the principles of this strategy in a full range. In addition, most companies do not know this concept at all. Based on the results we can state that the strategies of the blue ocean in Slovakia can be a benefit and a new opportunity for bus transport companies.

Acknowledgement

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Unmanned Control of Electric Drive of Mountain Transport Using a Neutral Regulator

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Abstract

The article is devoted to the possibility of using artificial neural networks (neural network regulators) in systems of unmanned control of electric drives of mining transport. A typical structure of an automatic control system with a PID controller and a neural network as an auto-tuning unit is considered. The neural network in this structure acts as a functional converter, which for each set of signals *r, e* and *u* generates the coefficients of the PID controller K, T_i, T_d, trying to minimize the error of the output signal from the signal setter. Thanks to the constant training of the neural network, the regulator allows you to adapt to changing conditions, predict and predict changes in the system and work ahead of the curve, reducing the inertia and delay of the system.
KEY WORDS: *control systems, artificial neural networks, neuroregulator, electric drives, auto-tuning block, mining transport*

1. Introduction

In the conditions of the modern development of science and technology, one or another of the latest scientific developments, and, in particular, neural network regulators, are increasingly being introduced. This article discusses one of the most promising areas, namely the possibility of using neural network regulators in systems of unmanned control (SUC) of electric drives of mining transport.

In order to understand what constitutes a neural network regulator, we turn to the concept of artificial neural network (ANN). This concept arose when studying the processes occurring in the brain, and when trying to create models of these processes. The first such attempt to recreate them was the neural networks of W. McCulloch and W. Pitts. ANN is a mathematical model, as well as its software or hardware implementation, built on the principle of organization and functioning of biological neural networks - networks of nerve cells of a living organism. After the development of training algorithms, the obtained models began to be used for practical purposes: in forecasting problems, for pattern recognition, in control problems, etc. [1-3].

ANNs are a system of connected and interacting simple processors (artificial neurons). Such processors are usually quite simple (especially compared to the processors used in personal computers). Each processor of such a network operates only with signals received periodically and signals that it periodically sends to other processors. Despite its simplicity, being connected to a sufficiently large

network with controlled interaction, such processors together are capable of solving rather complex problems [4].

In the mining industry, some mines use heavy-duty electric vehicles with automated control systems (self-driving cars). For such cars operating in extreme conditions, neural network regulators can be used, which provide better control of the electric drive, because thanks to the constant training of the neural network, the regulator allows it to adapt to changing conditions. In this paper, we consider the structure of an automated control system with a PID regulator and a neural network used for unmanned electric vehicles.

2. Methodology

Currently, the most widely used in SUC are proportional-integral-differential (PID) or proportional-integral (PI) controllers, used, in particular, in frequency converters. Consider the use of a neural network in PID controllers. Neural networks can both replace the PID controller and can be used to adapt its settings to current operating conditions. The neural network, with the ability to "learn", allows you to use the experience of an expert to teach the neural network the algorithm for setting the PID controller coefficients.

A neural network is a set of interconnected neurons, the number of connections of which can be thousands. Due to the nonlinearity of the activation functions and a large number of tunable coefficients, the neural network can perform non-linear mapping of multiple input signals to multiple output [5, 6].

An artificial neuron is represented by a functional block with one output y and inputs x_i: x_1, x_2, ..., x_n, which implements in the general case a nonlinear transformation:

$$y = F \cdot \left[\sum_{i=1}^{n} w_i x_i + b \right], \quad (1)$$

where w_i − weighting coefficients (parameters) for input variables x_i; b − constant displacement; $F(\bullet)$ − neuron activation function.

For example, a sigmoid function:

$$F(z) = 1/(1 + \exp(-az)), \quad (2)$$

where a is a parameter.

3. Results

Fig. 1 shows the structure of an automatic control system with a PID controller and a neural network as an autotuning unit, which we offer for a control system for electric drives of mining transport.

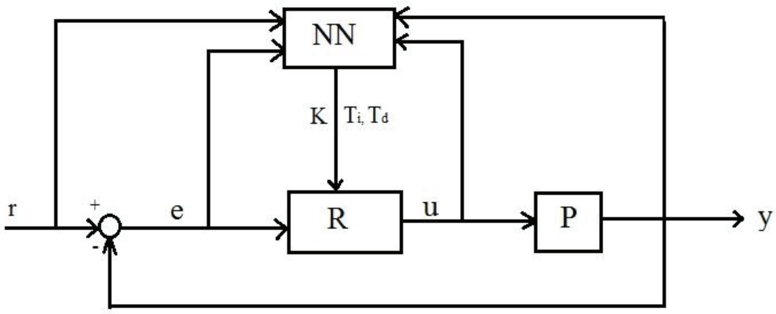
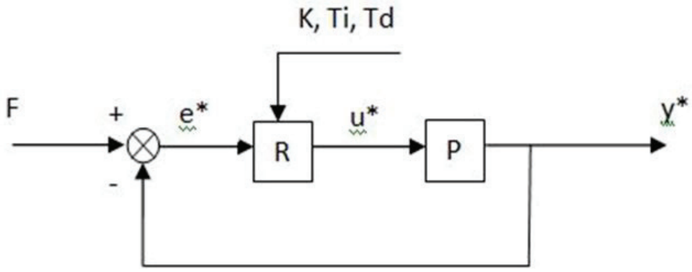


Fig. 1 Structure of an automatic control system with a PID controller and a neural network

The neural network (NN) in this structure plays the role of a functional converter, which for each set of signals r, e, and y produces the PID controller coefficients K, T_i, T_d, trying to minimize the error of the output signal from the setpoint signal. The most difficult in the design of regulators with a neural network is the training procedure.



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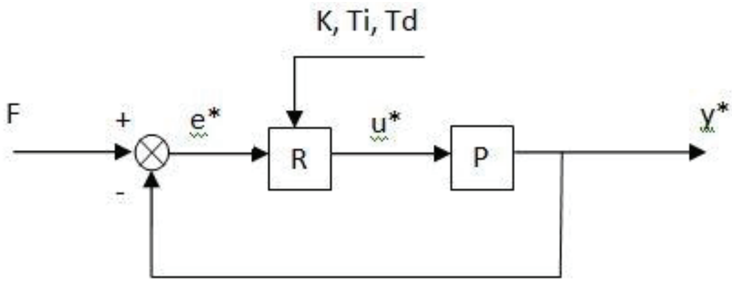

b

Fig. 2 Neural network training scheme in the auto-tuning block

"Training" consists in identifying the unknown parameters of the neurons w_i, b and a. To train a neural network, in electric drive control systems, usually use gradient search methods for minimum criteria function $\varepsilon = (u^*-u)^2$, which depends on the parameters of neurons. The search process is iterative, at each iteration all network coefficients are found, first for the output layer of neurons, then the previous one, and so on up to the first layer (method of back propagation of error). In addition, other minimum search methods are used, including genetic algorithms, annealing simulation method, and least squares method [7, 8].

The process of training a neural network is shown in Fig. 2, a.

The expert is given the opportunity to adjust the parameters of the regulator K, T_i, T_d in a closed-loop automatic control system for various input influences $g(t)$. It is assumed that the expert is able to do this with sufficient quality for practice. Timing charts (oscillograms) of the variables r, e^*, u^*, y^*, obtained in a system adjusted by an expert, are recorded in the archive and then fed to a neural network connected to the PID controller (Fig. 2, a).

The neural network is tuned in such a way as to minimize the error ε between the signal u^* obtained with the participation of an expert and the signal u received during the training of the neural network. After completing the training procedure, the parameters of the neural network are entered in the auto-tuning block (Fig. 2, b). In accordance with the theory of neural networks, a trained neural network should behave in the same way as an expert, and even with input influences that were not included in the set of signals used in the training [9].

For this, the performance of the neural network is checked with a new set of data not used for its training. If the error on the verification data does not exceed the permissible, the neural network is considered trained [10, 11].

The duration of the learning process and its quality are the main difficulties that do not allow the widespread use of the neural network method in PID controllers. At the same time, setting up a neural network and checking it for errors is often much faster and easier than compiling an adequate model of an electric drive and a control object and setting up a PID controller on its basis.

Moreover, far from always adjusting the controller based on the provisions of the theory of automatic control systems can be optimal. Other disadvantages of neural networks include the impossibility of predicting control errors for input actions included in the set of training signals; lack of criteria for choosing the number of neurons in the network, the duration of training, the range and the number of training effects.

4. Conclusions

In conclusion, it should be noted that after analyzing the given system, it is possible to highlight the advantages of using neural network regulators in systems of unmanned control of electric drives of mining transport.

Thanks to the constant training of the neural network, the regulator allows you to adapt to changing conditions, predict and predict changes in the system and work ahead of the curve, reducing the inertia and delay of the system. Neural network regulators are also less sensitive to parameter changes than other classical regulators. This is a positive property, since during operation the drive parameters can change. For example, when reducing the moment of inertia by 50%, the operability of the controller based on the ANN is maintained.

The disadvantages include the fact that the neural network regulator is designed and configured for a specific regulatory object and therefore its operability in another system is not guaranteed. There is also a need for training the network and choosing its structure. Another disadvantage is the difficulty of implementation and, as a consequence, the high price.

Given the rapid development of science and technology, it can be assumed that in the coming years, neural network regulators will be able to reveal all their advantages and be available at the serial production level for use in unmanned drive control systems.

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Theoretical and Experimental Determination of the Safe Value of the Stability Coefficient of Light Weight Freight Cars in the Train

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Abstract

Ensuring traffic safety is one of the most important requirements for the operation of railways. Among accidents and catastrophes on railway transport, the greatest danger is derailment, as this can lead to serious consequences. The reasons for the derailment of freight cars are related to the malfunctions of the rolling stock, deviations from the norms of track maintenance, unsatisfactory dynamics of the train and the conditions of their operation. These faults, in particular, related to the destruction the elements of the running gear, directly lead to the derailment.
KEY WORDS: *light freight cars, running dynamic tests, speed, stability factor, derailment, malfunction, dynamics, computer simulation*

1. Introduction

A significant disadvantage of the railway transport of Ukraine is the limitation of the speed of trains with freight cars in an empty state, which are equipped with bogies model 18-100. Among the reasons for the derailment of the wheels of cars from the rails associated with malfunctions of the running gear of the cars, we can name the following: fracture of the side frames and spring beams of the bogies, fracture of axles and wheels, malfunction of roller bearings of the axle box, wear on oversprung beams, inadmissible deviations of the sizes of bogies. Another important reason is the negative reduction of the car's packaging by more than 10% of the manufacturer's factory.

These faults, in particular, related to the destruction of the elements of the chassis, directly lead to the derailment. However, some of them do not directly cause the derailment, but are the reasons for the development of dynamic processes that cause increased force interaction of rolling stock. Among the cars that most often derail: empty platform cars, hopper cars for cement with the roof removed, tank cars. According to the results of the analysis of the circumstances of the derailment of empty cars, it was established that the consequences of the derailment are serious damage to rolling stock, railway track and other elements of railway infrastructure, speed reduction and violation of train schedules.

2. Materials and Methods

To date, a significant amount of scientific work has been devoted to the problem of determining the safe speed and determining the coefficient of stability from the derailment.

In works [1, 2] modern requirements which need to be considered at designing of new or modernization of already existing designs of bearing systems of railway universal gondola cars are resulted, ways of improvement of technical and economic and operational indicators of a running gear of freight cars are defined, approaches to designing of freight cars of new generation are offered. The article [3] presents promising areas of engineering work of a freight truck and their features. In [4] the introduction of an innovative design system for automatic coupling of cars is presented. In [5] the results of computer modeling of the dynamics of the load-bearing structure of the car body during transportation by rail ferry in the conditions of sea waves are presented. Article [6] presents the results, as well as the features of the theoretical and experimental studies on the implementation of the joint design of the spine beam of pellet wagons. In [7, 10] the necessity of specification of safety factor from failure of wheels of railway rolling stock is described and mathematical modeling of spatial oscillations of interaction of system "crew-track" is presented. Article [8] describes the preliminary results of a study of a new type of brake inserts for railway transport. The work [9] is devoted to the study of lateral oscillations and the assessment of the stability of the movement of a four-axle railway vehicle equipped with wheelsets with deviations. In works [11, 12] the design of the mechanism of installation of wheel pairs in a curve for tram cars is described. The normative documents [13, 14] describe the requirements for the dynamic qualities of empty freight cars. Given the above, we can conclude that the results of the analysis of information sources on the subject indicate the lack of sufficient methodological and practical materials to determine the safe speed of light freight cars. It is necessary to form the need to conduct these running dynamic tests. Theoretical and practical researches [15-18] with definition and an estimation of indicators of dynamic and running qualities of light freight cars, definition of a factor of a stock of stability of a wheel from derailment that in turn will allow to define safe speed of movement of freight cars in an empty condition are carried out. The purpose of the work is to solve the scientific and practical problem of creating theoretical provisions for determining the safe value of the coefficient of stability of light freight cars in the train and their experimental confirmation. The main factors that directly affect the coefficient of stability are vertical and longitudinal forces, which, respectively, depend on the own weight of the cars and the longitudinal weight of the train. Therefore, the main directions for determining the coefficient of stability were chosen to vary the location of cars in the train and reduce their own weight (containers). To achieve this goal, the following tasks were identified and solved:

– development of theoretical provisions for research;
– running dynamic tests with determination of indicators of dynamic qualities of the car during its movement and discharge from wedges with determination and estimation of natural frequencies of oscillations;
– analysis of results and definition of recommendations.

2.1. Practical Research

The objects of tests are freight cars: platform car model 13-4012, hopper car for cement with removed roof model 19-758-01 and tank car model 15-4443.

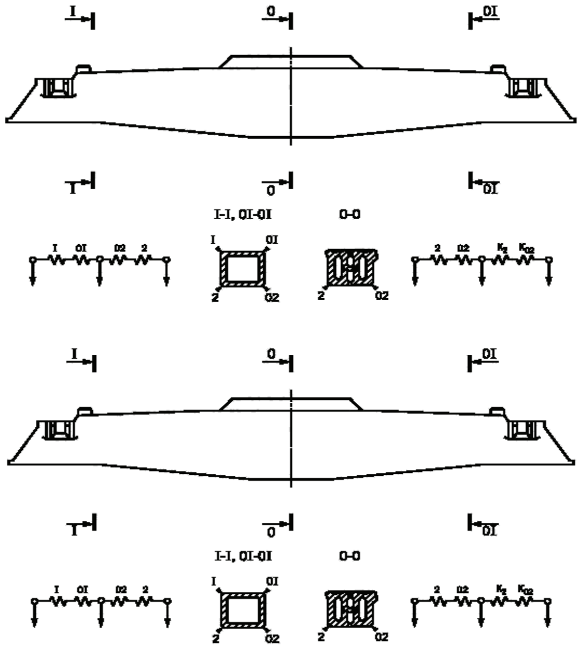


Fig. 1 Scheme of installation and connection of strain gauges for determining the coefficients of vertical dynamics in the cross sections of the spring beam of the freight car. K_2, K_{02} – compensation strain gages

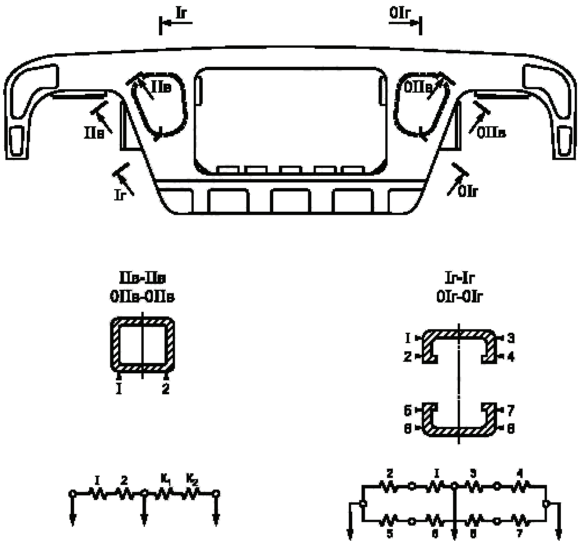


Fig. 2 Scheme of installation and connection of strain gauges for measuring horizontal (frame) forces (section with index "G") and vertical forces (section with index "B") on the frame of the freight car. K_1, K_2 – compensation strain gages

During the tests of dumping from the wedges, the frequency of oscillations and stresses in the spring beam and the sidewall of the bogie frame, dynamic and static deflections of the spring suspension of the bogie are determined. In the course of running dynamic tests of the car the following values and indicators are measured, analyzed and evaluated:

– vertical and horizontal (transverse) acceleration of the spring masses of the car in the area of the center pad;
– dynamic lateral (frame) forces acting on the axle boxes of the wheelsets;
– coefficient of stability of the wheel from the derailment;
– coefficients of vertical dynamics of sprung and non-sprung masses;
– coefficient of horizontal dynamics (restoration of lateral frame force to axial loading);
– forces acting on the test car;
– speed of movement.

Scheme of installation of strain gauges at tests of dumping from the wedges and running dynamic tests.

The choice of points for determining the frequencies of oscillations and dynamic stresses in the tests for dumping from the wedges is performed on the basis of the analysis of the result of the calculation of the stress-strain state of the load-bearing structure of cars.

Locations of strain gauges during dumping from the wedges tests and running dynamic tests.

In Fig. 3 are examples of installation of strain gages on experimental bogies of cars.

Fig. 3 Installation of strain gauges on experimental cars

Running dynamic tests.

Running dynamic tests were carried out by specialists of the research and implementation center of the branch "NDKTI" JSC "Ukrzaliznytsia", by the method of registration of processes in the control points of parts of the bogie during test trips in the operating speed range, if it does not threaten traffic safety. According to the results of measurements perform calculations, evaluate the running dynamic qualities.

Registration of the measured processes of running dynamic tests is carried out on straight and curved sections of a track and turnouts in all design range of admissible operational speeds.

Running dynamic tests are carried out during experimental trips in real operating conditions with registration of dynamic processes and deformations at control points.

Before the start of the tests, the test cars are weighed.

Carry out preparation of bogies of model 18-100:

– selection of strain gages;
– preparation of places of installation of strain gages, on elements of a design of bogies according to Fig. 1, 2;
– sticker of strain gages;
– calibration of carts;
– installation of strain gauges;
– installation of connecting cables to strain gauges and recording equipment;
– adjustment and check of serviceability of the equipment.

Test stages:

Stage I: experimental coupling: locomotive - platform car - tank car - dynamometric test car - hopper car with the roof removed (Fig. 4), speed from 30 km / h to 60-80 km / h with a step of 5-10 km / h.

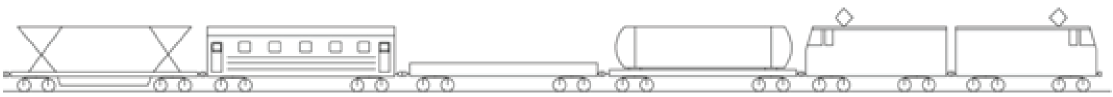


Fig. 4 Diagram of the location of rolling stock during stage 1

Stage II: train: Option 1 - locomotive - 6 empty gondola cars - test coupling - 30 loaded gondola cars; Option 2 locomotive - 15 loaded gondola cars - test coupling - 6 empty gondola cars - 15 loaded gondola cars; Option 3 - locomotive - 30 loaded gondola cars - test coupling - 6 empty gondola cars.

Determination of the coefficient of margin of stability from the derailment.

Processing of data of running dynamic tests of cars provides decoding, identification and systematization of parameters of the registered dynamic processes. At processing indicators of quality of the course of the car - to 20 Hz are considered. The quantization frequency when processing experimental data on a computer must be at least 100 Hz.

The experimental data are grouped according to the ranges of velocities (10-20 km / h), the characteristic features of the sections of the track (straight line, curve, arrows, etc.).

In the analysis of process records, the characteristic types of oscillations are established, and the dependence of the nature and intensity of oscillations on the motion conditions is estimated. Due to the probabilistic nature of the indicators of the dynamic load of the running gear of cars (including under the influence of the technical condition of the running gear and the transport structure), the corresponding apparatus of probability theory is used.

To assess the running qualities of the measured dynamic parameters of the car, using the ratios taking into account the calibration data, the probable maximum values of the coefficients of vertical dynamics of sprung K_{ds} and non-spring K_{dn} masses of the car, lateral (frame) forces, coefficient of horizontal dynamics K_{dh}, the value of the coefficients of the margin of stability from the derailment K_{sd}.

The method of calculating the coefficient of margin of stability of the car against derailment when the crest of the wheel on the rail under the action of dynamic forces arising during movement, the coefficients of vertical dynamics of the sprung and unsprung masses of the car are given below.

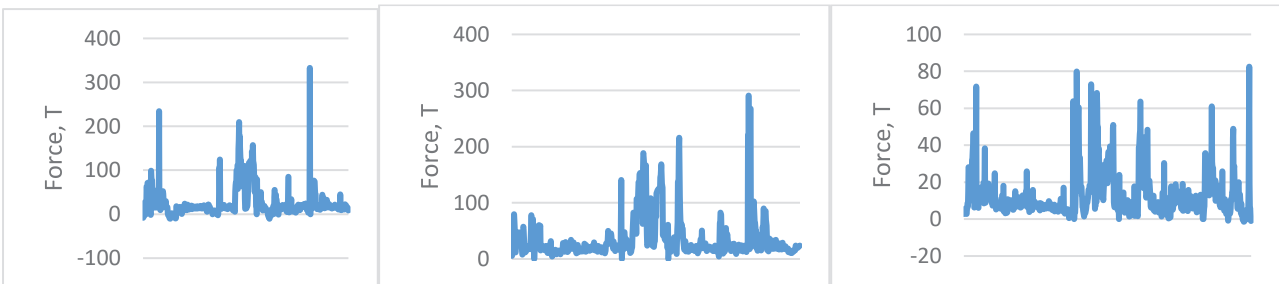
Estimation of stability of a wheel against derailment is made by the formula:

$$K_{sd}=\frac{tg\beta-\mu}{1+\mu tg\beta}\cdot\frac{Q_n\left(\frac{2(\mathrm{b}-a_2)}{l}+K_d^o\frac{2\mathrm{b}-a_2}{l}+K_d^{nr}\frac{\mathrm{b}-a_2}{l}\right)+q\frac{\mathrm{b}-a_2}{l}+\frac{r}{l}H_p}{\mu Q_n\left(\frac{2(\mathrm{b}-a_1)}{l}+K_d^o\frac{a_1}{l}-K_d^{nr}\frac{2\mathrm{b}-a_2}{l}\right)+\mu q\frac{\mathrm{b}-a_1}{l}+\left(1\frac{r}{l}\mu\right)H_p}, \quad (1)$$

where β – The angle of inclination of the wheel crest to the horizontal axis, $\beta = 60$; μ – coefficient of friction, $\mu = 0{,}25$; q – gravity of the mass of unsprung parts that come to the wheel pair, N; $2b$ – the distance between the middles of the necks of the axle of the wheel pair, m; a_1, a_2 – the estimated distance from the points of contact of the wheels with the rails to the middle of the respective (running and non-running) necks of the axle of the wheel pair are taken, respectively, 0.250 and 0.220 m; r – the radius of the wheel rolling, $r = 0.45$ m (for medium worn wheel) or by measuring the wheels of the prototype; K_d^o – coefficient of vertical dynamics on the oncoming wheel; the value of the coefficient is considered positive in the case of unloading wheels; K_d^{nr} – coefficient of vertical dynamics on a non-running wheel; the value of the coefficient is considered positive in the case of unloading wheels; H_p – horizontal lateral frame force; Q_n – gravity of the spring parts of the car acting on the neck of the axle of the wheelset, kN

2.2. Results and Discussion

As a result of the research of the force on the autocoupling-dynamometer during running-dynamic tests in different locations in the train (Fig. 5).



The beginning of the train The middle of the train The end of the train

Fig. 5 Force on the autocoupling-dynamometer

The analysis of catastrophes and accidents for 2016-2020 shows that the main share of catastrophes and accidents (over 67%) falls on track and wagon facilities. Of the total number of accidents and derailment in this period, more than 64% were cases related to the derailment of empty cars. Light freight cars most often derailed.

The input of theoretical and practical studies to determine the coefficient of stability of the wheel from the derailment depending on the location of light freight cars in the train in empty mode on straight and curved sections of the railway track in the range of operating speeds was found to change negatively, depending on the reduction of packaging by more than 10% of the normative, poor technical condition of the bearing and crew parts of the car and the location of the cars in the head and middle of the train. Thus, the obtained theoretical results will allow to evaluate the impact of container reduction, poor technical condition and location in the train, on the stability of the car from overturning and to establish the safe speed of light cars in the empty state and their location in the train.

3. Conclusions

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The following conclusions can be made from the research:

1. According to the results of the running dynamic tests of the platform car, tank car, hopper car for cement with the roof removed in an empty state by the specialists of the "Research and Implementation Center" of the "NDKTI" branch, the following compliance and non-compliance were established [14]:

– The platform car in the empty state corresponds to the coefficient of stability of the wheel from the derailment at speeds up to 60 km/h;

– The tank car in the empty state corresponds to the coefficient of stability of the wheel from the derailment at speeds up to 80 km/h;

– The cement hopper with the roof removed in the empty state corresponds to the coefficient of stability of the wheel from the derailment at speeds up to 80 km/h.

2. According to the test results, it is established that the values of compression forces acting on the test cars in the main and middle parts of the train reach, and in some cases (emergency braking, movement on the fracture profile) exceed critical values for empty rolling stock.

3. Taking into account the values of compressive forces obtained during the running dynamic tests, which act on the car couplings and reach or exceed the critical values in the main and middle parts of the train, it is advisable to place empty cars in the last third of the train.

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Rational Integration Level of Solar Generation in Traction Power Supply Substations for Supplying Auxiliary Consumers

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Abstract

The paper considers the existing levels of electricity consumption by responsible consumers of gas and evaluates the use of solar generation to meet these needs. Using mathematical modeling based on real statistics, the dependences of solar power on the time of day are determined, which allows to estimate the random component of solar generation and determine the possibility of compensating the variability by using AB. The method of choosing the optimal capacity of the battery, taking into account the stochastic nature of solar generation is presented.
KEY WORDS: *traction power supply facilities, auxiliary needs systems, solar generation, batteries, mathematical modeling*

1. Introduction

The development of humankind is inextricably linked with the increase in the consumption of energy resources [1]. At the same time, there is a negative impact of environmental pollution factors, which leads to an increase in CO levels$_2$ and other harmful components [2]. Recently, many efforts have been made to reduce the harmful effects on the environment by creating various programs to reduce the use of fossil fuels (climate agreement, green hydrogen, etc.). The content of these programs determines on the one hand, the reduction of consumption of various types of energy, and on the other hand, the widespread introduction of renewable energy sources (RES) in different sectors of the economy [3]. One of the critical consumers of electricity is electrified rail transport, which is constantly increasing due to known advantages: significant traffic capacity, speed, relative environmental friendliness and more. A difficult task is to find the components that allow you to achieve this goal [4].

Analysis of literature sources in this area indicates two approaches. The first is to assess the effectiveness of the complete replacement of the concept of building the topology of the power supply system of electrified railways [5, 6], which consists in the intensive use of RES (solar and wind generation), power electronics, and converters (storage systems and supercapacitors). This approach is quite costly and requires significant financial investment in railway infrastructure. The second approach involves the partial modernization of some aspects of the existing railway power supply system [7, 8] with the search for opportunities to expand the use of RES and increase the reliability and efficiency of the electricity supply. According to the authors, this approach is more acceptable for the development of Eastern European railways and needs further study.

2. Main Material

The system of providing electricity to railway consumers has a rather complex and branched structure. The main functional elements are traction substations, sectioning supply points (SSP) and parallel connection points (PCP), etc. To ensure reliable and economical operation of these objects, it is necessary to analyze their schematics (Figs. 1-2), given in [9, 10].

One of the responsible components of these facilities is the operation of the system of auxiliary needs designed to ensure reliable operation of protective, measuring, and switching equipment. The specific electricity consumption for the auxiliary needs of modern substations is about 0.3% per 1 kW/h of converted electricity, which, taking into account the significant volumes of consumption by electric transport, is substantial. Fig. 3 shows the scheme of auxiliary needs.

The auxiliary needs consumers on the traction substation should include electric motors of the cooling system of transformers; heating devices for switches (if necessary), distribution cabinets; electric lighting and space heating. The structure of the system's auxiliary needs of traction power supply facilities has specific features: consumers are divided into responsible and not responsible. Responsible consumers of auxiliary needs include control system devices, relay protection, signaling, automation and telemechanics. Cessation of power supply to these consumers, even for a short period of time, leads to a partial or complete termination of the facility. The auxiliary needs of electricity that don't require high reliability include those elements whose interruption in the power supply does not cause significant changes in the operation of the substation (heating, ventilation, lighting, etc.). Recently, there has been a tendency to reduce the power consumption of the auxiliary needs system through the use of more energy-saving equipment (LED lamps, microprocessor relays, modern high-voltage breakers, etc.).

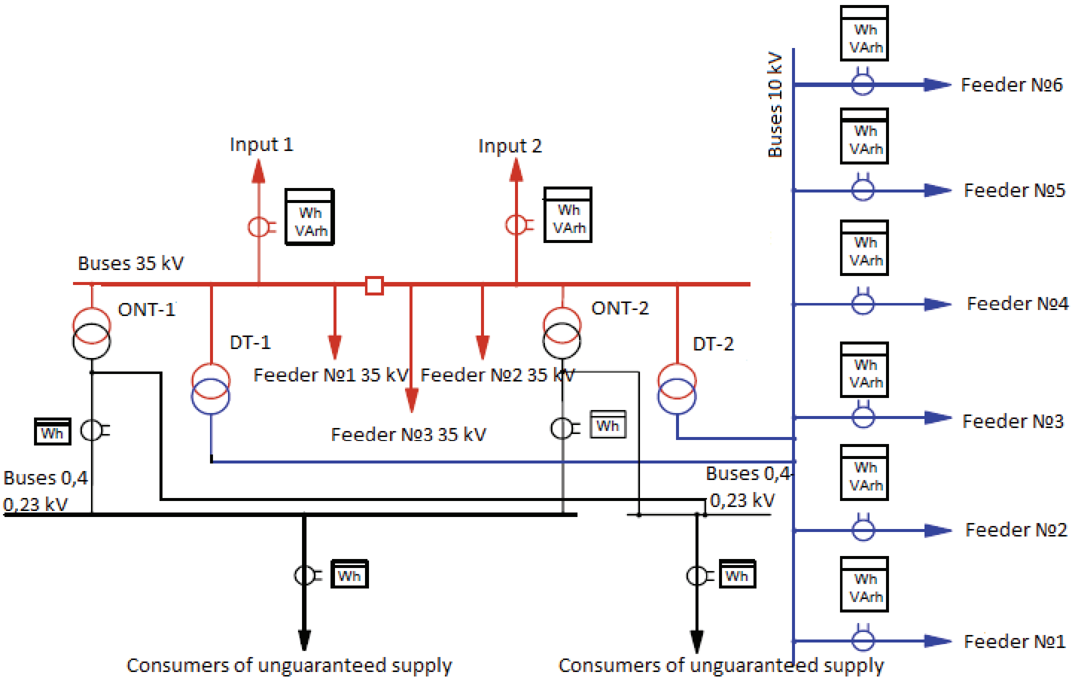

Fig. 1 Simplified schematic diagram of AC substation AC

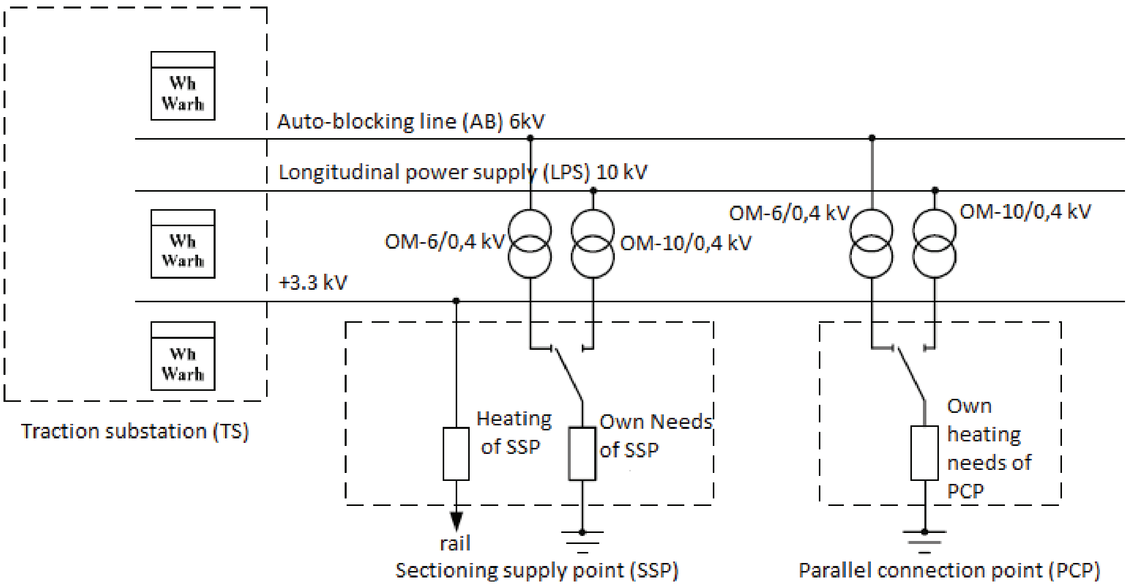

Fig. 2 Schematic diagram of power supply SSP and PCP in the DC system

The power supply of responsible consumers is provided through the bus of guaranteed power supply, others - through the bus of non-guaranteed power supply. To increase the reliability of the power supply system of responsible consumers use batteries (often lead-acid). The peculiarity of their work is the danger of deep discharge, so to control the degree of their discharge using charging and recharging devices (CRD), which perform the function of an energy source and only in the case of complete power failure, are connected to the battery. Due to the noted feature of lead-acid batteries and the inadmissibility of discharging them to 30% of the nominal capacity, there is a need to almost triple the installed capacity to ensure the established requirements for the reliability of the power supply. During operation, the battery must be periodically discharged (to maintain performance), as well as to carry out constant inspection and control of operating parameters. These shortcomings make batteries the most valuable element in the auxiliary needs power supply system.

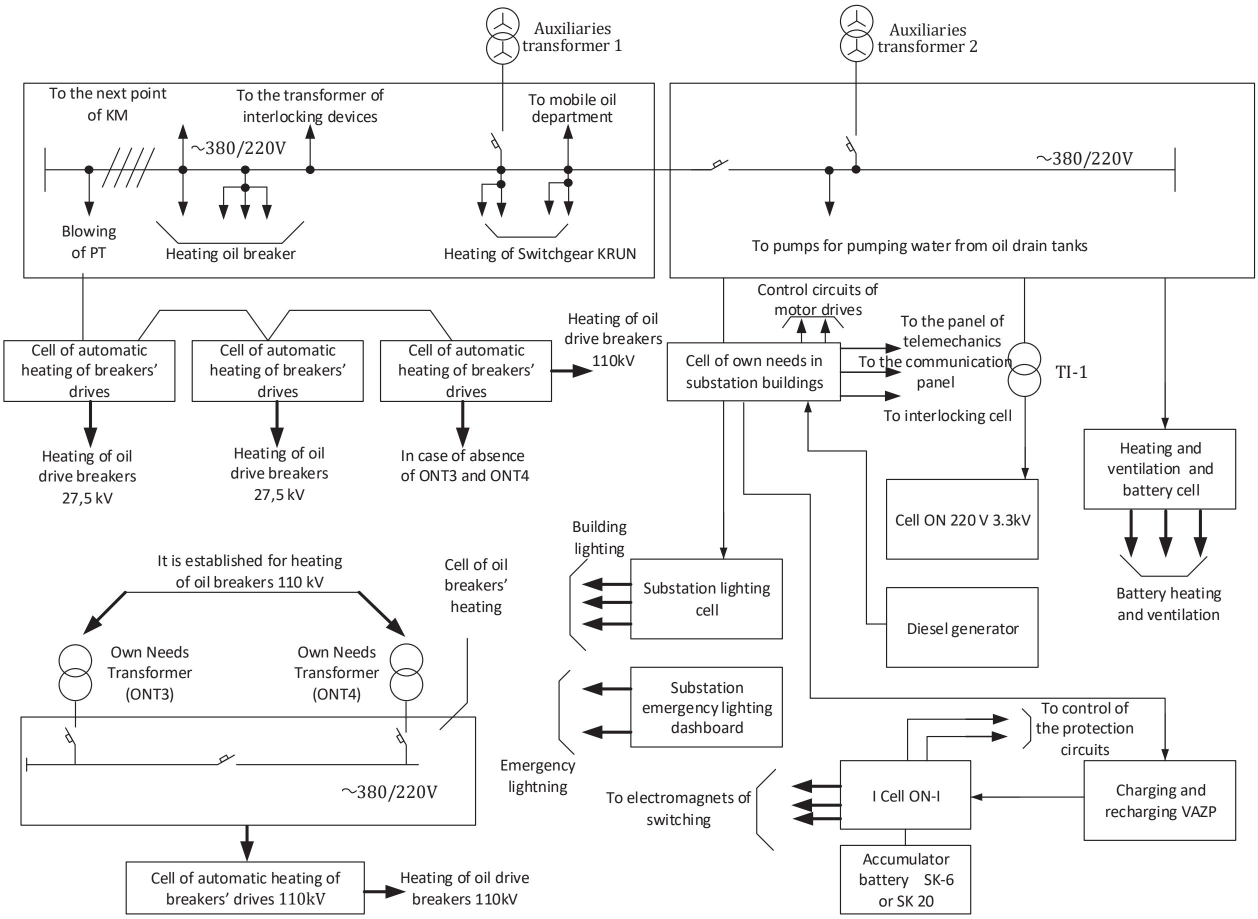

Fig. 3 Generalized scheme of auxiliary needs for the AC substation

Modern lithium-ion batteries do not have these disadvantages, provide a longer service life, allow you to automate the process of diagnosing and controlling the charge, so they are perfect as a source of energy [11-14]. This type of battery also works effectively from distributed generation sources (primarily solar), which allows you to build a compact backup power supply system without the constant operation of the CRD. Such a system is generally called a solar photovoltaic system or solar station (Fig. 4).

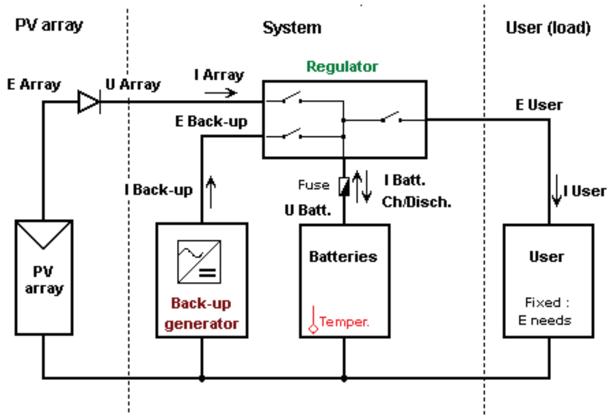

Fig. 4 Functional diagram of the backup power supply system

The following elements can be distinguished in its structure: photovoltaic modules (PV-generator) with supporting armature, communication cables, and, depending on the type of system, electronic inverter and charge controller with battery. In sunny weather, the source of electricity is a solar battery that charges the battery, when it reaches full charge, the solar generator interrupts. Due to the use of the inverter, the possibility of electricity supply to the consumers of auxiliary needs is provided. The charge controller monitors and controls the entire system, primarily to ensure maximum efficiency in the use of generated energy. Some manufacturers include a controlled recharge in the regulator's feature set to equalize the voltage on the batteries. To obtain the required power and operating voltage, the modules are connected in series or in parallel, the more carefully selected modules in the battery (or the smaller the difference in the characteristics of the modules), the less electricity loss.

Photovoltaic modules must be equipped with special protection against excessive discharge, which is provided by disconnecting the load. This protection is activated when the battery voltage drops below the trip voltage. The load cannot be connected until the voltage rises to a certain threshold (voltage connection). Given the above circumstance, when designing power supply system's auxiliary needs for traction power supply elements, it is necessary to determine the optimal capacity of the batteries system, taking into account the possibilities of solar generation in the region (Battery Energy Storage Systems - BESS).

To generalize the problem, it is necessary to create a mathematical model of appropriate adequacy, in which the parameters of the system would be formalized and allow a wide range of options for choosing the most optimal options for the formation of a mathematical model of capacity balancing, i.e. comparison for a long (at least a year) period of time. As the elementary time it is convenient to use 10-minute intervals that allow to observe behavior of system; the availability of this data is also an important factor.

For the considered system, the equation of power balance will look like [15]:

$$V(t) = P_S(t) \pm P_A(t) + P_G(t) - P_U(t), \tag{1}$$

where $P_G(t)$ − current capacity of FES; $P_A(t)$ − battery power; $P_G(t)$ − external controlled energy source (if any); $P_U(t)$ − known load function (planned consumption schedule); $V(t)$ - state function, the minimum of which is the purpose of optimization. In this case, the power of the PV station is a random function (process); consumer power (load) may also have random deviations (fluctuations). The sign next to the battery power value depends on the charging or discharging process, and the value is determined by the speed. The normalizing factor can be used to select the maximum load P_0, and then all other capacities are taken into account as relative values.

Energy balance (as the cumulative sum of the current power balance for time T will have components:

$$E_V(T,\alpha_x) = E_S(T,\alpha_S) + E_G(T,\alpha_G) \pm E_A(T,\alpha_A) - E_U(T,\alpha_U), \tag{2}$$

where the current value of the accumulated energy $E_A(t, \alpha_A)$, which in absolute value is equal to the state of charge of the battery and is within certain limits (C_{min}, C_{max}). To simplify the presentation of the process can be considered $C_{min} = 0$, and under C_{max} understand the range of charge change. The total balance (2) is zero, provided that the battery charge has not reached the limit value, ie retains the ability to participate in power maneuvering.

Since the recording of the random balancing process is discrete, the power of the imbalance is taken into account in the model as the average values in each elementary (for example, 10-minute) interval Δt, and the accumulated energy is defined as their cumulative sum taking into account the duration of the interval: $E_\Delta(t_i) = \sum_{n=1}^{i} p_i \Delta t$.

The random nature of the level of solar radiation is described by the decomposition of the current power to the average (for example, the average monthly) and random fluctuations within the maximum achievable values for a given region and season [16].

Since solar radiation has a daily cycle, and the average and maximum values are determined, as a rule, for each month, the record of the balancing process is convenient to present in matrix form. The result of taking into account the projected capacity schedule is a random uncontrolled component of deviations from the schedule, which is the subject of modeling and research:

$$p_{ij} = \left[(g_{ij} - g_i) + (s_{ij} - s_i) \right] - (u_{ij} - u_i), \tag{3}$$

where u_x − level of electricity consumption; g_x and s_x − external generation capacity and FES, respectively; i − time index (time interval number); j − number of days. Here p_{ij} − deviation from the load schedule. Indicators with one index − averaged over a certain hour of the day (daily course), in particular u_{and} should correspond to the planned schedule of consumption. Battery charge acts as an intermediate indicator of the internal state of the system.

To assess the efficiency of the use of batteries in the model, it is advisable to use the working volume of stored energy, considering it variable from zero to maximum. The designation for the battery type is written as Cx, where C − full capacity, x − the time in hours required to discharge the battery. It can also be written as kC, where $k = 1/x$ − batteries speed. Really accumulated energy is limited by limit values [0, C] and allowable growth $\delta C = k\Delta tC,$ ie determined by the dependence:

$$C_i = C_{i-1} + U(t_i)\Delta t; \quad U(t_i)\Delta t \le \delta C; \quad 0 \le C_i \le C. \tag{4}$$

Taking into account the energy loss in the battery can be taken into account by introducing the efficiency of the battery KKD: $C_i = C_{i-1} + KKD \cdot U(t_i)\Delta t$.

Taking into account the noted indicators, simulation of random processes of power balancing at different values of the studied parameters is performed, i.e. the process is set in discrete time with a random sequence and the parameters of distribution of simulation results are determined. A further conclusion about the optimality of the selected parameter can be made by constructing the response surface (on the grid of search of the corresponding coordinates) or determining the regression function of the desired parameter on random coordinate values. The coordinates are usually used set capacities or their ratios for the elements of the power system, and indicators of their variability. The studied parameter is the characteristics of energy storage elements (power or capacity) or control elements (balancing capacities). The evaluation criteria can be: indicators of variability of the obtained balance as the degree of predictability of probable situations, or the amount of lost (minimum) or stored (maximum) energy, with the most economical consumption of fuel resources and minimizing the cost of energy obtained. That is, traditionally used technical indicators as a prerequisite for the reliability of the power system, and economic results as desirable conditions.

Block diagram of calculations (Fig. 5) provides for obtaining data on weather factors, their statistical processing, analysis of parameters of the mathematical model for the current electric power of the FES. A similar model applies to load capacity and is based on electricity consumption data for a specific time of year (usually for a particular month). Comparison of generation and consumption modes gives a random component, according to which the characteristics of the battery are selected. The mode of energy storage and consumption includes taking into account the available capacity, speed and energy efficiency of the battery. The result is data on total energy stored (E_{total}) and residual power imbalance, the parameters of the distribution of these random values, which can be used to calculate the reliability indices of the power system.

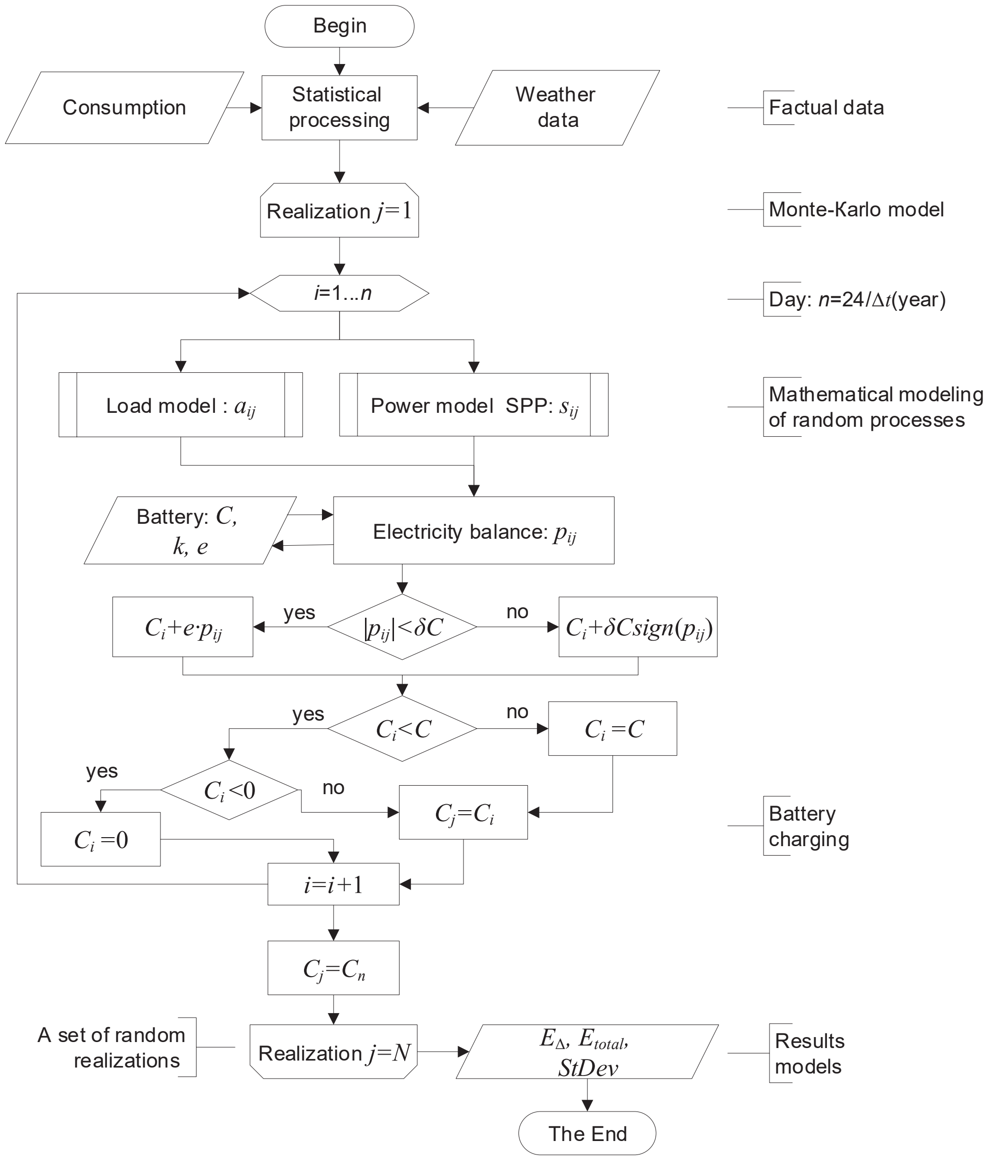

Fig. 5 Block diagram of the calculation of energy balance

The presented algorithm allows to obtain a set of implementations of a random process that describes the balancing of electric energy at random changes of generating and consumed power in the simulated power system, as well as the intermediate accumulation of energy by the storage system. Each individual variant of power system construction includes installed RES capacity, energy characteristics of solar installations, characteristic weather conditions (average values and possible variations), accumulation parameters, accepted restrictions. In this study, each calculation option is represented by several thousand random implementations. The result is a set of data that describes the possible states of the power system and are suitable for statistical evaluation and calculation of the required values. The results of estimates of variability of imbalances of power and energy in the absence of restrictions on the capabilities of batteries are given in Table.

Since the input statistics relate to multi-year data for a particular month (monthly cycle), each individual implementation of the daily average may differ from the monthly average, so as indicators of the variance of the values of the available set of sales are considered rms deviation of the total, i.e. monthly data set - σ_N, as well as the average values of daily variations σ_d, and the daily rms deviation, i.e. the spread of daily averages - σ_{ad}. If the load schedule takes into account the daily forecasting of the expected daily averages (daily cyclicity), it would be assumed that $\sigma_{ad} = 0$, $\sigma_N \approx \sigma_d$.

Table

Dispersion of the general imbalance without the restriction of the batteries

Month	Power balance, acting			Energy storage, acting hours		
	σ_N	σ_d	σ_{ad}	σ_N	σ_d	σ_{ad}
January	0.08	0.068	0.04	0.67	0.37	0.50
April	0.12	0.09	0.07	1.07	0.62	0.80
July	0.09	0.08	0.05	0.65	0.37	0.53

3. Conclusions

The probability distribution for the full set of energy imbalance values (cumulative power sums) is close to normal, although it does not meet all the criteria. The mathematical expectation should be zero due to the accepted assumption of cyclicity. Since during the daily implementation of the random process, the current stored energy can increase many times and return to the system, the nature of the accumulation can be judged by the average daily battery charge level and deviation from the average, with a hypothesis about the distribution density function. When the charging rate is limited within certain limits, the battery discharge also slows down. As a result, the average charging level is maintained. However, the possibility of accumulation of excess energy decreases the more, the lower the speed.

The need for accumulation to ensure a reliable energy balance significantly (at times) depends on the ability to predict the generation of RES, which forms a planned schedule of load on the power system. The energy efficiency of batteries, i.e., the level of losses in the conversion of energy types, should be considered when determining the need for useful capacity. However, proper consideration in this model allows only a linear representation of energy processes. Analytical study of a set of interconnected random processes is impossible without an accurate description of random parameters because these parameters themselves are dynamic quantities, and their evaluation depends on the available finite sample of data. Qualitative behavior of processes can be described by mathematical modeling, and the simulation model estimates numerical values. An accurate description of the dynamic processes of energy accumulation and reuse requires further research.

Acknowledgment

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Computational Analysis for Aerodynamic Coefficient of Rocket Target RT-400M

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Abstract

RT-400M is the rocket target designed and developed for the military personnel live-fire exercise. In this study, the drag force generated by the body of RT-400M will be obtained using the computational fluid dynamics analysis method. The aerodynamics characteristics and the influence of the drag coefficient on the rocket target are studied using the finite volume method and k-ω SST turbulence model. The obtained forces and coefficient will be used for further study on the ballistics of the rocket target. The academic version of the commercial design and fluid analysis software is used. Pressure, velocity, streamline, and forces contour are obtained to visualise the behaviour of the fluid above the rocket. This will help to optimise the design for higher performance.
KEYWORDS: *rocket target, external ballistics, aerodynamics, CFD analysis, drag coefficient, k-ω SST.*

1. Introduction

Rocket targets are used in the live-fire exercise to practice and familiarize with the battle situation. These target rockets should imitate real missiles to provide a realistic scenario that helps the personnel to improve their skills in the operation of military hardware [1]. Incorporating real missiles with advanced guidance and navigation system in practice is not economical [2]. During practice, the personnel require to use multiple shells. To solve this problem team of researchers at Kaunas university has developed a rocket target RT-400. The extended range of this target missile is RT-400M with four motor configurations.

Analysis of the Aerodynamics of the rocket is essential to predict the drag force based on the external shape. The coefficient of drag is necessary to analyse the external ballistics of the rocket [3]. Solid-fuel rocket targets may be fueled and stored for longer periods. Maintenance of solid-fuel rockets requires lesser resources than liquid fuel or drone targets. To obtain the full benefits of using a rocket target for a military exercise, the hardware must be designed and tested [4]. Aerodynamic analysis can be theoretical, computational, and experimental [5]. Computational design and analysis give economic benefits comparing with experimental tests [6]. Preliminary analysis will be carried out in the computational model. Based on the results the model can be altered computationally. The prototype is made based on the computational results.

2. Methodology

The model of RT-400M is similar to the short-range rocket target RT-400. The length of the rocket is 5.4 meters, and the diameter of the body is 0.41 meters. The outer diameter including the fins is 1.2 meters. This model has four RM-12K motors producing 48 kN thrust force propel the rocket to the velocity of a maximum of 330 m/s. The parabolic nose cone is adapted to reduce drag. The fin has a clipped delta or trapezoidal shape. The rocket nozzle thermal protection is attached at the rear end of the body. The model is designed in SolidWorks student premium. For analysis, the geometry is simplified to the single part model as only the external geometry is essential for the computational fluid dynamics analysis. Technical data of RT-400M is given in Table 1.

Table 1

Technical data of the rocket target RT-400

s.no	Property	values
1	Length of the rocket (m)	5.4
2	Diameter of the target (m)	0.41
3	Rocket mass (kg)	104
4	Maximum flight range (km)	20
5	Maximum flight altitude (km)	10
6	Velocity range of the rocket (m/s)	280-330

A computational model for aerodynamics analysis shown in Fig. 1

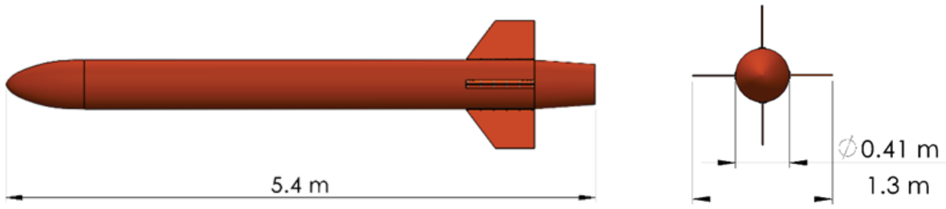

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Fig. 1 Computational model; a − side view; b − front view

Ansys fluent academic version is selected for the computational fluid analysis. The finite volume method is considered in this study. After the 3d model designed in SolidWorks, the model is imported into the Ansys fluent design modeller to make a computational domain where the impact of fluid flow is to be analysed. For simplicity and to reduce the computational time the model is cut into half through the longitudinal axis and symmetry condition is applied. The fluid domain is cylindrical with 30 m long and with a 10 m radius and 10 m frontal length (Fig. 2).

The single solid body is meshed in Ansys meshing software. Fine meshing is necessary to make the solver to solve finite element problems more accurately. For meshing CFD is selected for physics preference with 500mm element size and high smoothing. As the academic version is limited to the number of cells. The higher number of elements cannot be solved. So, the element size is selected with higher value to reduce the elements. After the mesh is generated, the boundaries are required to be named. This allows the solver to apply the necessary methodologies to solve the problem. The frontal area of the air intake is considered an inlet and the exit is named as outlet. The sidewall is given as a wall and the body is selected as the rocket. The adjacent wall to the faces of the rocket is considered as symmetry. As we consider no-slip conditions on the boundary layer of the body, it is necessary to give data to the solver regarding the near boundary of the rocket. An inflation layer of 10 with a growth rate of 1.2 and a maximum thickness of 100 mm is given to make the inflation layer. This inflation gives us accurate results on the drag force with considering the boundary layer. The inflation layer can be seen in the meshing (Fig.3 (b)). This meshing method has produced 59186 nodes and 381115 elements.

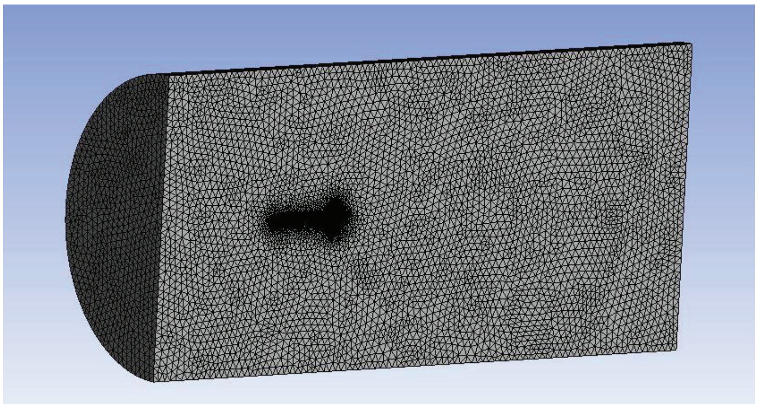
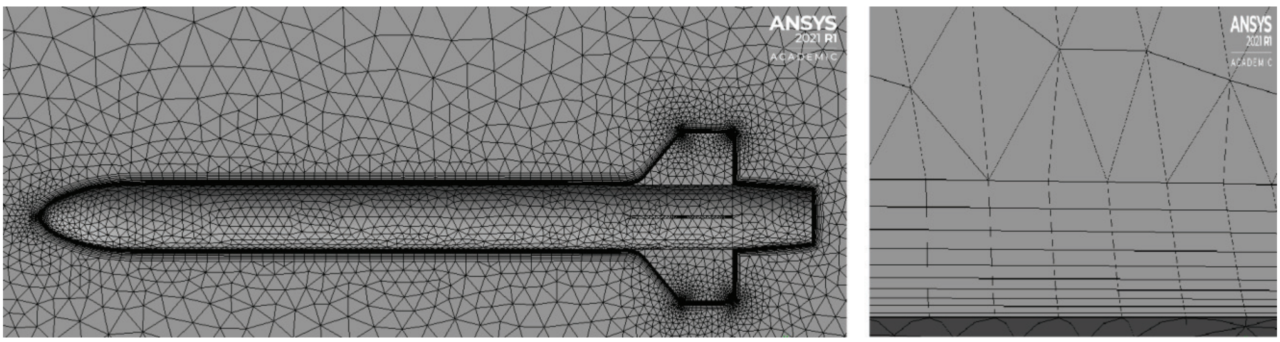


Fig. 2 Computational domain with mesh



a b

Fig. 3 Meshed model; a − mesh over the rocket body; b − inflation layer

The finite element model is opened in Ansys solver. The solver uses different methods to solve the fluid problem. For this problem, the pressure-based solver type is selected. And the k-omega turbulence model is selected for the Reynolds Averaged Navier Stokes (RANS) equation. The Navier-Stokes equation uses the equation of mass and momentum in conservation form is given in equations 1 and 2.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0; \tag{1}$$

$$\frac{D(u_i)}{Dt} = \frac{\partial u_i}{\partial t} + U_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + V \frac{\partial^2 u_i}{\partial x_j^2} + F_i, \tag{2}$$

where ∇ − divergence; ρ − fluid density; u − flow velocity; t − time; F_i − external force vector, V − local kinematic viscosity; U_j − velocity vector; x_j − position vector.

The RANS equation is explained with x, y, z components in Eq. 3.

X component:

$$\rho \frac{D\bar{u}}{Dt} = \rho\left[\frac{\partial}{\partial x}\left(\overline{u^2}\right) + \frac{\partial}{\partial y}\left(\overline{uv}\right) + \frac{\partial}{\partial y}\left(\overline{uw}\right)\right] = \rho g_x - \frac{\partial \bar{P}}{\partial x} + \frac{\partial}{\partial x}\left[\mu \frac{\partial \bar{u}}{\partial x} - \rho u'^2\right] + \frac{\partial}{\partial y}\left[\mu \frac{\partial \bar{u}}{\partial y} - \rho \overline{u'v'}\right] + \frac{\partial}{\partial z}\left[\mu \frac{\partial \bar{u}}{\partial x} - \rho \overline{u'w'}\right] \tag{3.1}$$

Y component:

$$\rho \frac{D\bar{v}}{Dt} = \rho\left[\frac{\partial}{\partial x}\left(\overline{uv}\right) + \frac{\partial}{\partial y}\left(\overline{v^2}\right) + \frac{\partial}{\partial z}\left(\overline{vw}\right)\right] = \rho g_y - \frac{\partial \bar{P}}{\partial y} + \frac{\partial}{\partial x}\left[\mu \frac{\partial \bar{v}}{\partial x} - \rho \overline{u'v'}\right] + \frac{\partial}{\partial y}\left[\mu \frac{\partial \bar{v}}{\partial y} - \rho \overline{v'^2}\right] + \frac{\partial}{\partial z}\left[\mu \frac{\partial \bar{v}}{\partial z} - \rho \overline{v'w'}\right] \tag{3.2}$$

Z component of the equation:

$$\rho \frac{D\bar{w}}{Dt} = \rho\left[\frac{\partial}{\partial x}\left(\overline{uw}\right) + \frac{\partial}{\partial y}\left(\overline{vw}\right) + \frac{\partial}{\partial z}\left(\overline{w^2}\right)\right] = \rho g_z - \frac{\partial \bar{P}}{\partial z} + \frac{\partial}{\partial x}\left[\mu \frac{\partial \bar{w}}{\partial x} - \rho \overline{u'w'}\right] + \frac{\partial}{\partial y}\left[\mu \frac{\partial \bar{w}}{\partial y} - \rho \overline{v'w'}\right] + \frac{\partial}{\partial z}\left[\mu \frac{\partial \bar{w}}{\partial z} - \rho \overline{w'^2}\right] \tag{3.3}$$

where ρ − mass density; P − mean static pressure; g − gravity; μ − molecular visocity.

This model uses two partial differential equations with two variable k (turbulence kinetic energy) and ω specific rate of dissipation is given in Eqs. 4 and 5 [7]. K-ω model gives better results on the pressure gradients and the boundary layer separations. So, this model is preferred for aeronautical applications. The shear stress transport (SST) model in addition to the k-ω model corrects the overprediction of separation at the boundary layer.

Equation for turbulence kinetic energy (k):

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho u_j k) = \rho P - \beta^* \rho \omega k + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma^* \frac{\rho k}{\omega}\right)\frac{\partial k}{\partial x_j}\right]; P = \tau_{ij}\frac{\partial u_i}{\partial x_j}, \tag{4}$$

where k − specific turbulence kinetic energy; t − time; σ^*; β^* − closure coefficients; τ − specific Reynolds-stress tensor; u_i, u_j − velocity vectors; x_j − position vector.

Specific rate of dissipation (ω):

$$\frac{\partial}{\partial t}(\rho \omega) + \frac{\partial}{\partial x_j}(\rho u_j \omega) = \alpha \frac{\omega}{k} P - \beta \rho \omega^2 + \sigma_d \frac{\rho}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma \frac{\rho k}{\omega}\right)\frac{\partial \omega}{\partial x_j}\right]; \; P = \tau_{ij}\frac{\partial u_i}{\partial x_j}, \tag{5}$$

where ω − specific dissipation rate; α, β, σ, σ_d − closure coefficient.

The material of the domain is selected as air. As the analysis is similar to the wind tunnel analysis, the model is kept stationary, and the air is allowed to flow over the model to analyse the effect for the corresponding forces and coefficient. The inlet boundary condition with velocity magnitude of 280 m/s and the outlet with a gauge pressure of 0 pa is given. The reference values for the solver are computed from the inlet with a reference area of 0.132 m^2. This area is the frontal area of the circle of 0.41 m of the rocket. The y Plus value of 300 is selected. This value is important for the meshing near the wall to analyze the boundary layer.

The coupled solution method with a second-order upwind method for pressure, momentum, turbulent kinetic energy, and specific dissipation rate is selected. The residual of 10e-6 is given with 100 iterations for initialization and the calculation with 500 iterations is performed. The drag force and coefficient are obtained in the report and the comparison and flow over the rocket are visualized in the postprocessing window.

3. Results

The analysis is carried out for various Mach numbers. The velocity and the pressure at the various region of the rocket body are visualized and the forces on the body due to the flow of air in the fluid domain is noted for the further analysis.

Different pressure contour and velocity vector plots show the behaviours of the fluid over the rocket body. At 280 m/s the pressure at the nose and leading edge of the rocket fins is higher compared to the body of the rocket. Maximum pressure of 46 kPa is observed at the leading edge of the nose cone (Fig 4). The lower pressure region at the rear end of the rocket nozzle is visualized. The rocket is analysed with zero angles of attack so, the body region has an equal pressure gradient and does not produce lift forces. The stagnation point is visible at the front of the nose cone.

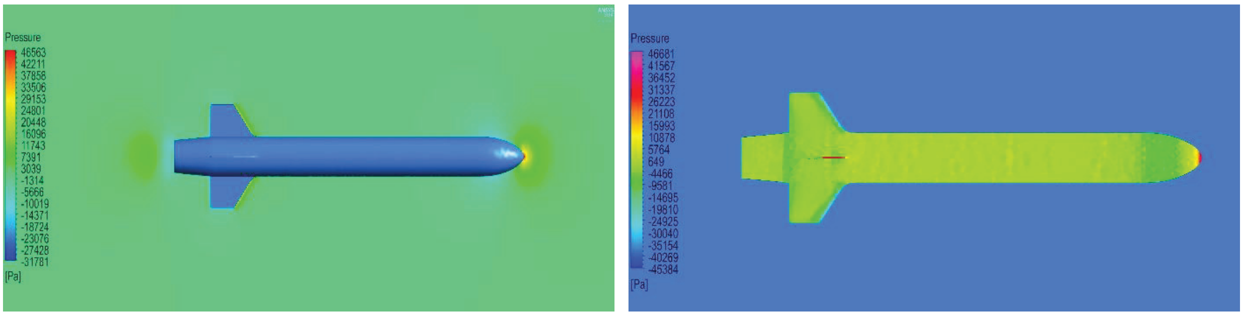


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Fig. 4 Pressure contour; a – pressure at symmetry; b – pressure on the rocket body

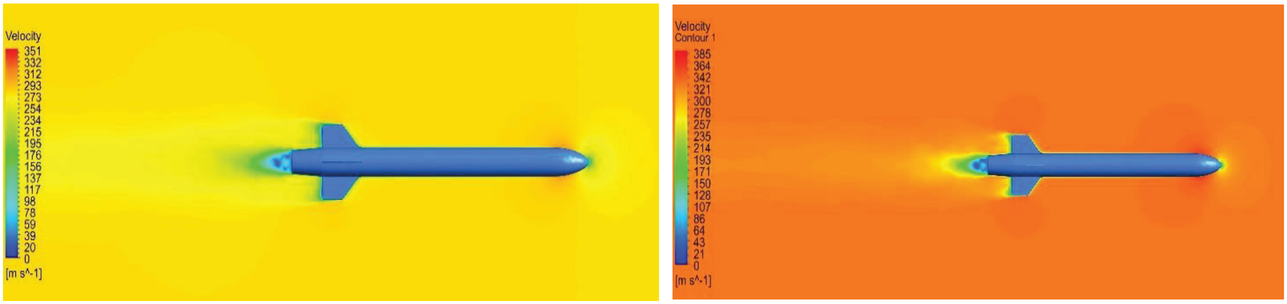

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Fig. 5 Velocity contour; a – velocity at Mach 0.8; b – velocity contour at Mach 0.9

The velocity of over 280 m/s is shown in the domain with the yellow region and the velocity of 320 m/s is shown in a red region which corresponds to the 0.8 and 0.9 Mach numbers (Fig. 5). The boundary layer is visible in the vector contour and vortex due to the flow circulation at the rear end is visible. The y+ value for the higher velocity creates finer mesh near the boundary of the body to make the boundary layer more accurate to analysed and visualized.

The velocity streamlines track the movement of the air over the body and the rear end. This gives a clear picture of the boundary layer separation circulation of the fluid over the rocket shown in Fig. 6.

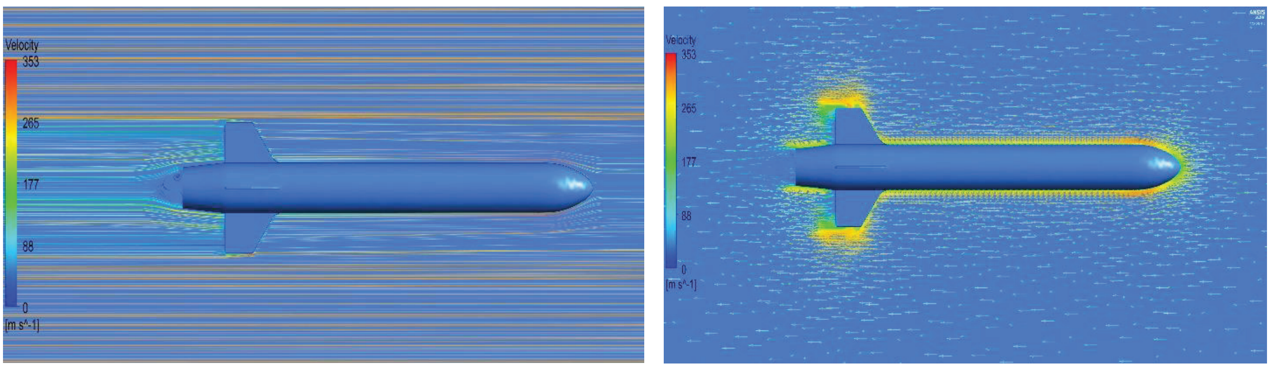

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Fig. 6 a – streamlines; b – velocity vectors

In the turbulent kinetic energy is visualized in the Figs. 7, a and b higher energy is observed at the vortex region at the rear end of the rocket. The linear and logarithmic color visualization is shown.

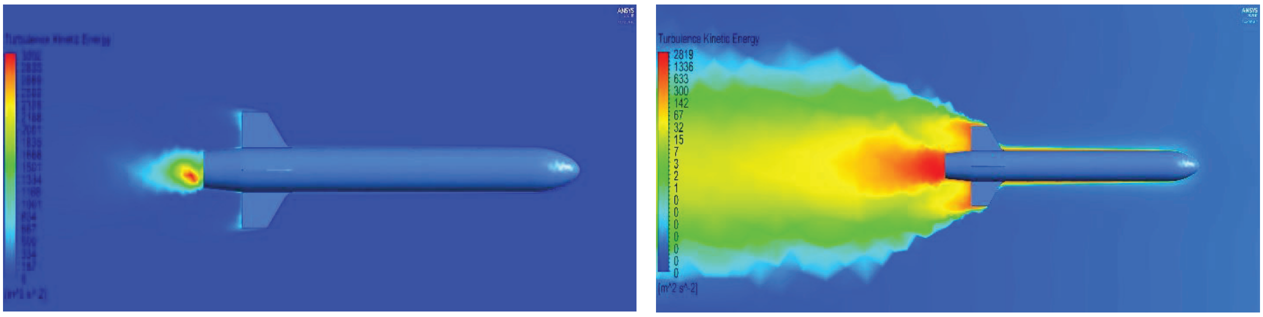

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Fig. 7 Turbulent Kinetic energy; a − linear scale; b − logarithmic scale

The drag force and drag coefficient are calculated and compared with different Mach numbers ranging from 0.5 to 0.9 as the drag forces increase gradually for the velocity increment (Fig. 8).

$$c_d = \frac{2F_d}{\rho v^2 A}, \tag{6}$$

where c_d = coefficient of drag; F_d = drag force; ρ = density of the fluid; v = velocity of the object; A = reference area.

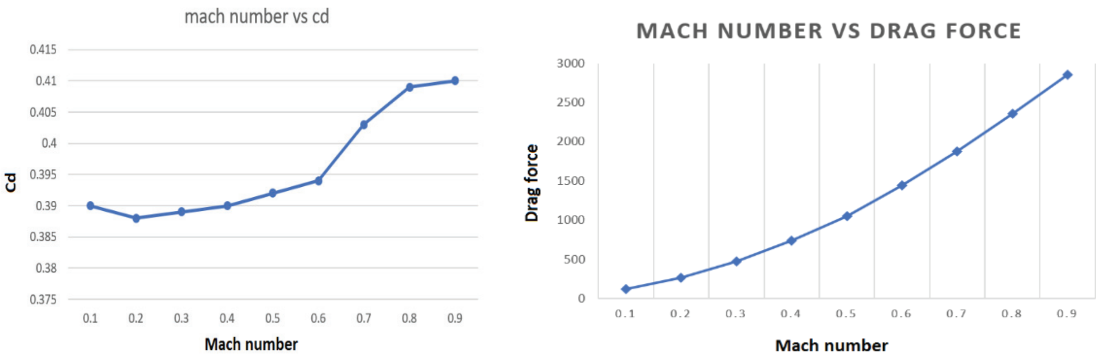

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Fig. 8 a − Mach number vs cd; b − Mach number vs drag force

4. Conclusions

Computational analysis of the rocket target 400M with four motor configurations for the drag coefficient is studied and the required forces and coefficient is obtained to analyze the ballistics at various Mach numbers. The drag force increases with significant increase in velocity. The average drag coefficient of 0.4 will be considered for the ballistic analysis. From the results the drag coefficient moves around the value of 0.3 to 0.4. A notable increase in drag coefficient is observed at the 0.8 Mach number. As the rocket is analysed only for the subsonic flow regime the velocity maximum of 320 m/s is considered. Future studies will be required for the supersonic flow analysis above mach 01. Modification on the design of RT-400M that can be performed to reduce the drag force will be carried out for future study.

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Development of Transport – Transit Potential of the Republic of Kazakhstan as of Today

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Abstract

The article investigates the essence and significance of the transit potential of the Republic of Kazakhstan, presents the state of the country's transport system, the prerequisites for using the transit potential, large projects carried out to increase the efficiency of transit, considers the development trends of railway transport, the main directions of improving the transport and logistics infrastructure. Within the framework of the EAEU, the following factors will contribute to the full use of the transport and transit potential of Kazakhstan: reduction of transport costs, unification of transit capabilities of all countries of the union, de-bureaucratization of transport procedures, development of a logistics base, the possibility of equal access to Russian pipelines and ports in the Baltic.
Keywords: *transit potential, transport and logistics system, transport infrastructure*

1. Introduction

The transit potential can be considered as one of the main strategic resources of the country. Its efficiency has a positive effect on the economy, making it attractive for investment. The development of the transport industry, logistics and transit are also sources of replenishment of the state budget with additional revenues through payments for transit and transportation. Kazakhstan, having a favorable geographical position at the junction of two parts of the world, has the opportunity to realize its transit potential, to effectively integrate into the world economic system.

Speaking of the transit potential of the national economy in growth

we will consider the ability to maintain international transport streams in the presence of the necessary resources to maintain international transport flows in the presence of the necessary resources, while stimulating the country's economic growth in particular, increasing export income [1].

In our opinion, in the development strategy of the transport sector of the Republic of Kazakhstan [2] the most informative determination of transit potential is diven: "Transit potential is a set of external and internal conditions and factors that determine the possibilities of the state to provide services for international transport through their territory".

Issues of transit transportation and problems of implementing regional transit

opportunities in literature are covered in the scientific works of Western researchers- economists [3-8].

Currently, the transit potential of Kazakhstan is not fully utilized. Most of the cargo transportation is carried out within the republic, and the volume of transit traffic is insignificant. There are problems in the Republic of Kazakhstan that hinder the development of transit:

- low level of transport infrastructure, where there is a significant deterioration of its facilities - from 40 to 100%;
- the number of days required to complete export and import procedures, a high degree of bureaucratization;
- slow introduction of modern transport technologies;
- unsatisfactory condition of highways;
- underdevelopment and inefficiency of transport logistics, which contributes to the rise in the cost of transportation and the price of goods.

Today, the development of international transit is associated not only with the peculiarities of the geographical location of countries, but also with the introduction of the latest technologies, the processes of unification and concentration in the world transport system.

The geographical location of the Republic of Kazakhstan determines its importance in terms of ensuring flow of transit cargo, which requires optimization of the technology for the transportation of goods. One of the most effective ways to deliver goods in international traffic is the development of container shipping.

World practice shows that low trade volumes are the result of high costs in conducting trade operations, among which transport costs, paperwork, border crossing, and the state of infrastructure and organization of transportation occupy a significant percentage. All this in the concept of trade is the cost of logistics. The experience of successful development models of a number of developed European countries shows that the development of transit brings significant income to their budget. For example, in Netherlands, the transit crossroad of Europe, the income from transit makes up to 40% of the total volume of export services [9, 10].

2. Research

An essential condition for the development of transit in Kazakhstan is an increase in cargo turnover between Europe and China, which is currently developing the "Great Leap Forward" transport strategy. The program provides for the development of the western regions of China, as well as transport infrastructure, including the introduction of new railway lines to the free economic zone "Khorgos".

In ensuring the competitiveness of transit services the transition to containerization of cargo transportation is important.

Figs. 1-3 below show the dynamics of container traffic transported through the Republic of Kazakhstan in different directions.

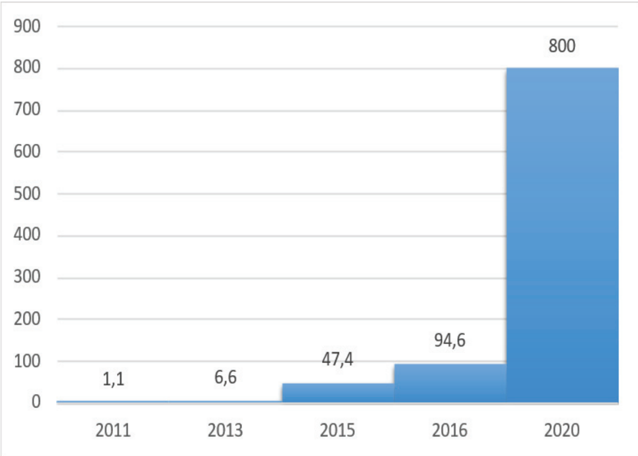

Fig. 1 Container traffic in the directions China-Europe-China (thousand TEU). Source: According to the Statistics Committee of the Ministry of National Economy

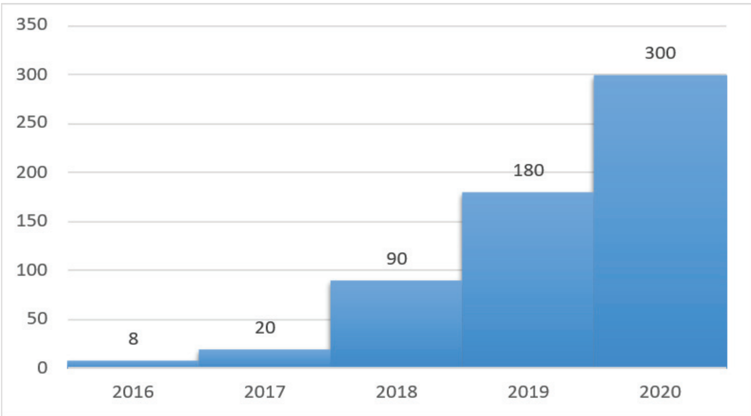

Fig. 2 Container traffic in the directions China-Caucasus-Turkey (thousand TEU). Source: According to the Statistics Committee of the Ministry of National Economy

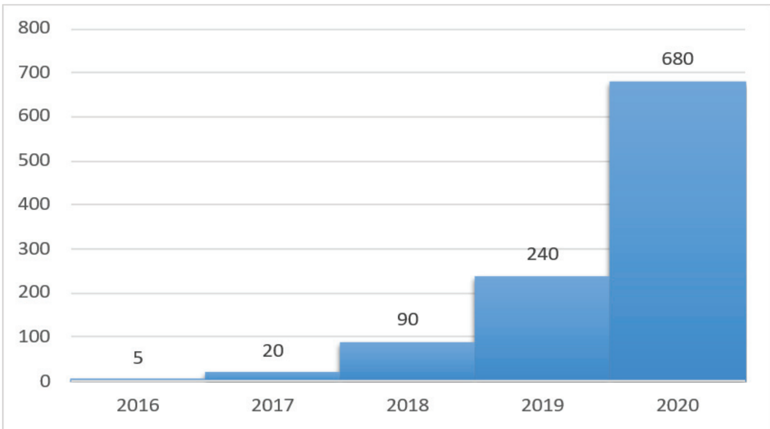

Fig. 3 Container traffic in the directions China-Eastern Europe-Russia-Iran-India (thousand TEU). Source: According to the Statistics Committee of the Ministry of National Economy

As you can see from the diagrams, there is a tendency towards an increase in the volume of container traffic. As a result, there is a need for the development of transport and logistics services, respectively, the implementation of various projects to improve the transport infrastructure.

Fig. 4 shows the main directions of the development of transport infrastructure in Kazakhstan.

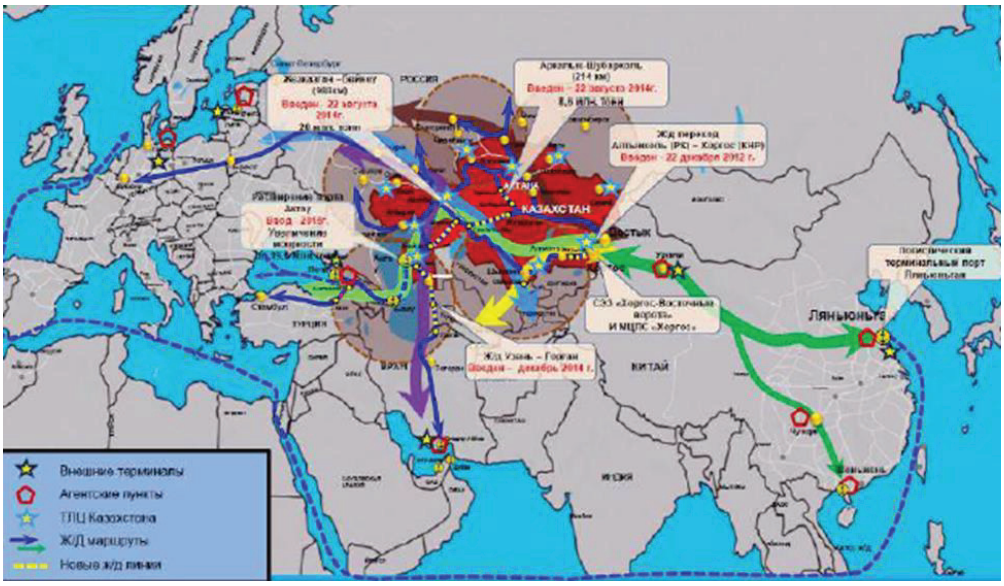

Fig. 4 Main directions of development of transport infrastructure in Kazakhstan

The transport strategy of Kazakhstan provides for the implementation by 2021 of a two-fold increase in the volume of transit in comparison with 2010, which actually makes it a "transit hub" as part of the Trans-Asian transit artery.

Promising directions for the implementation of the transit potential for Kazakhstan: through Russia to the EU countries; to China, Japan, the countries of Southeast Asia; through the countries of Central Asia and the Caucasus to Iran and Turkey.

For each of these directions, there are transport corridors, both by land and waterways.

New transport routes are also being developed. Two transport hubs are of particular importance in Kazakhstan - the Dostyk - Alashankou railway pass in the east of the country and the Aktau seaport in the west. Transit through Kazakhstan has a number of advantages:

– reduction of speed and distance from producer to consumer from Asian countries to European countries. Unlike the sea route in this direction, where the cargo is in transit for 35-40 days, the time of delivery by land is reduced by 2-3 times;

– a stable political situation and a favorable investment climate in the country.

The development of the EAEU made it possible to create a single customs border between China and the EU countries, which eases customs clearance procedures. Currently, the trade turnover between the EU and China is over USD 500 billion and is growing steadily. Kazakhstan is able to receive great benefits from the transit of goods and increase the share in freight traffic between them from 1 to 8% by 2020.

The dynamically developing economy of China and its main trading partner, the EU, create preconditions for the development of transit opportunities for Kazakhstan.

Overland transport corridors make it possible to reduce the delivery time of cargo by reducing the distance in the East-West traffic. Five international automobile routes with a total length of 23 thousand km pass through Kazakhstan.

One of the largest projects in the region is the Western Europe - Western China automobile corridor. This road corridor provides the shortest route for Chinese goods to Western Europe and returns the shipment of supplies of machinery and equipment to the PRC; it reduces the delivery time of goods between the EU and China by 3.5 times. This project is important for the development of business, tourism, trade, and finance in Kazakhstan.

The implementation of the Dostyk - Green Corridor project includes engineering and technical work to improve the Dostyk border station. The work includes the construction of a transshipment site for large-tonnage containers, the construction of exhibition tracks to the transshipment points 2, 4, the construction of the E park along the 1435mm gauge, as well as measures to increase the capacity of the adjacent rail sections Aktogay-Dostyk, Almaty Aktogai, Moyynty-Aktogay.

The creation of a hub in Khorgos is one of the tools of the concept of development of the transport and logistics system. It provides for the creation of a single transport and logistics operator to ensure the necessary level of coordination of management, the formation of integrity and integration of multimodal services, as well as the implementation of the "one window" principle.

The construction of a container terminal at the port of Lianyungang in China is of great geostrategic importance. Today, the port, being one of the largest ports of world importance, contributes to the integration of Kazakhstan into international transport and logistics chains.

The entry into service of the Kazakh-Chinese terminal contributes to the fulfillment of the task of an increase in traffic of goods from the countries of Southeast Asia in the direction of Central Asia, Kazakhstan, Russia and the European Union. At the same time, in 2019, the terminal handled 84 thousand containers in a 20-ton equivalent, storage of goods amounted to 360 thousand tons. In the long term, the terminal is expected to handle over 550,000 containers per year by 2021. Currently, it is planned to build a logistics zone for the member countries of the Shanghai Cooperation Organization (SCO).

Table

SWOT - analysis of the transit potential of JSC "NC KTZ"

Strengths:	**Weaknesses:**
Favorable geographical position on key transit routes	High current prices for rail transit, resulting in a current low share of international transit routed through Kazakhstan
Availability of the necessary production facilities for the services of the mainline railway network	Infrastructure bottlenecks
	Insufficient level of coordination and involvement of countries along the targeted transit routes
	Early stage of development of the sales function in China and the EU
Opportunities:	**Threats:**
Growth through the Republic of Kazakhstan of transit freight traffic China-Europe and in other directions	Failure to agree with countries on the target transit routes on the required reduction in railway tariffs to obtain a sufficient level of transit
Building a strong sales function in China and the EU to ensure and control the volume of transit through Kazakhstan	Low level of prices for the transportation of containers by sea
	Lack of demand for a transit route from large forwarders due to current contractual relationships with sea carriers

The implementation of a large-scale project Western Europe-Western China will provide cargo transportation in the following directions China - Central Asia, China - Kazakhstan, China - Russia - Western Europe [11].

Comparison with alternative delivery options (road Transsib, sea through the Suez Canal) shows that the advantage of this route is its length and the shortest travel time (10 days). The infrastructure of this corridor will provide high quality of transport and logistics services due to integration into the transport and logistics supply chain of goods. The technical characteristics of the roads will make it possible to travel at a speed of 80 km/h (an alternative average speed is 30 km/h), possibility to use the services of a satellite navigation system, the ability to track cargo along the entire route length [12].

The transit corridor system includes international transport and logistics centers across various locations in Kazakhstan. These locations are on the territory of the Almaty region in the special economic zone Khorgos and Almaty, in Aktobe, in the Taskalinsky district of the West Kazakhstan region and in Shymkent, South Kazakhstan region, as well as regional transport -logistic centers in settlements and cities of Almaty, Taraz, Shu, Shymkent, Turkestan, Kyzylorda, Baikonur, Aralsk, Karabutak, Aktobe, Uralsk.

Currently, there is a lag in the country's competitive positions in comparison with neighboring countries. The lag is primarily due to the unsatisfactory state of the transport infrastructure, the slow process of its renewal, the lack of investment in the modernization of the technical equipment of roads and transport hubs.

To take into account the peculiarities and choose the right direction in the development and improvement of the transport and logistics system of the Republic of Kazakhstan and transit potential, a SWOT analysis of the transit potential of JSC "NC KTZ" is presented (Table).

This analysis identifies the strengths and weaknesses for the further development of the transit policy and contributes to the formation of the country's transit potential.

In order to implement the transit policy, the following measures are taken [13]:

– assistance in solving issues of development of transit traffic at the international level;
– development of the logistics infrastructure of transit corridors;
– improvement of technical equipment and services to the level of world standards;
– ensuring the safe passage of transit cargo through the territory of the Republic of Kazakhstan;
– the use of modern communication systems and software;
– digitalization of the transport complex, the introduction of intelligent transport systems and unmanned technologies
– creation of favorable conditions for attracting domestic foreign investment in infrastructure development.

3. Conclusions

Thus, in modern conditions of market globalization, increased competition within the framework of a single economic space, fierce competition from alternative routes, a complication of supply chains - the development and increase of the competitiveness of the country's transport and logistics system is vital necessity. Within the framework of the EAEU, the following factors will contribute to the full use of the transport and transit potential of Kazakhstan: reduction of transport costs, unification of transit capabilities of all countries of the Union, de-bureaucratization of transport procedures, development of a logistics base, the possibility of equal access to Russian pipelines and ports in the Baltic.

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Aircraft Maintenance and Maintainability

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Abstract

Maintenance and maintainability engineering as science is developed to keep the aircraft operational and available as long as possible. The one way to achieve this is the combination of all types of maintenance in order to reduce technical service costs. Nowadays, no one type of aircraft maintenance is perfect.
KEY WORDS: *maintenance, maintainability, maintainability engineering*.

1. Introduction

Maintenance and maintainability are critical to the aviation and aeronautical industry as it very much affect performance and also finances [1]. It is recognized that maintenance costs are about ten percent of all costs for commercial airlines [2]. Commercial airlines operators would like to have their aircrafts to be available as much as possible for safe operation and all aircraft systems to be 100 percent functional and also available when needed. In the good practice there are some quite different ways to achieve this. The best one is to create for aircraft highly reliable systems but that will increase the price. Other is the design, construction, and development aircraft systems and its components that might be easily maintained and quickly removed and installed by performing scheduled maintenance or unscheduled repair [3]. For the so-called low-price airline, it is usually accepted as a combination of the two ways. The cheaper design by using less expensive materials also means shorter time between heavy maintenance events. Therefore, using the balance of the two above mentioned ways, are good practice to achieve higher aircraft flight operability and safety [4].

2. Definitions of Maintenance

Maintenance is an essential part of aircraft operations in order to ensure its availability, reliability, and safe flights [5].

There are many definitions of maintenance, and one of these that might be useful for better understanding is written in quality vocabulary [5]. According to this vocabulary it is *"combination actions"* [5] with the intention to keep aircraft in the state in which it can perform all required functions for successful flight operations [6]. Airlines Technical Operations Glossary additionally points that *"these actions"* are required to keep all aircraft items "in serviceable conditions" [7] by performing all kinds of work such as all kinds of inspections, servicing, repair, modification, overhaul and others.

Independent Aviation & Aerospace Professional Jack Hessburg, the former Boeing Chief Mechanic with 42 years experience in the aviation field in just few words define that "maintenance is the management of failures and assurance of availability" [2].

Kinnison and Siddiqui describe maintenance as "the process to ensure functionality of system at its designed level of reliability and safety" [8].

From the aircraft continuing airworthiness assurance point of view the definition is provided by European Aviation Safety Agency (EASA) and the rest part of definition is the same as mentioned above [9].

By summarizing all above given definition it might be concluded that the maintenance purpose is to have aircraft fully serviced and available for save operational flights. This purpose might be achieved by effective management of all tasks for inspections, overhaul, and repairs in order to restore aircraft and its systems functionality as much close to design state as possible by all modern means [10].

3. Aircraft Maintenance Classification and Philosophies

Maintenance can be also divided into two main types as corrective maintenance (after a detected fault) and predictive maintenance (before a detected fault) according to an ISO 13306 standard. Predictive maintenance can be divided into preventive (predetermined, time-based, scheduled) maintenance and conditional (condition-based scheduled, continuous, or on request) maintenance [11]. Corrective maintenance has also two types defined as deferred corrective maintenance and immediate corrective maintenance.

International ISO 13306 standards gives to us explanation how the maintenance is divided as per today's development level of this area of science. The first group belongs to predictive – means "predetermined, time based, scheduled" and conditional – "scheduled based on condition, continuous also might be on request" [12]. The second group is corrective that includes "deferred" and "immediate" maintenance tasks carefully assessing before it influences to aircraft flight safety. The visual picture from this ISO standard of the maintenance division is in Fig. 1.

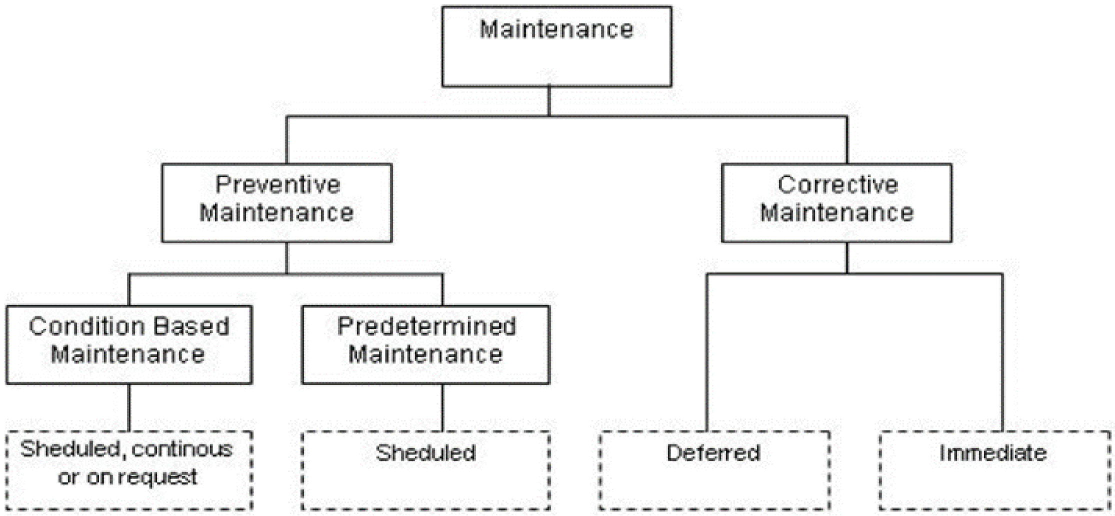

Fig. 1 Source: CEN - EN 13306 Maintenance - Maintenance terminology

Based on this ISO was given maintenance division there is also identification (as per today's level of development on this issue) four philosophies for mentioned types of maintenance [13]. So, there are identified: corrective, preventive, risk based and condition-based aircraft maintenance philosophies. Corrective maintenance philosophy is based on reaction to the specific failure of the systems or some parts on aircraft. This might be used in practice just for systems and parts that cannot drastically influence aircraft safe flight operations (mostly for redundant systems or elements). This kind of philosophy is very much in favor of operators who wants to take risk on safety in order to save expenditure on maintenance cost. In general this philosophy is not very much welcome in the aviation and the aeronautical industry as it is "related to the cost of ignoring safety". Based on the requirements for "flight safety the first" [14], therefore the most used is preventive maintenance philosophy for the planning and performing inspections, servicing, overhaul, and repairs on flying vehicles. This maintenance philosophy is very much excessive and insufficient from the view of costs, but by having careful prepared plans (by a good experience maintenance planner in field) it is possible to avoid the unnecessary heavy workloads and to save some time and costs. Risk-based maintenance philosophy is very much promising, but it is just useful and reliable if the huge amount of data is collected for computation and also the risk is to be taken for choosing right probabilistic methods for the qualitative and quantitative analysis. At per today development, it is just a very good approach towards "the problem of aircraft maintenance from a risk-based perspective" [14]. On-condition maintenance philosophy is on performing inspection task before the failure system or element of aircraft and chosen the right element which needs to be replaced by a new one. This maintenance philosophy is very much developed by Boeing company. Together with General Electric Aviation it was developed and presented to the public in 2008 the method called "Open System Architecture for Condition-Based Maintenance" [15]. Actually, it was set up standards requirements for doing maintenance on aircraft based on its elements and systems using real-time data collected from many sensors with very advanced hardware and software for assessment [16].

4. Aircraft Engineering

According to the Cambridge Academic Dictionary "using the scientific principles or methods" [17] in any field of human activities "to design and build" might be called "engineering" [17]. Therefore, today aircraft engineering is inspection, repair, all kinds of modifications (recommended and obligatorily related to flight safety), removal, reinstallation, and installation of aircraft equipment. This is named just small part maintenance work must be performed by the licensed aircraft mechanic, technician, and engineer. With the aircraft and its systems complicity there is natural requirements to use more different scientific methods for aircraft engineering. Aviation engineering in some countries (the UK) now is defined just development of airspace and ground facilities like aerodromes and airports and development of aircrafts and spacecrafts is called aerospace engineering moved from "originally name aeronautical engineering" [17]. This change of names is related to advanced flight technologies allowing for aero "vehicles operate in outer space" [17].

As part of scientific studies in aircraft maintenance, there is need to be equipped with the advanced technologies and scientific methods of maintenance management broadly using also influence of human factor by inspecting aircraft components and systems, diagnosing all aircraft-related problems, and rectifying these issues accordingly. There also is requirement to include the legal issues related to the operation and maintenance of aircrafts. Based on scientific studies and experience (good and bad) was developed maintenance program for the aircraft. Maintenance programs include line or light maintenance and base or heavy maintenance. All these maintenance program tasks are scientifically created and written in manuals as legal base to follow in order to meet strict aircraft airworthiness requirements for safe flights [18]. Summarizing aircraft engineering one recommendation is good to be followed: if the aircraft is historical heritage object, then from the efficiency (economical) point of view maintenance costs should be not more than the aircraft original value [7].

5. Maintenance and Maintainability Engineering

Based on all nowadays information on maintenance and maintainability engineering as science is developed to keep the aircraft available for operations as long as possible. The best way is to have the combination of all types of maintenance in order to reduce technical service costs. No one type of aircraft maintenance are perfect [18].

Aircraft Maintainability is the ability of the aircraft to meet operational objectives with a minimum expenditure of maintenance effort under the operational and environmental conditions in which scheduled and unscheduled maintenance are performed [19]. By simple definition the maintainability is an assessment of an air vehicle as the item ability to be restored to its designed condition by trained and skilled personnel using all available resources and legally approved rules and procedures [19].

It is recognized that because of the possibility for failure and deterioration in performance an aircraft as almost any item is impossible forever operate or keep it with the original functionality. Private owners and airlines that use aircraft extensively to operate flights must also know when and how mandatory maintenance is to be performed in order to follow airworthiness requirements [20]. Owners and airlines operators are keen to spend money as less as possible for the aircraft maintenance.

Based on airworthiness requirements and also to be profitable owners and operators count the aircraft or its separate system availability and calculate life cycle cost. In these matters is helpful the sustainability or maintainability engineering as science, which answers what and when should be performed in order to maintain aircraft and its systems in full operational scale [21]. This discipline as science develops methods for quantifying, evaluating, predicting, and improving aircraft system performance. Maintainability engineering is now powerful tool for aircraft maintenance personnel to assess the designed aircraft systems before performing maintenance tasks in the best efficient way. As the result this also helps to reduce maintenance costs [22].

In order to improve quality and to shorter aircraft maintenance time it is very much depending on the designer's creativity to improve the access for the inspections and to make the parts more interchangeable [23].

6. Conclusions

There are currently articles that the best way is maintenance by condition [24-26]. This method of aircraft maintenance is a very attractive and promising significant saving. Is the aircraft more or less reliable if every work on aircraft performed just based on aircraft condition? This method involves the use of a large number of sensors, computer processors with fault display in the cockpit or in a specially equipped panels for technical personnel, to verify information before and after the flight. All this extra equipment increases the weight of the airplane and then is less payload or passengers can be taken. Each additional element also requires a probabilistic reliability assessment. This needs to be done using qualitative analysis - quantitative using formulas for calculating the probability of failure or functibonality (failure). To make this whole system of sensors, computers, computer programs as reliable as possible - might be required duplication of elements or even entire systems. Therefore, it appears the pessimistic conclusion that this condition-based maintenance method is only acceptable for test airplanes to determine the frequency of failures and then uses the information gathered to prolong or reduce the frequency of maintenance also might be even to avoid some maintenance operations without affecting the reliability and safety of the airplane. The balance between aircraft reliability and savings on its maintenance must always be as a priority for aircraft safety and seeking flights without failures.

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Overcoming a Stair-type Obstacle with Classic Arrangement of Unmanned Ground Tracked Vehicle

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Abstract

This paper will describe the movement of an unmanned ground tracked vehicle (UGV) while overcoming stairs. Overcoming the stairs will be demonstrated in the classic form of the tracked vehicle. Movement of the tracked vehicle on the stairs can be simply described as climbing a slope (on an inclined surface) - assuming the vehicle will move along the edges of the stairs. All these aspects will be illustrated in the MATLAB simulation.
KEY WORDS: *tracked vehicle, stairs climbing, unmanned ground tracked vehicle*

1. Introduction

The involvement of different UGV's in combat or various reconnaissance tasks has been a question of the last decade. War situations caused military conflict to move from open to built-up areas. The fighting in this area had a fatal consequence for the soldiers because the enemies could use the moment of surprise, knowledge of the area, and the fact that even an inexperienced fighter can cause colossal damage at close range. For that reconnaissance plays a crucial role in a military operation. And this is the domain of UGV's lately. Unfortunately, the movement of the UGV in the built-up area and inside the building brings many challenges in the form of various obstacles. The most problematic interior obstacle is stairs.

2. Climbing Stairs

2.1. Stairs

Stairs are one of the most difficult interior obstacles for UGV (Fig. 1). To overcome them, the robot must meet four basic requirements:

- overcoming the first step of stairs;
- stability during climbing (risk of flipping over);
- moving up the stairs;
- moving down the stairs.

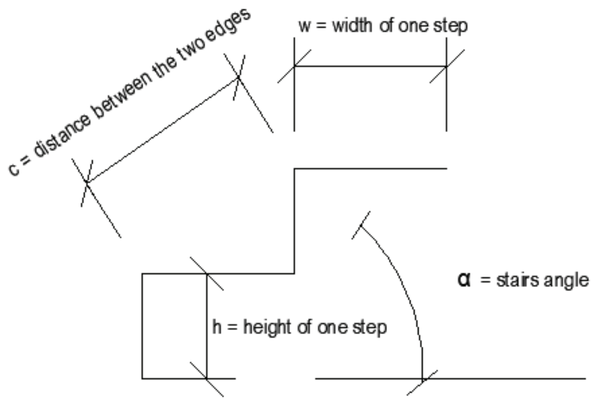

Fig. 1 Steps dimension

It is practically impossible to define the exact size of the stairs because each country has its own technical standards. Normal stairs can be defined:

- Stair angle 25-35 [α°];
- Height h of one step 150-180 [mm];
- Width w of one step [mm].

Width can be calculated as:

$$w = 630 - 2h, \tag{1}$$

where 630 mm is the average human stride length.

2.2. Tracked Vehicle

The movement mechanism consists of tracks that have greater friction force than others and have a larger area in contact with the road. Regarding the way the geometry [1, 4, 6] of the track is used, they can be divided into two groups:

- vehicles with fixed geometry - a smaller version of classic tracked vehicle (Fig. 2 - A);
- vehicles with variable geometry – they have additional tracks that can change positions (Fig. 2 - B).

The subject of our interest will be tracked vehicles with fixed geometry.

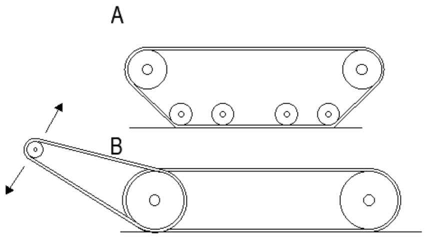

Fig. 2 Types of the track geometry

2.3. Overcoming the First Stair Step

In the first phase, it is important to lift the front of the tracks to the upper edge of the step. For vehicles with a fixed geometry, it´s very important to have tracked at an angle, which makes it easier to climb the first step. The vehicle comes to the vertical edge of the step, at a constant speed and lines up with stairs. Fig. 3 shows the situation when the robot touches the first step.

Based on the classical mechanical analysis we can describe this movement and set up the robot´s dynamic model [5] in process. The force F_M is generated by the engine and F_N is a component of the tractive force perpendicular to the surface. F_T represents the friction force between the lower edge of the tracks and the step edge.

$$m\ddot{x}_G = F_M - F_N \sin(\beta+\gamma) + F_T \cos(\beta+\gamma); \tag{2}$$

$$m\ddot{y}_G = -mg - F_N + F_N \cos(\beta+\gamma) + F_T \sin(\beta+\gamma); \tag{3}$$

$$J_S = -mg\rho\cdot(\varphi+\gamma) + F_N\left[L\cos\beta + \frac{(h - L\sin\gamma)}{\sin(\beta+\gamma)}\right] + F_T L \sin\beta - m\ddot{x}_G(y_G + R) - m\ddot{y}_G x_G, \tag{4}$$

where β – approach angle [°]; γ – angle between bottom of the track and ground [°]; ρ, φ – angle made with the X-axis [°]; J_S – moment of inertia [kg.m^2]; v – vehicle speed [m.s^{-1}]; L – vehicle length [m]; R – drive wheel radius [m].

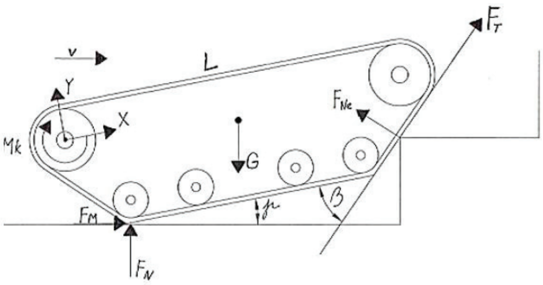

Fig.3 Overcoming the first step

Friction force F_T is calculated according to the formula:

$$F_T = \mu F_N. \tag{5}$$

Overcoming this obstacle is strongly influenced by the adhesive conditions - the vehicle track mustn´t slip. Due to the lifting of the front part of the vehicle, the contact area of the track is also reduced. The center of gravity of the vehicle should be located mostly at the rear, but not too much because it would flip the vehicle backward.

2.4. Movement Along the Edges of the Stairs

It can be defined as a motion on an inclined surface. After overcoming the first step the robot lands on the edges of the steps. For this case, robot parameters must meet certain requirements. The length L of the track, which is in contact with the road, must be longer or equal to the distance between the two edges of the steps.

$$L \geq 2c \,, \tag{6}$$

where c – distance between two edges.

These conditions must be met so that the robot doesn't fall from the edge of the step. Concerning the elasticity of the track, stability during climbing is very important (Fig. 4). The left and right track´s contact with the edge of the step might differ. This might lead to the vehicle being turned to the side. When the robot is moving up the stairs the smooth track is being considered.

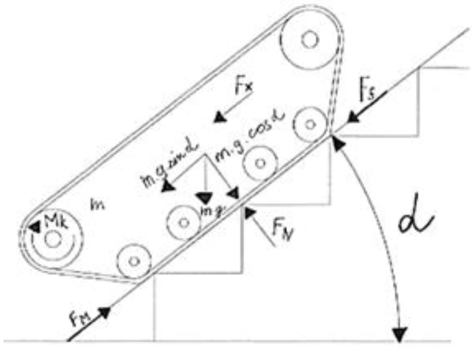

Fig. 4 Stairs climbing

The values of the resulting forces and moments are calculated according to the formulas. However, some of them are not mentioned below because they were demonstrated in the previous chapter.

$$F_N = mg \cdot cos\,\alpha \,; \tag{7}$$

$$F_x = -m\ddot{x} \,, \tag{8}$$

where m – mass of vehicle [kg]; g – gravitational acceleration [m/s^2]; $\ddot{x}$ – vehicle acceleration [m/s^2].

3. Matlab Simulation

Dynamic analysis of vehicle movement was described and simulated in the MATLAB program. The main result of this simulation is how powerful the electric motor should be. The basic request that the electric power unit must realized is a speed of movement 0.3 m/s. This speed represents a constant speed of movement of vehicle up the stairs.

3.1. Mathematical Model

This model is based on the movement of the vehicle on an incline surface [2, 3] and uses the second Newton´s law (Fig. 5). This law states, that the rate of change of momentum of body over time is directly proportional to the force applied and occurs in the same direction as the applied force. For tracked vehicle with constant mass, the Newton´s law can be re-stated in terms of vehicle acceleration.

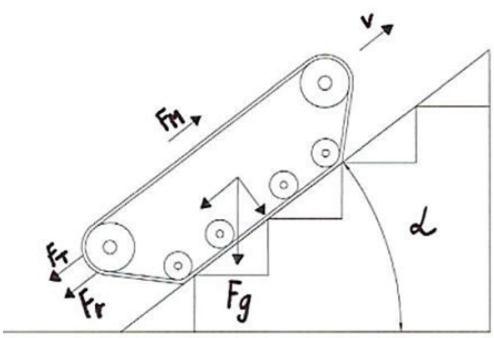

Fig. 5 The scheme on which the mathematical model is based

The second Newton´s law can be described by equation:

$$ma = \sum F \,, \tag{9}$$

where m – mass of vehicle which is 1.6 [kg]; a – vehicle acceleration [m/s^2]; F – all forces influence and acting on the vehicle [N].

Detailed form of Eq. (9) is:

$$ma = F_M - \left(F_M + F_r + F_{G_x}\right), \tag{10}$$

where F_M – represents the value of the required engine power.

Each terms of this equation expresses the force acting in the direction or opposite direction of the vehicle´s movement on the stairs. In the next step, the individual forces and values that were needed to calculate them were defined.

$$F_T = \mu mgv\,, \tag{11}$$

where F_T – friction force; v – required speed of climb 0.3 [m/s]; μ – friction coefficient. In our case it represents a value 0.002 [s/m], which expresses the time loss per meter of length traveled.

Aerodynamic drag of the vehicle:

$$F_r = \frac{1}{2} c_r A v^2 \,, \tag{12}$$

where c_r – aerodynamic drag coefficient (the value for our vehicle is 0.01); A – 0.014 [m^2], expresses the value of the front area of the vehicle.

x axis component of the vehicle weight acting against the direction of movement of the stair:

$$F_{G_x} = mg\,sin\,\alpha \,, \tag{13}$$

where α – stairs angle (was used 27° which was selected from the values mentioned in section 2.1).

After substituting into the equation arises:

$$ma = F_M - \mu mgv - \frac{1}{2} c_r A v^2 - mg\,sin\,\alpha \,. \tag{14}$$

Eq. (14) was divided by the value m:

$$a = \frac{F_M}{m} - \mu gv - \frac{c_r A v^2}{2m} - g\,sin\,\alpha \,. \tag{15}$$

In general acceleration is defined as the first derivate of velocity. The equation will remain valid even if it is written as:

$$\dot{v} = \frac{F_M}{m} - \mu gv - \frac{c_r A v^2}{2m} - g\,sin\,\alpha \,, \tag{16}$$

F_M – the force that the power unit must to develop.

Model described by the equation (16) was constructed in MATLAB-Simulink (Fig. 6). The goal is to set F_M to value for that the velocity will be close to 0.3 m·s^{-1}.

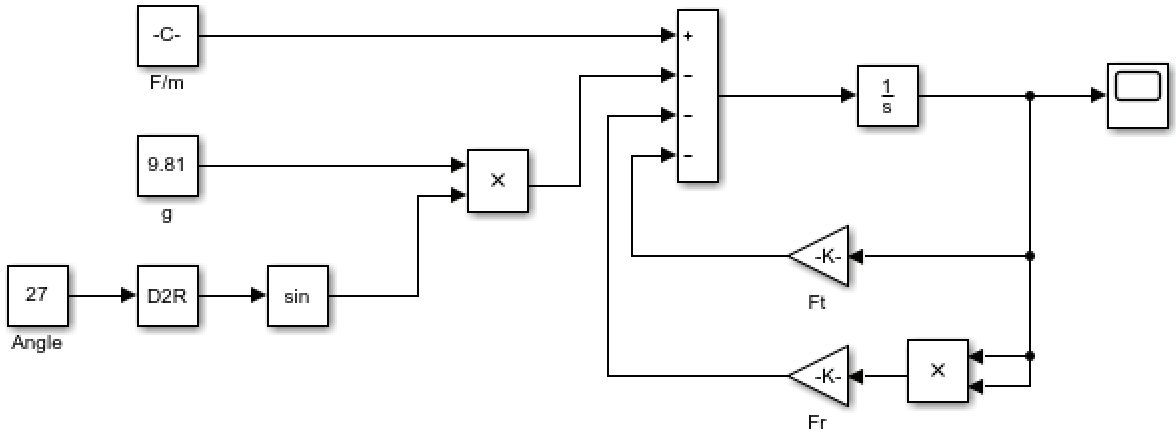

Fig. 6 MATLAB model according Eq. (16)

A way how to compute tensile force of vehicle power unit is to use linear controller output error method, as it is shown in Fig. 7.

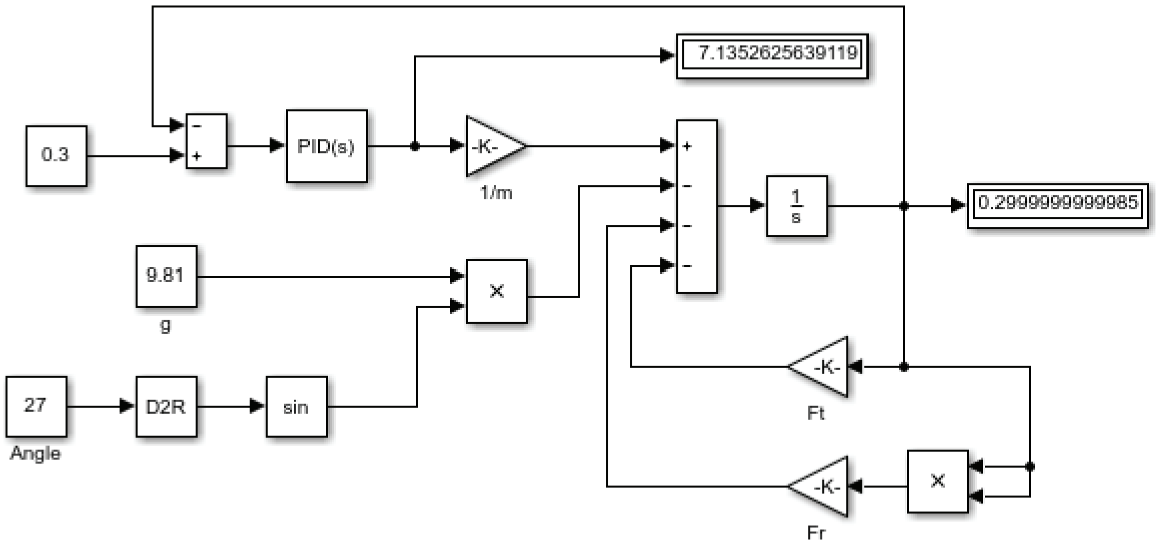

Fig. 7 Computing structure of tensile force

The output of the simulation for the F_M = 7.14 N is shown in the Fig. 8.

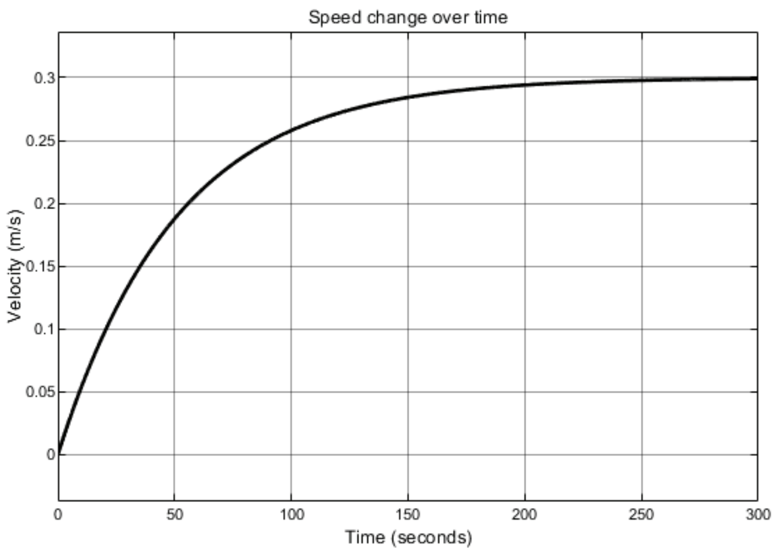

Fig. 8 Output of the simulation

4. Conclusions

Using MATLAB simulation was found that the minimum tensile force of the engines (which is needed to overcome the stairs at a constant speed 0.3 m/s) is approximately 7.14 N. Based on this value we can choose an electric motor that will meet this requirement. Fig. 8 shows time 250 s, when the vehicle reaches the required speed. However, the simulation does not consider discharging the battery, which would cause the vehicle to be unable to move a long time with constant speed.

Acknowledgement

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Technical Diagnostics of a Vehicle Combustion Engine

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Abstract

The current development of vehicle propulsion in almost all categories is linked with the field of electrification. Despite the legislative pressure to introduce purely electric vehicles, diesel combustion engines with rectilinear return movement of pistons will continue to play an important role in special vehicles' drive systems. This is mainly due to the sophisticated design, performance parameters, and decades of improvement and optimization of individual engine parts, thus achieving high efficiency. A number of operational advantages and considerations of the operational reliability of current diesel engines plays an important role in the choice of drives for special vehicles. In order to maintain the high reliability of diesel propulsion units in operation, various diagnostic methods are used. Currently, the general trend is to use such methods that are able to determine the current technical condition and detect a possible failure before it occurs.
KEY WORDS: *combustion engine, diagnostic methods, operational reliability, technical diagnostics*

1. Introduction

The current requirement in the field of special vehicles operation is a significant improvement in the use of the equipment. This requirement can be met by creating optimal technical, technological and organizational conditions as well as improving maintenance methods. Wear processes are expectable during the life cycle of the equipment, but at the same time undesirable, because they lead to massive degradation of materials, which can often cause a failure or even an accident. We try to systematically prevent these phenomena and increase the operational reliability and service life of the equipment. Specific requirements are imposed on the special vehicles over a relatively long and diverse life cycle. The equipment is operated under extreme conditions (weather, terrain, time, operation, maintenance, storage, various degrees of load, or no load, etc.) for a relatively long time, during which the full use alternates with only partial use or even no use at all. Technical diagnostics plays an important role in the entire process of use. Technical diagnostics is a scientific discipline and a field of practice that monitors the forms and mechanisms of failures in technical systems, develops methods for their detection and principles of designing diagnostic equipment. Diesel combustion engines are a very important and at the same time the main group of special vehicles. Diagnostics of a diesel combustion engine includes detection of the technical condition of the engine cycle, the four-stroke engine gears and crank mechanism system, bearings, and other systems (lubrication, cooling, fuel, air, optimizing the combustion process, reducing pollutants, etc.). The engine cycle diagnostics deals with monitoring the process of converting the energy supplied to the combustion engine in the fuel to the indicated work, where the following indicators play a major role: tightness of the combustion chamber, the efficiency of filling exchange, adjustment and function of the fuel and cooling systems, operation of the four-stroke engine gears. Diagnostics of the four-stroke engine gears includes the determination of clearances, checking the wear of parts of the four-stroke engine gears and its adjustment. Diagnostics of crankshaft bearings deals with the issue of bearing wear and the inspection of their technical condition.

A combustion engine is a complex mechanical device in which any mechanical intervention (disassembly, reassembly) can worsen its technical condition and cause other failures. Thus, an effort is to determine the technical condition using non-disassembly diagnostics. During the non-disassembly diagnostics, the characteristic parameters (symptoms) of the technical condition of the engine are monitored and evaluated, and the basic connections between the manifestation, symptom, fault and the cause of faults are used. Based on indirect symptoms and manifestations, probable failures of the combustion engine can be identified [1]. The basic, but insufficient parameter of the technical condition of a vehicle combustion engine is the power or the instant torque. Standard diagnostics of the power and the torque includes measurements on the engine brake, which is, however, associated with disassembly. This procedure is not feasible for special vehicles; therefore indirect methods are used, such as measuring angular acceleration and crankshaft delay [2], etc.

Modern special vehicles are equipped with electronic systems that ensure optimal engine operation in given conditions. The amount of information that is recorded by these electronic systems is also used in the systems of monitoring the actual technical condition. With the help of on-line diagnostics, vehicle networks are used, which enable the implementation of an effective OC maintenance system (On Condition). The system for monitoring the technical condition of special vehicles while using HUMS (Health and Usage Monitoring System) allows the collection, processing and display of data. The data has a common format, can be interpreted and shared with other systems that help manage maintenance at different levels.

2. Methods for Solving Diagnostic Tasks

The vehicle's combustion engine as a diagnostic object is a very complex device that cannot be examined directly without impairing its function. It is advantageous to adopt an abstract approach to the study, i.e. to build a diagnostic model. Abstract models can be very diverse; according to their form they can be analytical, vector, graphic, tabular, etc., according to the used device they can be probabilistic and statistical, logical, topological, formed by a system of algebraic or differential equations, intuitive, etc., according to the implemented calculations, models and analyses they can be linear, nonlinear, deterministic, stochastic, static, dynamic, with concentrated or distributed parameters, etc.

The requirements for the mathematical model can be expressed as follows: a diagnostic object is given and is characterized by a set of parameters of the technical state $W = (x_1, x_2, \dots, x_n)$, or corresponding diagnostic parameters $V = (s_1, s_2, \dots, s_n)$. Let us denote the set of conditions imposed on the parameters $W(V)$ as $P = (p)$. If any of $W(V)$ parameters does not meet the conditions of P we can state that a fault has occurred. Let us denote the set of all possible faults as $D(d)$. Let us denote the system of all the above subsets as φ. The compilation of the diagnostic model then consists in:

- finding a mutually unique isomorphic representation of the state space into the signal space and vice versa, i.e. between the sets W and V;
- finding a certain combination of variables from the set of parameters $W(V)$ to the corresponding element in the set of failures $D(d)$.

When solving the tasks of determining the state of the object and its operability, it is not necessary to use all the parameters that characterize the operability, but it is necessary to select a subset H of diagnostic parameters that meets the following conditions:

- it must contain all the elements on the accuracy of which the operability of the evaluated system depends;
- the number of assessed elements must be minimal, but sufficiently informative;
- the selected elements must have sufficient resolution for information on the correctness of the function or failure rate;
- it must contain only the elements for which the correctness or failure rate can be determined without disassembly;
- it must contain basically the elements for which the correctness of the function or failure rate can be determined relatively quickly and with minimal costs.

Various methods can be used to determine the set of selected diagnostic parameters H, e.g. intuitive empirical method (for simple objects), active experiments, linear, nonlinear or dynamic programming, image recognition, etc.

When determining the fault and its location for complex objects, diagnostic parameters are selected in a similar way as in the case of determining the condition of the object and its operability. To determine the set of diagnostic parameters and determine the classes of object states, we can use the following methods: image recognition theory (topological models), linear programming (optimal purpose function), expert systems using sophisticated tools such as neural networks, simulated annealing, fuzzy systems (sets), etc.

Expert systems are software that simulates the decision-making processes of real experts with specialized unique knowledge in solving complicated tasks [4-8]. In the field of expert diagnostic systems, it is the implementation of fault diagnosis (detection and localization tasks), interpretation of acquired data (hypotheses and their verification), condition monitoring (real-time data evaluation to determine the optimal moment of intervention - maintenance, repair, adjustment, etc.). Standard expert systems consist of a knowledge base, a database, an inference (control) mechanism, an explanatory module and an up-to-date model [5]. The knowledge base contains exclusive knowledge of experts for the solved task or about the diagnosed object. The database contains quantities characterizing the technical state of the diagnosed object (measurement results, diagnostic signals, information from the dialogue with the user, design parameters, etc.). The explanatory module implements communication between experts and users. The inference mechanism usually uses logical methods of induction, deduction, implication, or AND, OR, NAND, NOR gates, etc., direct or reverse chaining, generation and testing, use of analogies, etc. Methods of knowledge representation are a key area of the expert system; they include rules, predicate logic, semantic networks, frames, etc. The advantage of expert systems is the fact that they are repeatable and always provide the same, well-reasoned results, integrate the experience of multiple experts even in case of disagreement, enable knowledge base optimization, have the ability to learn, their data is distributed, allow remote access using clouds, knowledge is formalized, use uniform terminology, etc. The disadvantage of expert systems is the fact that the knowledge is only mediated, the same errors can appear repeatedly, the experts usually cannot describe all aspects of their decisions, the system does not understand the domain and explains the decision only in a programmed way, the expert has features that cannot be projected into the system, e.g. common sense, intuition, the ability to recognize exceptions and adapt to them in real time, etc. In technical practice, expert diagnostic systems based on rules are often used; these include procedural semantics (meaning, abstract sense) or declarative (descriptive, stated) semantics, i.e. the science of meanings. An example of a declarative expert system expressed through an oriented graph is shown in Fig. 1, the relevant knowledge base containing rules is in Table. For a formal description using the terms: object, e.g. crankshaft, with the attribute of crankshaft speed and the logical value yes/no. For this object we can use the rule: *"IF the crankshaft does not rotate & the engine is OK, THEN the bearing is sized".*

A very interesting area in cases where there is no exact boundary between state classes is the use of fuzzy sets. This method allows the expression of not only functional and probabilistic relationships. An example of standard logic operations and fuzzy set operations is shown in Fig. 2 [9]. Models of complex systems include quantities of various natures and it is often necessary to distinguish the role of the quantity in the model by its weight, i.e. the importance in the system. Let $X = \{x_i\}$ be a set of system parameters that is finite and let the relationships between them be considered.

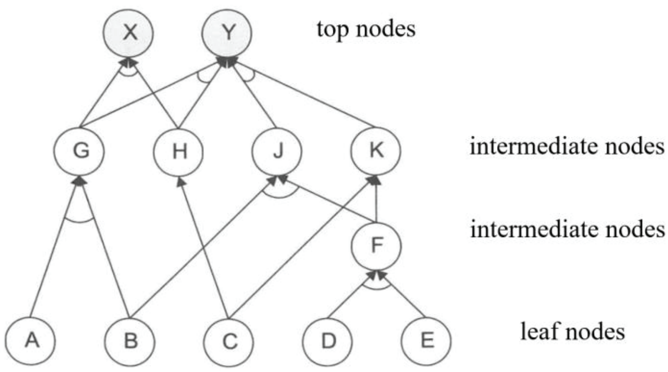

Fig. 1 Example of inference network graph

Table

Example of inference network rules (Fig. 1)

Regulations	Symbolic notation	Regulations	Symbolic notation
R1	$A\ \&\ B \rightarrow G$	R5	$A \lor B \rightarrow G$
R2	$D\ \&\ E \rightarrow F$	R6	$G\ \&\ H \rightarrow X$
R3	$C \rightarrow H$	R7	$G\ \&\ H \rightarrow Y$
R4	$B\ \&\ F \rightarrow J$	R8	$J\ \&\ K \rightarrow Y$

Considering the above, it is possible to obtain the relation *X*, which can be understood as an abstract system *S*, which is an image of a real system. At the same time, each parameter x_i expresses a characteristic feature of the system's behaviour and is determined by all parameters that are influenced by it or affect it. These facts create the abstract system, which is a subsystem *S* and can be used to define the weight of the parameter x_i, using fuzzy sets. The fuzzy set *A* is defined on the set *E* as the set of all elements $x \in E$, to which the value of the membership function $h_A(x)$ is assigned, which takes values from the complete ordered set *M* as a closed interval <0,1>. The algorithm of the fuzzy set method is based on a matrix of constraints *G*, whose rows and columns are parameters x_i arranged in the order of selected parameters. The element of this matrix $a_{ij} \in <0,1>$ expresses the degree of dependence of the parameter x_i on the parameter x_j. If we consider the function *G*(*i, j*), and if *G*(*i, j*) = 1 then the parameter x_i depends on the parameter x_j and if *G*(*i, j*) = 0 then such a dependence does not exist. The algorithm for assigning parameter weights using fuzzy sets is as follows:

1. construction of a matrix of connections of fault location of the respective system *G*;
2. specify fuzzy sets I_i and J_i for each parameter x_i:
   - I_i is a fuzzy set of the parameter x_i with the membership function $h_{I_{i(j)}} = G_{(i,j)}$, while supp (set carrier)

contains the indices of all parameters that depend on the parameter x_i;

   - J_i is a fuzzy set *k* of the parameter x_i with the membership function $h_{J_{i(j)}} = G_{(i,j)}$, while supp (set carrier)

contains the indices of all parameters that depend on the parameter x_i;

3. construction of a fuzzy set T_i, T, P_i^{**}, E_i:
   - $T_i = I_i \bigcup J_i$ .... unification of sets;
   - $P_i^* = I_i \times J_i$ .... cartesian product;
   - $P_i^{**} \subseteq T_i \times T_i$ .... reflective function;
   - $E_i = P_i^* \bigcap P_i^{**}$ .... intersection of sets.
4. calculation of R_i, which is the weight of the parameter x_i in terms of its importance in the system, according to the relation:

$$d(R_i) = d(P_i^*) + d(P_i^{**}) - d(E_i). \tag{1}$$

5. arrange the parameters according to the calculated evaluation.

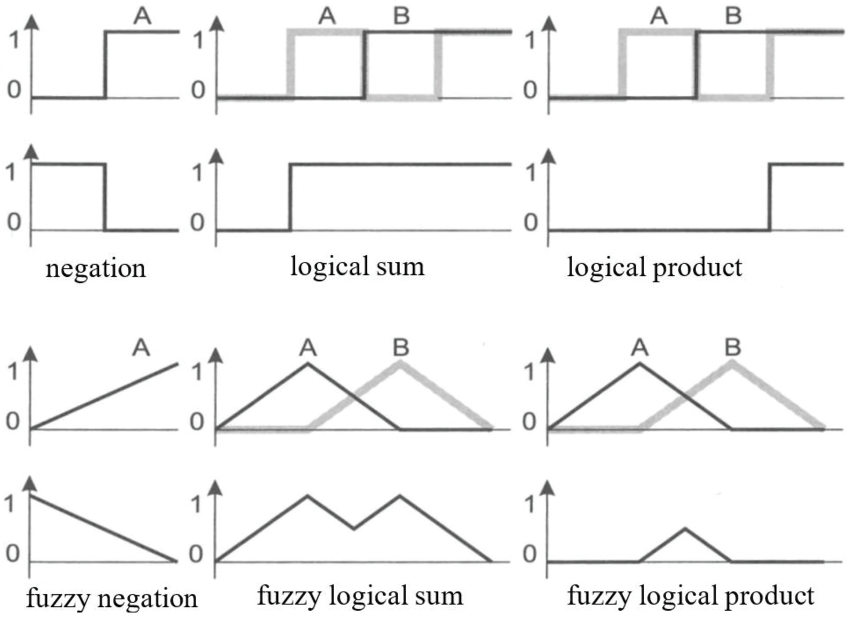

Fig. 2 Standard and fuzzy logic operations

3. Current State of Combustion Engine Diagnostics

Currently used methods of combustion engine diagnostics can be dividend as follows:

Power measurement methods

In practice, we indirectly obtain information about the mechanical power of a combustion engine, which expresses the amount of work per unit time, during a rotary movement, e.g. at a dynamometer. The rotating parts transmit effective power, which is determined from the relationship $P = M \cdot \omega = M \cdot 2\pi n$, where M [Nm] is the torque, ω [rad·s^{-1}] is the angular velocity, n [min^{-1}] is the speed. The torque can be determined from the relationship $M = F \cdot r = I \cdot \varepsilon$, where F [N] is the force acting on the strain gauge, r [m] is the distance of the axis of rotation from the dynamometer to the force field F, I [kg·m^2] is the moment of inertia, and ε [rad·s^{-2}] is the angular acceleration. Power brakes are usually used for power measurement. The name brake originates from the fact that a braking torque, the magnitude of which we know or can measure accurately, acts against the measured unknown torque.

Methods of sensing mean thermodynamic quantities

Appropriate information on the technical condition of an engine can be obtained by indicating the thermal circulation, which, however, places relatively high demands on the measuring technique used and the entire diagnostic process. Operationally sufficient information can be obtained by measuring the mean thermodynamic quantities, i.e. by measuring the temperatures and pressures sensed during steady engine operation. These are the five basic quantities, namely the measurement of mean pressure and temperature without fuel supply and with fuel supply, mean pressure and exhaust gas temperature, mean pressure and air temperature at the engine inlet, intake manifold and gases leaving the engine. Based on the size of the measured quantities, it is possible to judge the technical condition using the mean indicated pressure, the thermal load of the engine, resistance in the intake or exhaust, heating of the intake air. The advantage of these methods is the possibility of using simple sensors. Tests and practice have shown that the exhaust gas temperature and intake manifold pressure have great information value.

Gas sensing methods

One of the most important variables in the diagnostics of the technical condition of combustion engines is the tightness of the combustion chamber, which massively affects the performance and economic parameters of the engine. To determine the tightness of the combustion chamber, it is generally possible to use direct or indirect methods of pressure sensing, or the evaluation of the pressure value at the end of the compression stroke. The direct pressure sensing method has a very good resolution and allows the location of leaks. The disadvantage is the need for openings in the individual combustion chambers and the relatively difficult placement of pressure sensors. The method of indirect pressure sensing consists in measuring the deformations of selected engine parts. The disadvantage is the relatively less accurate determination of pressure. Furthermore, methods based on the irreversibility of work during compression and expansion due to cylinder leakage can be used. The implementation of this method consists in rotating the engine by an electric starter with the fuel supply switched off. The difference between compression and expansion work is measured based on the starter's power input. Another method uses the air pressure that is supplied to the combustion chamber at a defined crankshaft position, with the engine not running. Leaks are determined based on the amount of air escaping from the combustion chamber. The last method used to determine the size of a combustion engine leak is to determine the amount of gas that penetrates the crankcase. Volumetric flow meters or orifices are used for the measurement. The disadvantage of this method is the fact that it is not possible to determine the leaks of individual cylinders, but only the entire engine.

Vibroacoustic methods

During the operation of the engine, its individual parts are loaded by variable forces, which cause the oscillation of these components. In addition to variable forces, oscillations are also caused by impulses caused by the mutual movement of surfaces of different roughness, deviations of the geometric shape, imperfect machining, etc. During use, the components wear out by various mechanisms, their dimensions, shape, morphology change and the clearances increase. This changes the vibration parameters (deflection, speed, acceleration, frequency), also the acoustic signal changes (sound pressure level, etc.), or spectral analysis of noise is used. Vibration and acoustic methods make it possible to diagnose piston clearance in the cylinder, valve clearance, function of injection units, bearing wear [3], etc.

Tribotechnical methods

The technical condition of a combustion engine is, among other things, characterized by the condition and changes in the oil filling. These are, for example, the concentration and type of impurities in the oil, changes in its physical and chemical properties, increasing consumption, etc. Tribotechnical methods are very common, generally divided into simple (operational), standardized and special methods. Various principles are used, e.g. magnetic and electromagnetic, inductive, resistive, methods based on high-frequency field energy absorption, emission and absorption spectral analysis methods, polarographic and infrared spectrometry methods, X-ray and fluorescence analysis methods, methods based on specific properties of radionuclides and filtration, optical and densitometric methods, etc. The advantage of these methods is currently the fact that selected methods of tribodiagnostics are automated, do not require sampling, and information about the oil level appears on the vehicle display, in the service information system, etc. The disadvantage is the need for sophisticated equipment to perform more complex tribodiagnostic measurements that requires methodical sampling of the oil filling.

EOBD (European On Board Diagnostics)

EOBD is a set of standards, e.g. J1939 ISO 27145 (WWH OBD), J2403, etc., which include diagnostics of engine control units; it has been in force since 2000 and the world's carmakers have switched to it first for petrol and later for diesel engines. EOBD functions that are fixed by the standard include vehicle identification, reading of the fault memory, erasing of the fault memory, Freeze Frame, measured values including graphs, control of λ-probes, etc. The basic idea of the EOBD was to prevent an increase in pollutants in the exhaust gases of vehicles due to a malfunctioning or defective engine component. Because direct measurement of pollutants in the exhaust gases (CO, HC, Nox, particulate matter) is not possible while driving, a diagnostic system has been developed to monitor all components involved in the composition of the exhaust gases. The EOBD system has many functions, such as diagnosing the above components, using a standardized socket, visual warning to the driver in the event of a fault, catalytic converter protection, fault storage, fault display, use of standardized fault codes, display of fault conditions, determining when a failure affects the composition of emissions, the use of standardized marking of components, systems, and defects. Fig. 3 shows an example of a possible connection of individual components of the EOBD system.

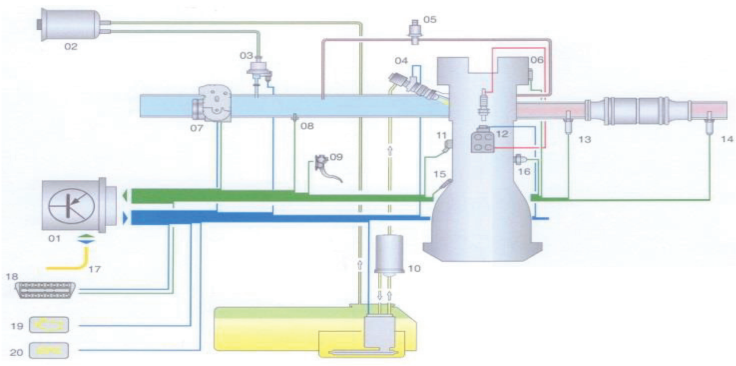

Fig. 3 Possible connection of individual components of the EOBD system. *01* – engine control unit; *02* – canister with activated carbon; *03* – activated carbon canister solenoid valve; *04* – injection valves of the cylinders 1 to 4; *05* – exhaust gas recirculation solenoid valve; *06* – camshaft position sensor; *07* – throttle control unit; *08* – intake air pressure and temperature sensor; *09* – accelerator pedal position sensor; *10* – fuel filter; *11* – knock sensor; *12* – static high-voltage distribution; *13* – Lambda probe in front of the catalytic converter; *14* – Lambda probe behind the catalytic converter; *15* – engine speed sensor; *16* – coolant temperature sensor; *17* – CAN data line; *18* – diagnostic socket, *19* – light; *20* – accelerator pedal warning light.

Small change method

The mathematical method of small changes is used to minimize the number of measured diagnostic quantities. Phenomena and processes that depend on a larger number of quantities and can be described by equations can be analyzed in order to reduce the number of measured diagnostic quantities. The mathematical method of small changes is based on determining the effect of changes in individual measured parameters on the resulting quantity. The result is the elimination of quantities that prove to be insignificant, while only quantities that significantly affect the result are considered. If the quantities x and y characterizing a certain process are given and if they are bound by the functional dependence $y=f(x)$ and if $x = x_0$ and $y = y_0$ apply to the initial zero point then the increment Δx of the argument x corresponds to the increment Δy of the function y, which can be - assuming that it is a continuous function - decomposed by Taylor series. After calculations that are outside the scope of this text, we obtain the so-called gain coefficients, details e.g. in [1]. Based on these factors, it is possible to select quantities that have a decisive influence on the change of the function y. These quantities are then preferably used in diagnostics.

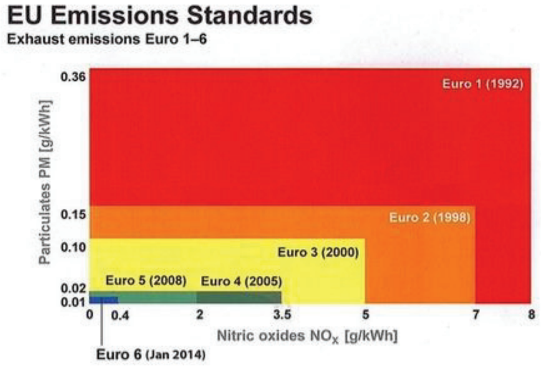

Fig. 4 Development of EURO emission regulations for diesel engines (nitrogen oxides and particulate matter)

4. Conclusions

In general, diesel engines are a more economical and in some respects more environmentally friendly propulsion variant for several reasons: for example, higher efficiency due to higher compression ratio and higher ignition temperature, high injection pressures, lower pump losses (unrestricted intake of air, therefore the power is controlled only by the amount of diesel injected). The operational advantages of diesel engines are due to the high traction at low and medium speeds and the advantageous operation especially for partial loads. Another advantage of diesel engines is that up to 20% more energy is stored in diesel than in petrol, it has a higher density and a higher calorific value. Modern diesel engines with selective catalytic reduction systems have even lower CO_2 emissions (despite the European anti-diesel campaign), relatively low nitrogen oxides and low particulate matter, Fig. 4 [10].

In the paper, the authors present selected methods of diagnostics of diesel power units, which commonly determine the mechanical condition of the engine (control unit test, automatic fault test, turbocharger condition, start of fuel injection, compression test, crankshaft and camshaft synchronization check, etc.). These methods present different possibilities for obtaining information about the current state of the drive unit and detecting possible faults.

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Condition for Selecting the Type of Divergence Maneuver of a Vessel with Two Targets

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Abstract

In a close quarter situation of a vessel with two targets at locally-independent control over divergence of ships the selection condition of type of the divergence maneuver depending on initial relative position and parameters of movement of a vessel and targets has been described. The article determines the possibility of application of three types of maneuver of a ship divergence with two targets and use of corresponding unacceptable values of parameters.
KEY WORDS: *navigational safety, divergence process, locally-independent control, domains limit of invalid data of parameters, divergence with two targets*

1. Introduction

The imperfect procedure for identification of a dangerous approach situation, as well as lack of an operational decision-making method for selection of safe manoeuvre, to a great extent determine high risk of collision between approaching ships. This problem is especially actual at navigation of a vessel in congested waters when situations of dangerous approach of a vessel with two targets appear, thus in such situations application of various types of divergence manoeuvre is possible.

The problem of a choice of non-contradictory structure of binary coordination system of interaction of pair of ships in a dangerous approach situation is considered in detail in article [1], and in article [2] formalization of interaction of ships in case of situational disturbances of various types is performed.

Article [3] deals with a way of forming flexible divergence strategies depending on the level of situational disturbances, taking into account significant factors. Article [4] deals with autonomous ship collision avoidance system and requirements for autonomous navigation. It states that classical or computer based approaches can be used to investigate issues for automating ship control. The situation of excessive vessels convergence is considered in [5] and an emergency divergence strategy is proposed.

As noted in [6-8], due to the fact that the vessel motion control process is multidimensional with nonlinear and non-stationary characteristics, the problem of choosing the optimal manoeuvre of divergence is very complex; moreover, it has an inherent game character.

Article [9] deals with the problem of providing a safe divergence of ships using domain limits of ship courses or speeds, and article [10] shows the application of domains limit of invalid data of ship motion parameters to a divergence with two dangerous targets.

2. Research

The purpose of this article is to consider three types of ship divergence manoeuvre with two targets and the condition of choosing a particular type of divergence manoeuvre depending on the initial convergence situation.

In a situation where a vessel is dangerously approaching two targets, its safe divergence from them is possible by three basic manoeuvres: a single evasion of both targets, two successive evasions from each target, and evasion of one target followed by braking to prevent collision with the second target. The first type of manoeuvre is the most preferred and the last is the least preferred. Consider the condition of choosing one of these types of divergence manoeuvres, taking into account their proposed preference priority. The first parameter Q affecting the choice of divergence type is sufficient safe water space in the manoeuvring area, with $Q = 1$ if there is sufficient safe water space and $Q = 0$ if not. Therefore when $Q = 1$ the first and second divergence manoeuvres can be used, as there is no limit on vessel evasion, and when $Q = 0$ the third manoeuvre should definitely be used. To determine the divergence manoeuvre at $Q = 1$, the second parameter $\Delta K_y^{(1)}$, which is the maximum value of the divergence course increment at the first type of divergence manoeuvre, is introduced. If the divergence by the first type of manoeuvre requires a course change by the value of ΔK_y, then this manoeuvre is performed in the case of $\Delta K_y < \Delta K_y^{(1)}$. Otherwise the divergence is performed by the second type of manoeuvre.

By denoting the type of manoeuvre to be chosen by M_n, and considering the aforementioned, the selection condition can be formalised as follows:

$$M_n = \begin{cases} 1, \text{ if } Q=1, \Delta K_y < \Delta K_y^{(1)} \\ 2, \text{ if } Q=1, \Delta K_y \geq \Delta K_y^{(1)} \\ 3, \text{ if } Q=0 \end{cases}. \quad (1)$$

If the first type of divergence manoeuvre is selected, the limit safe courses of the ship in relation to the first target are determined using the domains limit of invalid data of parameters of ship movement $\Omega_d^{(c,1)}$, the formation of which is shown in article [11]. Similarly, the formation of domains limit of vessel movement parameters $\Omega_d^{(c,2)}$ when the vessel approaches the second target is performed.

As an example for a given approach situation, Fig. 1 shows the domains $\Omega_d^{(c,1)}$ and $\Omega_d^{(c,2)}$, from which it follows that the ship is dangerously close to both targets. Therefore, to diverge safely from both targets, the ship must turn either to the right to course $K_{1y} = 118\,°$ or to the left to course $K_{1y} = 58\,°$ (Fig. 1). In this case, the point (K_{1y}, V_1) is on the limit of one of the domains.

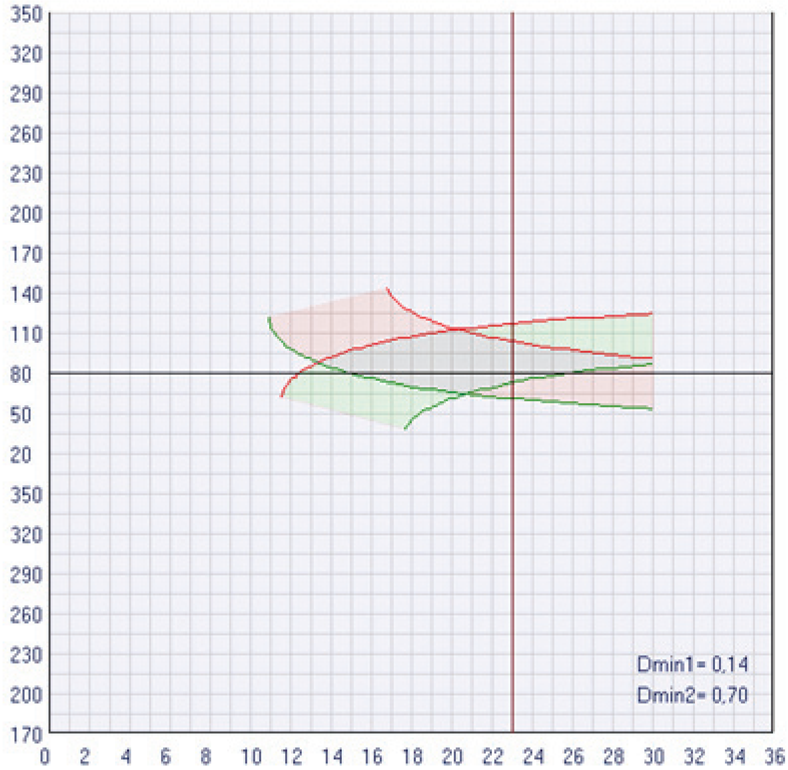

Fig. 1 Domains $\Omega_d^{(c,1)}$ and $\Omega_d^{(c,2)}$ in situations of dangerous approach

In case of vessel divergence, the second type of manoeuvre forms the domain $\nabla_{K1,K2}$, by which the divergence manoeuvre is selected. As an example, the situation of dangerous approach is selected with parameters: $K_c = 52°$, $V_c = 23$ knots, $K_1 = 255°$, $V_1 = 21$ knots, $K_2 = 178°$, $V_2 = 20$ knots, $\alpha_1 = 60°$, $D_1 = 3$ miles, $\alpha_2 = 20°$, $D_2 = 5$ miles and $D_d = 1$ mile.

The domain limit $\nabla_{K1,K2}$ shown in Fig. 2 has been calculated by a computer program for this situation. If one selects an arbitrary point on the limit, as shown in Fig. 2 and "clicks" on it, the program displays course values and turn times. The relative safe divergence trajectories of the ship from each of the targets are shown in Fig. 3.

If the third type of divergence manoeuvre is selected, the domain $\nabla_{K1,V2}$ of permissible combined manoeuvres is formed and used to select the divergence manoeuvre. As an example, we consider the situation of a dangerous approach of a vessel to two targets with the following parameters:

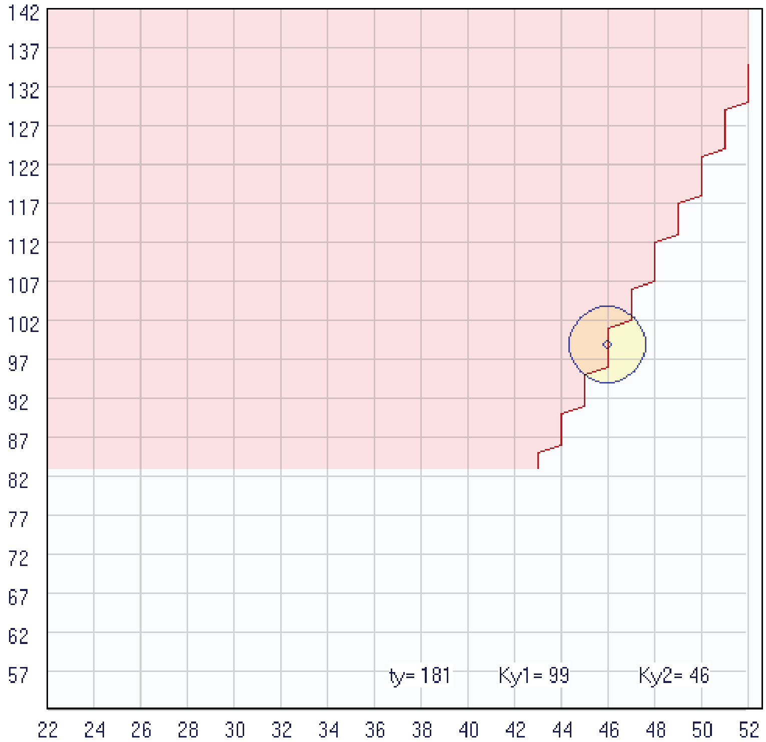

Fig. 2 Selecting an arbitrary domain limit point $\nabla_{K1,K2}$

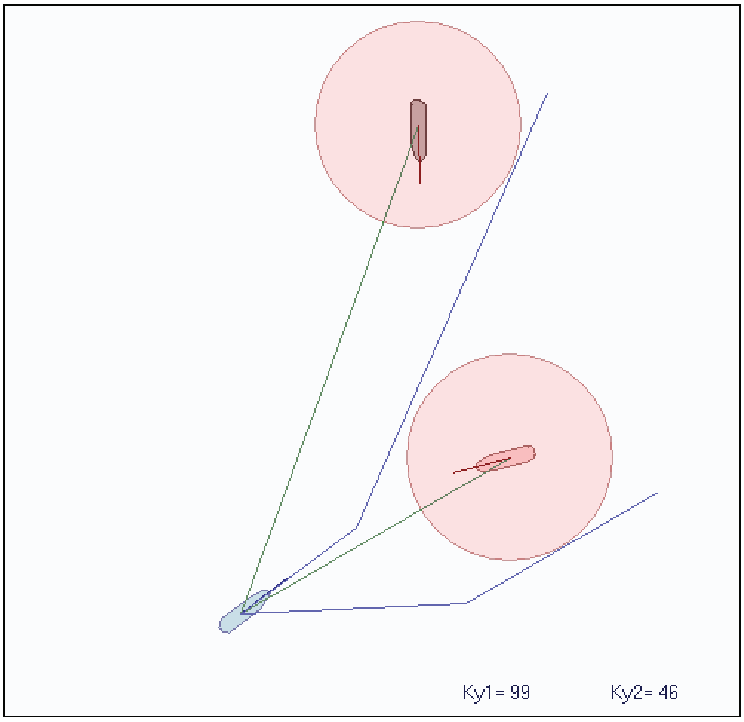

Fig. 3 Relative safe divergence trajectories of the vessel

$K_c = 80°$, $V_c = 23$ knots, $K_1 = 190°$, $V_1 = 20$ knots, $K_2 = 10°$, $V_2 = 21$ knots.

The relative position of the ship and targets is characterised by bearings $\alpha_1 = 40°$, $\alpha_2 = 135°$, $D_1 = 3$ miles and $D_2 = 5$ miles.

For this situation, a domain $\nabla_{K1,V2}$ of permissible combined manoeuvres was formed to evade the ship to the right, the limit of which is shown in Fig. 4. In the same figure, a combined right deviation manoeuvre of 100° course is selected which corresponds to a passive braking speed of 12.8 knots, with braking commencing at 335 of manoeuvre

(Fig. 4). Fig. 5 shows the relative safe divergence trajectories of a vessel at the closest approach distance of 1 mile.

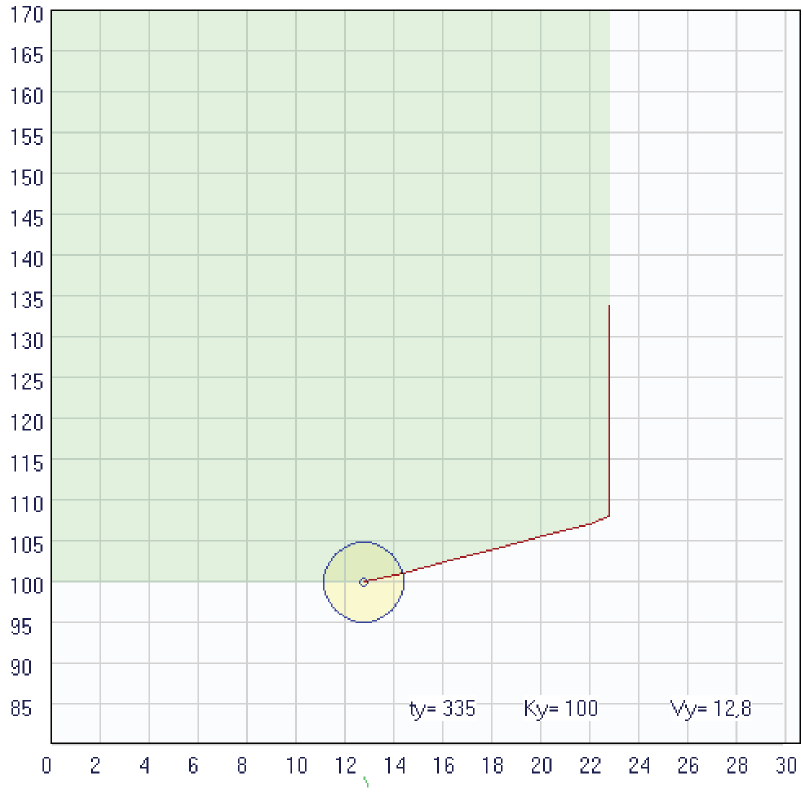

Fig. 4 Domain $\nabla_{K1,V2}$ of combined evasive manoeuvres to the right

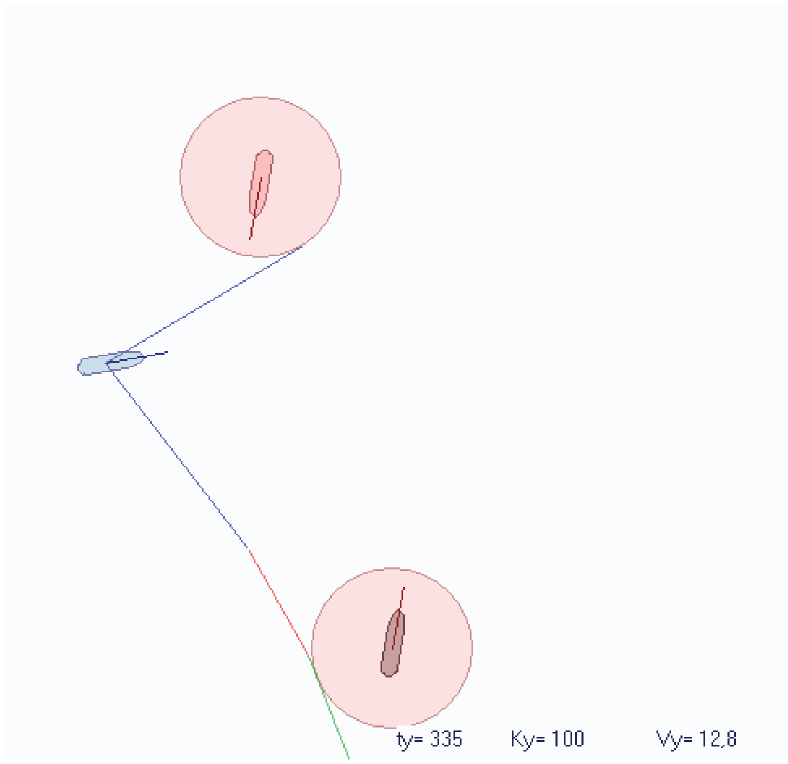

Fig. 5 Relative safe trajectories of the ship to target divergence

3. Conclusions

Three types of two-target ship divergence manoeuvre are considered, using changes in ship's course and decreasing ship's speed.

A condition for selecting a particular type of divergence manoeuvre is obtained, taking into account sufficiency of safe water space and allowable change of evasive course.

Application examples of considered divergence manoeuvres with two targets are given.

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The Practice of the Remote Sensors Data Management Informational System Creating

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Abstract

The article describes the experience of building an information system for collecting and processing data from remote sensors. The system is implemented as a local SCADA [0] shell that does not have direct access to the Internet. The specificity of the organization of a local system that provides storage, visualization and processing of data from a certain set of external sensors is considered. Both the general architecture of the system and its modules are described, which provide a local graphical user interface, asynchronous data collection, visualization, notifications about reaching unacceptable values by the sensor, and processing of sensor data. The structure of interaction of the system with an external WEB-site through the implementation of the REST API [2] is shown. The issues of software emulation of sensors and risk management were also touched upon.
KEY WORDS: *space environmental simulation, spacecraft testing, SCADA, time series, asynchronous data processing, Python, ModBus protocol, JavaScript visualization, WEB REST API*

1. Introduction

The task of certification of microcircuits used in the space industry has always been relevant. To allow a node to be used in a spacecraft, any node used must be tested for its ability to operate under conditions of large temperature differences, space radiation, possible high vibrations, pressures and vacuum [3]. To confirm the compliance of microcircuits with all the declared requirements in the European Space Agency (ESA), several testing centers are used. However, the development of nodes can take place in any of the European countries and therefore sometimes it takes a lot of time to obtain certification.

As a solution to this problem, it was proposed to implement remote access to the certification center's sensor system during tests. This will reduce the time and financial costs of the certification process. There will no longer be a need to send a responsible employee to the certification center on a long business trip along with the tested node.

This article describes the theory and practice of creating a local SCADA system that provides remote access to a system of sensors that receive environmental values and characteristics of the node itself during testing for compliance with the stated requirements.

Despite the fact that during testing, various sensors receive values of different indicators: temperature, vibration level, radiation, etc., but from the point of view of the monitoring system, each sensor provides a data stream with a certain frequency. This allows us to abstract from the specifics of the tests and create a system of a general type that simply works with time series of different lengths.

2. Main System Functionality

The resulting system provides the minimum required set of functions that allows you to receive, store and process sensor data. The system has the ability to receive data from both real and software-emulated sensors.

The system has the ability to work in conditions of inaccessibility of the Internet. A fully local mode of operation will ensure the impossibility of remote hacking of the server. Additional security procedures are also provided: authorization for user access, periodic backups of all data and real-time error notification.

An embedded SQLite [4] database was used to store the internal data of the system. The graphical interface subsystem provides rich opportunities for interactive visualization of sensor data both in real time and in historical data graphs. In addition, a notification subsystem has been implemented, which notifies the responsible personnel if the sensor value exceeds a certain threshold value during a certain number of measurements.

3. Architecture of the Created Solution

The complete architecture of the system being created is shown in

Fig. 1. The system is built as a set of related software nodes. This approach allows, if necessary, to change only its individual parts, and not change the entire system as a whole.

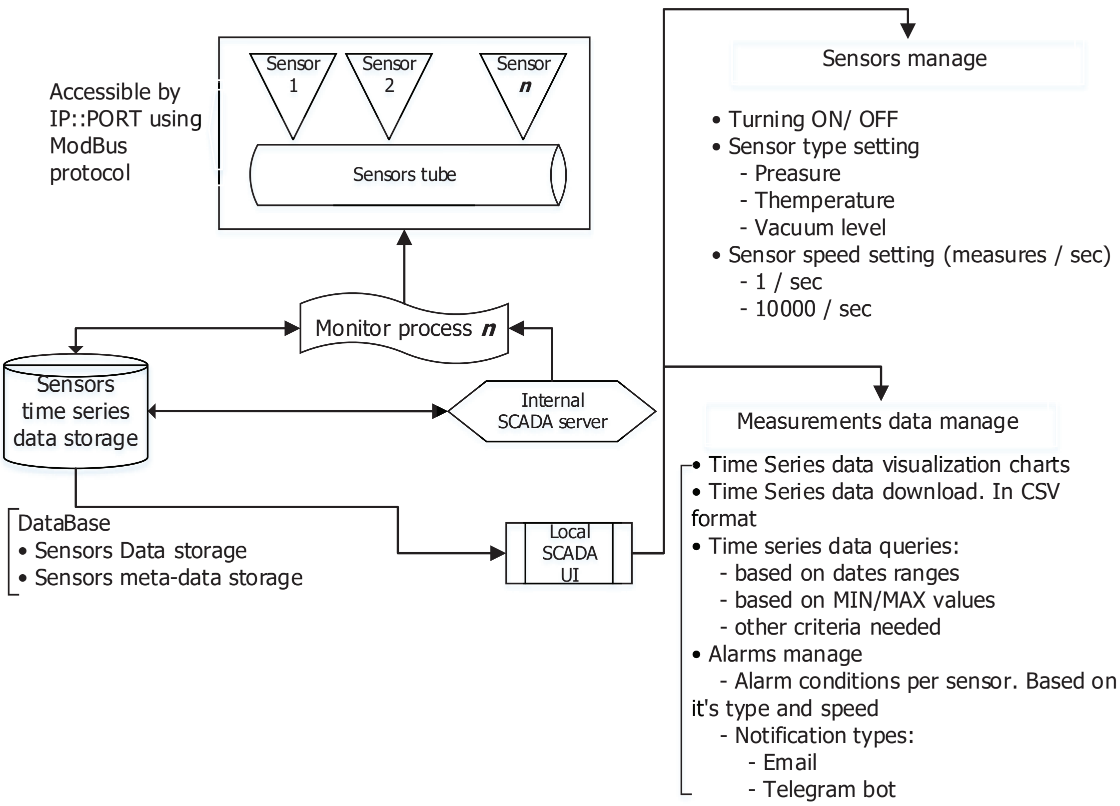

Fig. 1 General structure of the created solution

Each of the subsystems is implemented using its own set of technologies. Sensors are not part of the system, but are used as some kind of data providers available at a specific address. A certain interaction is possible with them, they can be turned on / off or the value of the current measurement can be requested. Also, the system has an internal storage of sensor metadata, where data such as its text name, description, address, current activity status and some others are stored.

The database for storing sensor values is not a development created within the framework of this project, a third-party storage was used, only a software interface was implemented to work with it. This approach allows, if necessary, it is relatively easy to change the storage type to another.

The local SCADA interface is the main graphical interface that allows you to work with the system. It is the main entry point for most of the functionality provided.

4. Sensor Data Storage Systems

There are several of the most popular time series data storage engines. Some of them are open source products, and some are commercial solutions. The systems are quite different in terms of their functionality, therefore, in order to choose the best one within the framework of the current project, it is necessary to compare and evaluate the capabilities of the most popular solutions.

Basic requirements for the sensor data storage system:

- Ability to provide high recording speed;
- Availability of query capabilities for data sampling by several criteria simultaneously (minimum: Time range + device identifier);
- Availability of Python interface;
- Popularity among Data Science specialists, who working with Time Series will be an advantage;
- Availability of Open Source version will be an advantage;
- The presence of the WEB REST API is not required at the moment, but it may be requested in the future.

Each of the systems listed in the list was evaluated according to the main criteria that are important specifically for the system being developed. The comparison results are shown in Table 1. Based on specifications compassion table, InfluxDB [4] was selected as data storage engine to be used in project.

To store internal meta-information, the local SCADA system uses a SQLite database. At the moment, it stores data about sensors and alerts. The data schema is shown in
Fig. *2*.

Each sensor measurement data is presented in a simple structure containing only the sensor id, measurement value and time stamp.

Table 1

Comparison of characteristics of time series storage systems

	Recording speed	Query language	Python interface	Popular in DS	Has Opens Source version	REST API available	Total
InfluxDB	7	8	9	10	1	1	**36**
Arctic	8	7	8	8	1	0	**32**
TimescaleDB	7	9	7	9	1	1	**34**
Prometheus	9	6	6	7	1	0	**29**

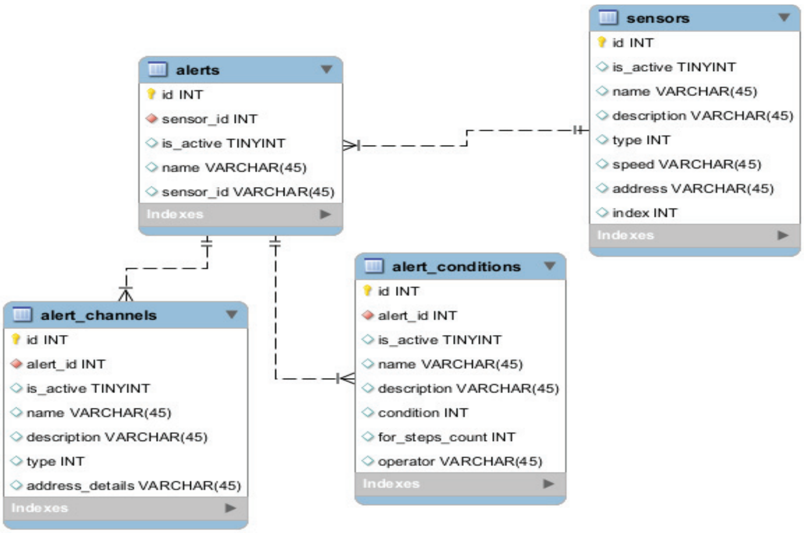

Fig. 2 Local data schema

5. Final System

The main part of the system's functionality is managing sensors and alerts. The sensor is supplying data. Alerts indicate that the current sensor values have exceeded the preset limit levels.

On the sensor settings page, it is possible to set its name, a small text description, address and immediately activate or deactivate its monitoring.

If sensor monitoring is started, then a graph of its current values for the last minute is available (Fig. *3*, a). It is also possible to display a graph of sensor values over a longer period (Fig. *3*, b).

a b

Fig. 3 Sensor values charts

In addition to displaying data in the form of a graph, it is possible to save it from a CSV file for further analysis by other means. CSV format is a universal text format for storing structured tabular data. Most modern software tools for working with data have the ability to import data from files of this format.

As shown in the data diagram in

Fig. *2*, each sensor can have a large number of alerts connected to it. Each alert has its own triggering condition, its own range of analyzed data and its own triggering interval.

Each alert has its own activation settings (Fig. 4). The settings consist of a threshold level and a condition. Additionally, notifications have channels of notification about exceeding the threshold level. At the moment, only two notification channels have been implemented: *Email* and *Telegram* channel.

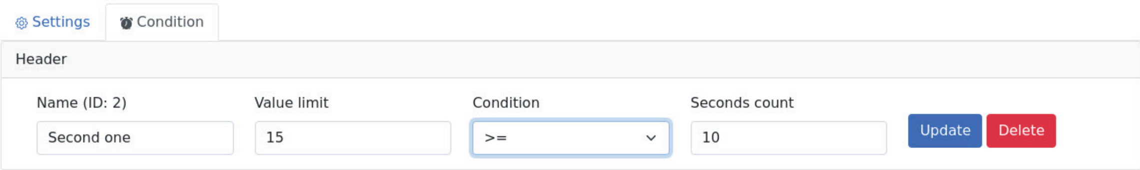

Fig. 4 Controlling alert conditions

Table of risk levels taken directly from standard ESA documentation (Table 2). Main criteria of system quality it's providing access to archived and real-time sensors data. System should have ability to not get *Catastrophic* and *Critical* incidents at all.

Table 2

Used risk levels

Score	Severity	Example of problem
5	Catastrophic	Losing all data collected.
4	Critical	More than one day of system unavailability.
3	Major	1. Less than one day of system unavailability. 2. Real time data not collecting.
2	Significant	Real time data may not available.
1	Negligible	Minimal or no impact (minor problems that not affects to sensors data collecting).

The system has a notification channel for all incidents that happen in the system. It's realized as follows:

- Email **and** Telegram bot about *Catastrophic* and *Critical* level errors.
- Email **or** Telegram channel to notify about lower level errors in real-time.
- Possible other notifications channels may be added if needed (like SMS).

6. Conclusions

The article describes the experience of implementing a non-standard SCADA system that provides maintenance of the certification system for hardware nodes for working in space. Due to the presence of special requirements, none of the existing OpenSource systems could provide the entire set of required functionality, so our own system was implemented. The solution architecture is based on open technologies and solutions, and is not based on any proprietary product. The resulting system provides monitoring and control of sensors, and also provides the ability to organize alerts when they exceed preset limit values.

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Computer Vision Based Sensor System for Autonomous Vehicles

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Abstract

This study is devoted to solving the perceived problem of autonomous transport systems by Convolutional Neural Network(CNN) application. The goal of this paper is to develop a functional software based sensor to detect and recognize objects in real-time, as well as estimate the speed of the detected vehicle using the solo camera as a sensor. This paper aims at evaluating the workability of this sensor in different weather conditions for autonomous vehicle applications. This sensor can be applied for different levels of abstraction like road safety, autonomous drone navigation, a guiding system for the disabled, animal survey, surveillance to name a few.
KEY WORDS: *autonomous vehicles, CNN, object recognition, speed estimation, computer vision*

1. Introduction

There has been significant increase in research in the field of autonomous vehicles. Artificial intelligence and automation go hand-in-hand in the field of automation in recent past. Computer vision systems are the basis of Advanced Driver Assistance Systems (ADAS) and autonomous vehicle technology and various sensors act as eyes and ears of autonomous vehicles

The machine learning based applications that run an autonomous car's infotainment system the information is received from the sensor fusion systems and predictions are made accordingly. The neural network based algorithms in these systems can integrate the driver's gesture, speech recognition, and language translation in the car's infotainment system. Despite such advancement in the autonomous technology, as per a survey on Tesla (leading autonomous vehicle manufacturer), one of the main fundamental challenges for autonomous cars to be out on our roads are sensors and their inputs. The goal of this paper is to develop an algorithm and software for a computer vision-based sensor to detect and recognize objects in sight, measure its distance and speed of movement.

In existing systems the detection and speed estimation are being determined by different sensors for example, camera along with Convolutional Neural Network(CNN) detects object and LIDARs are used for speed estimation. The novelty of this thesis is developing a model of sensor system which will not make use of any external physical sensors like LIDAR, radar but is solely dependent on CNN and camera input to detect object and its speed. There are several recent works for object detection and recognition in real time. In the work of Oltean et al. [1] real time vehicle counting using Tiny YOLO for detection and fast motion estimation for tracking by considering the region of interest.

Do et al. [2](2021) proposes a system for vehicle speed estimation by tracking taillights of vehicles during night time using You Only Look Once as the backbone algorithm. With the use of Kalman filter, the algorithm can achieve high level speed estimation accuracy by calculating distance between two taillights. In the work El Bouziady et al. [3] propose a novel system for vehicle speed estimation from videos captured from urban traffics. Using a combination of the SIFT and KLT algorithms a precision of 0.87 and a recall of 0.92 for license plate detection is achieved. Vehicle speeds were estimated with an average error of 0.59 km/h, staying inside the +2/-3 km/h limit.

The work Gorobetz et al. [4] (2018) proposes a CNN based algorithm to solve the problem of trains passing through red lights to decrease the dangerous level. The system structure is based on embedded device with artificial intelligence. Four main tasks were implemented for better results namely railway traffic light recognition, red signal recognition, decision to brake and generate signal to locomotive's transmission and braking system.

A novel and effective method based on convolutional neural networks was used to achieve high-quality and real-time vehicle detection, as well as their speed using solo camera as the sensor. The proposed system in this study is stationary (i.e. it is independent and doesn't move with reference to the moving object) and hence, can be calibrated after the installation. All this makes it enough to use camera as the only sensor.

2. Problem Formulation

The goal of the current research is to develop a simulation model of a sensor that is able to recognize objects in sight and determine their motion parameters using a convolutional neural network in real time to improve road safety.

Following tasks are defined and solved:
1. To define the structure of the improved simulation model;
2. To develop a model for object recognition using CNN;

3. To develop a model for speed estimation using CNN;
4. To develop the computer model and simulation of sensor and analysis of data;
5. Implementation of the simulation model to test expected experimental results.

3. Development of System Structure & Mathematical Model for CV based Sensor System

There are four main steps for the operation of autonomous vehicles namely perception and localization using IoT technologies [7], planning and control of electric motor and electric drive [8]. Computer vision and sensor fusion together form perception. This work solves not only the problem of perception and object detection and recognition in real time, but also the task of determining the motion parameters of the recognized object. In-order-to solve this problem a system structure with supporting mathematical model and algorithm was developed. In general a working system has two parts, hardware and the software. The hardware part of the simulation sensor consists of camera, processing unit (computer or embedded system), wireless transmissionmodule to send out the data.

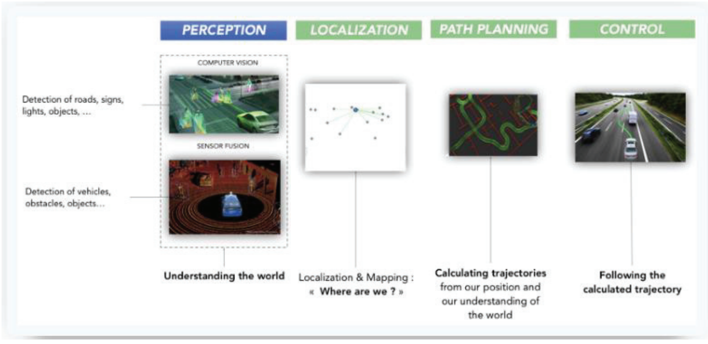

Fig. 1 Working of Autonomous vehicle [5]

The software part consists of Convolutional Neural Network. The functions of the software part are to capture video, process frames, detect objects and estimate speed.

The simulation system structure consists of the following units as shown in Fig. 2:

1. Capturing of an object by the camera;
2. Sensor system simulation;
3. Object detection using CNN with training;
4. Distance measurement of objects with reference to frames by point object tracking;
5. Speed estimation using consecutive frames;
6. Transmission of output;
7. Display of results with bounding boxes around detected objects and speed of the vehicle.

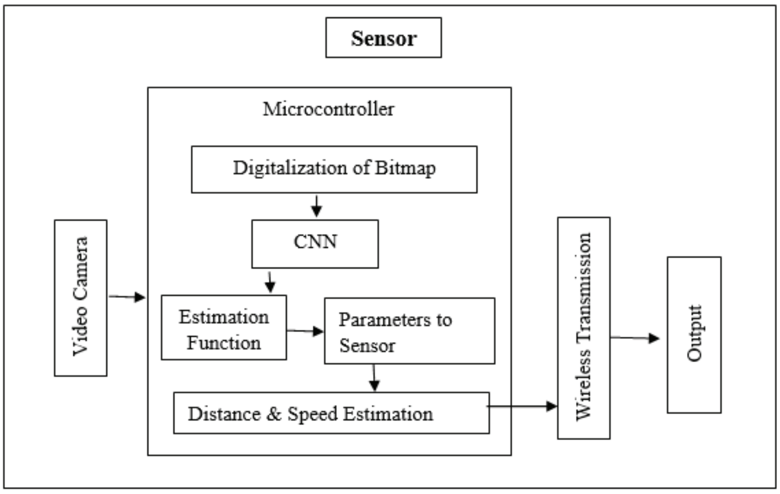

Fig. 2 Sensor System Structure

Developed object-oriented mathematical model of the computer-vision based sensor consists of the following components:

1. Digitalization of bitmap image

$BM = DF(CAM) = (p_1 , p_2, \dots , p_n)$ is a image obtained from the camera CAM and digitalized by function DF, represents as a set of bitmap pixels, where:

– $n = w \cdot h$, w – width of BM, px; h – height of BM, px;

- each pixel $p \in BM$ contains:
  - $x_p = 1..\ w \in \mathbb{N} = \{0,1,2,...\}$ X-axis coordinate in BM;
  - $y_p = 1..\ h \in \mathbb{N} = \{0,1,2,...\}$ Y-axis coordinate in BM;
  - $c_p = CCS$ – color code structure, that depends on the type of color: single value for grayscale, 3-tuple for RGB or HSL, 4-tuple for CMYK.

2. Detection algorithm of bitmap image

$U = DET(BM) = (u_1, u_2, \ldots, u_k)$ – set of objects detected by the detection algorithm DET using input image BM, where:

- $k = 0..\ max \in \mathbb{Z}$;
- each $u \in U$ described by:
  - $TY_u \in \{ty_1,...,ty_m\}$ – type of the object *u*, that belongs to the predefined class of objects ty_i, and ty_1 is a class of vehicles;
  - $x_u = 1..\ w \in \mathbb{N} = \{0,1,2,...\}$ – localization of the detected object u in the BM by the X-axis;
  - $y_u = 1..\ h \in \mathbb{N} = \{0,1,2,...\}$ – localization of the detected object u in the BM by the Y-axis.

3. Estimation function

$VH = EST\left(U \middle| \forall u \in U \,\&\, TY_u = ty_1\right)$ – set of parameters of the detected vehicles U calculated by the estimation function *EST*,

- $\forall vh \in VH$, $vh = <lat, lon, d, v, r>$, where

lat – geographical latitude of the vehicle, deg; *lon* – geographical longitude of the vehicle, deg; *d* – horizontal distance from the sensor to the vehicle, m; *v* – speed of the vehicle, km/h; *r* – course, i.e. motion direction, deg.

4. Parameters for sensor

- $SET = \{lat_0, lon_0, h_0, r_0, CAL\}$, - settings of the sensor, where

lat_0 – latitude of the sensor position obtained by GNSS; lon_0 – latitude of the sensor position obtained by GNSS; h_0 – sensor position above the ground, m; r_0 – orientation (direction) of the sensor, deg

- $CAL = \{<x^1_{cal}, y^1_{cal}, d^1_{cal}>, \ldots, <x^q cal, y^q_{cal}, d^q_{cal}>\}$ – calibration parameter
  - x^i_{cal} – X coordinate of the predefined calibration point *i* at BM;
  - y^i_{cal} – Y coordinate of the predefined point i at BM;
  - d^i_{cal} – distance to the predefined point in meters.

4. Implementation & Results

Expected experimental results:

1. Simulated sensor system is expected to detect and recognize pedestrians, animals, sign boards, etc on road.
2. Sensor system is expected to detect the cars and trams and their measured speed is displayed above the individual object boxes. Object detection algorithm was applied to basic GPU configuration (Lenovo G50-70, Intel® HD Graphics 4400, Intel i3-4030U, Webcam 720p or 0.3M, OS Linux) and satisfactory results were obtained which can be a main leverage for hardware installations. The system's software is developed using Ubuntu OS which can be a great advantage to be used in most of embedded computers.

4.1. Object Detection Results

A series of experiment was conducted to arrive at the desired results. The developed algorithm was tested for its efficiency and accuracy in both real and synthetic data. To realize the real-time detection, both webcam detection and real-time video feed experiments were conducted.

Analysis: Fig. 3 shows the results obtained for real-time object detection. Few sample images available on google were tested to ensure the workability of the algorithm. Algorithm was able to detect pedestrian, bicycle along with the rider, multiple cars from the video that was captured outside the university campus (Kipsala bridge).

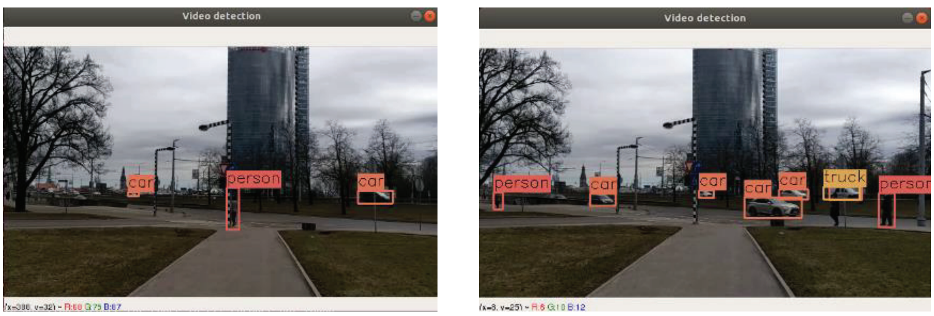

Fig. 3 Object detection results

4.2. Synthetic Data Results

To check the functionality of the algorithm in different weather conditions, fog filter and night filters were added to the video captured outside university campus and algorithm was put to test. The fog filter was applied to the image in an increasing scale of 10% to 90% and tested. The algorithm was able to detect objects with certainty till 70% as shown in Fig. 4 of fog filter application and failed to detect objects after that.

Fig. 4 Object detection with fog filter = 50%(left) and 70%(right)

Similar to fog filter, one more filter to create night effects was applied. The results obtained are shown in Fig. 5 where a pedestrian and few vehicles near to camera are detected. the algorithm failed to detect objects after 60% of filter application.

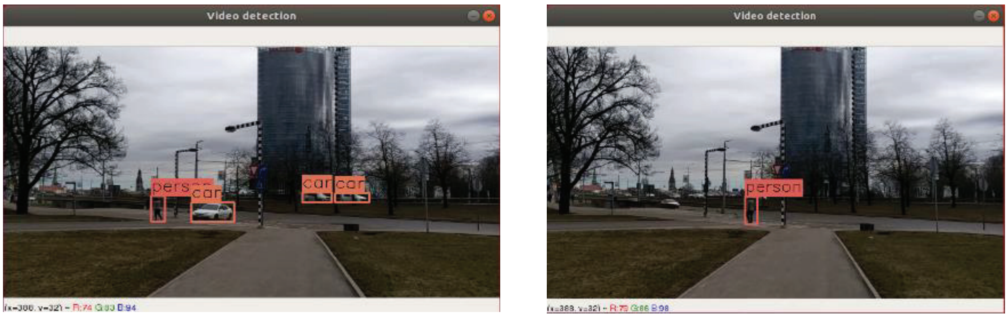

Fig. 5 Object detection with night filter=50%(left) and 60%(right)

4.3. Speed Estimation Results

Two different experiments were conducted for obtaining speed estimation results. Tracking of objects was one of the main subtasks needed to be achieved in-order-to achieve the speed estimation. Speed estimation is calculated by using the distance of the object from the camera within a defined Region of Interest(ROI). In this paper the defined region of interest was around (3x4) meter and the defined ROI was around 2 meters away from camera.

The following steps are adopted for speed estimation of vehicle:

1. Sensor preparation and input of video;
2. Region of Interest (ROI), vehicle attributes are initialized;
3. Pre processing of frames takes place by convolution neural network;
4. ROI is extracted;
5. Object detection using algorithm;
6. Now if objects like animals or humans are detected then algorithm creates bounding boxes and displays results;
7. If vehicles are detected, tracking ID is generated;
8. Distance calculation of the tracked vehicles takes place;
9. Consecutive frames of same vehicles are updated and difference between the points and time is calculated;
10. Speed is estimated using formula, $speed = \frac{distance}{time}$.

Distance Calculation

The pre-requisite for speed calculation is distance measurement. Measuring the distance on the road with the help of installed camera and images is a whole different task. To calculate distance, angle-of-view formula is been adopted from where a method for distance calculation is been proposed. The graphical view of the distance calculation is shown in Fig. 6 and Fig. 7.

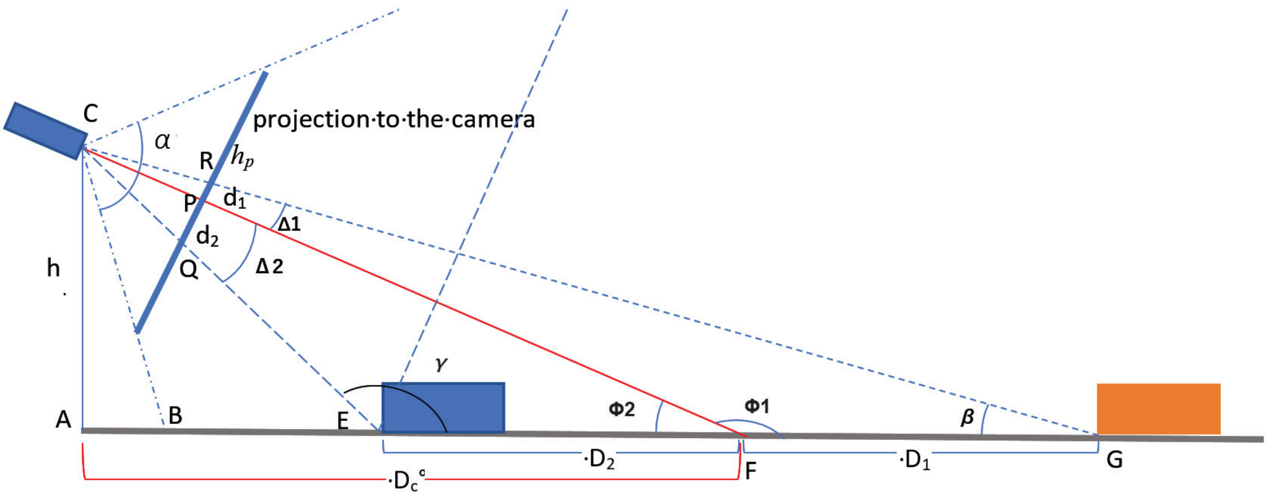

Fig. 6 Geometry for distance calculation. 2D side view [6]. Where h – vertical location of the camera, m; D_c – calibrated distance to the center point, m; h_p – vertical size of the picture, px; α – view angle of the camera; d_1 – distance in the projection to the vehicle 1 from the center, px; d_2 – distance in the projection to the vehicle 2 from the center, px.

Calculation of D1 and D2:

$CF = \sqrt{h^2 + D_c^2}$ – distance from camera center line to the road (red line), m;

$CP = \frac{h_p}{2} tan\left(\frac{\alpha}{2}\right)$ – part of red line from camera eye to the picture frame, px.

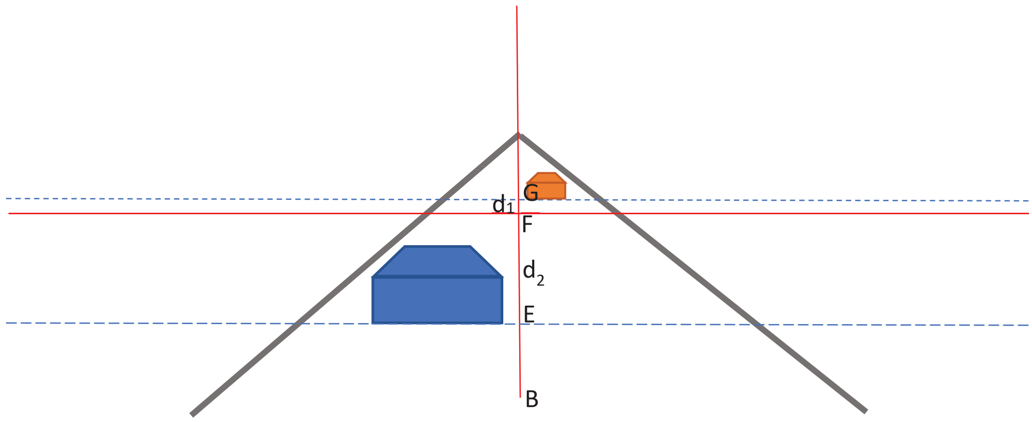

Fig. 7 Geometry for distance calculation. 3D frontal view from camera

$\Delta 2 = \arctan(d_2/CP)$ – angle between dashed line of vehicle2 projection and red line;
$\varphi 2 = \arcsin(h/CF)$ – angle between red line and the road;
$\gamma = (180 - \varphi 2 - \Delta 2)$ – angle between dashed line and the road (within the triangle CEF);
$\varphi 1 = (180 - \varphi 2)$; $\Delta 1 = \arctan(d1/CP)$;
$\beta = (180 - \varphi 1 - \Delta 1)$ – angle between dashed line and the road (within the triangle CFG);
By sine theorem $D_2/\sin(\Delta 2) = CF/\sin(\gamma)$, $D_1/\sin(\Delta 1) = CF/\sin(\beta)$:

$$D_2 = CF \cdot \sin(\Delta 2)/\sin(\gamma), \text{ m}; \quad (1)$$

$$D_1 = CF \cdot \sin(\Delta 1)/\sin(\beta), \text{ m}. \quad (2)$$

The distances to vehicle1 (AG) and vehicle2 (AE) will be: $AG = D_c + D_1$; $AE = D_c - D_2$.

Taking practical application of the simulated sensor into consideration, a video was taken from the bridge 6-7 meters above ground, same height as where physical sensor would be installed on street lamps. Fig. 8 shows results of speed estimation of car which is inside defined ROI(left) and speed estimation of cars outside defined ROI(right).

Fig. 8 Speed estimation within ROI(left), outside ROI(right)

5. Conclusions

The algorithm and model of speed estimation using only images can be used for intelligent transport system for autonomous driving. The algorithm and software of computer vision based sensor assures that physical sensor for speed estimation and distance calculation can be eliminated.

The developed algorithm is able to detect objects in an image with a 70% fog filter applied with certainty but fails to detect beyond 70%.

The developed algorithm is able to track vehicles and estimate speed with a 60% night filter applied with certainty but fails to detect beyond 60%.

Object detection algorithm was applied to basic GPU configuration and satisfactory results were obtained which can be the main leverage for hardware installations.

The simulated model of object recognition with speed estimation is intended to reduce road accidents by using the sensor as a means of safety device. The developed sensor is intended to be used in a guidance system for disabled people, aerial surveys and in self-navigation systems of UAVs and safety devices for the disabled.

Acknowledgement

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Model Design of the Life Cycle Cost Analysis for the Acquisition of a Motor Vehicle

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Abstract

The article focuses on the possibilities of using the proposed model for life cycle cost (LCC) analysis when purchasing a new motor vehicle. It defines the initial requirements and principles necessary to create a life cycle cost model for motor vehicles. The article specifies in detail the criteria on which this LCC model is based. The introductory part of the article defines the essential life cycle costs of a motor vehicle, including the factors that have an impact on the modelling of these costs. The final part of the article presents an example of the proposed model for purchasing (selecting) a new motor vehicle in terms of life cycle costs.
KEY WORDS: *life cycle costs of motor vehicles, costs of purchasing a motor vehicle, operating costs, preventive maintenance costs, corrective maintenance costs.*

1. Introduction

Currently, it is required to ensure the reliability of the vehicle and to keep the life cycle costs to a minimum. At the same time, vehicles must perform their function safely without undue impact on the environment and road traffic The decision to purchase a vehicle is not affected only by the initial (purchase) costs but also by the expected operating and maintenance costs throughout the life of the vehicle (ownership costs) and the costs of the settlement (disposal). Vehicle suppliers could then optimize and evaluate different operation, maintenance and settlement strategies according to the model.

Life cycle cost analysis is a process of economic analysis to assess the total cost of purchase, ownership and settlement (disposal) of a product. It can be used throughout the whole life cycle or in some parts or combinations of different life cycle stages [1, 2]. LCC analysis is used to determine which product is more advantageous in terms of LCC. The article presents in detail the LCC model, which is intended for the customer, not only when deciding on the purchase of a new motor vehicle but also for the retrospective calculation of the ownership costs of an already purchased motor vehicle. Furthermore, the LCC model can be used to determine the optimal service life of a motor vehicle.

2. Model Design for the Life Cycle Analysis of a Motor Vehicle for Economic Benefit Assessment

The model for evaluating the economic viability of products is based on the general LCC model which is based on acquisition and ownership costs 2, 3:

$$LCC = C_P + C_{OW}, \tag{1}$$

where LCC – motor vehicle life cycle cost; C_P – acquisition cost; C_{OW} – ownership costs.

Acquisition cost (C_P) is represented by the purchase price at the time of acquisition of the assessed motor vehicle. Although it is not necessary to deal with it in more detail, we must not forget the warranty costs for motor vehicles, which are sold with a warranty for quality (nowadays this is quite typical). Warranty costs include free corrective maintenance. However, this absence of charges is only apparent, as the seller includes warranty costs in the selling price. On the contrary, the costs of ownership (C_{OW}) will be the subject of a more thorough analysis.

Ownership cost (C_{OW}) is significant during the life cycle of a motor vehicle and varies according to the type of the motor vehicle. This cost includes the costs of use, improvement and decommissioning (disposal) and can be defined as follows 4:

$$C_{OW} = C_U + C_E + C_D, \tag{2}$$

where C_U – cost of use; C_E – improvement cost; C_D – decommissioning (disposal) cost.

The cost of using a motor vehicle (C_U) can be defined as follows:

$$C_U = C_O + C_{OMC} + C_{OMP}, \tag{3}$$

where C_O – operation cost; C_{OMC} – corrective maintenance cost; C_{OMP} – preventive maintenance cost.

The cost of use (C_U) may include the operating and maintenance costs which consist of the corrective maintenance cost (C_{OMC}) and the cost of preventive maintenance (C_{OMP}) of a motor vehicle 5.

Due to the defined purpose of the model for life cycle cost analysis, when selecting a motor vehicle during purchase, improvement costs (C_E) and settlement costs (C_D) will not be included in the calculation model. The settlement costs can also be in the nature of income. This stated income occurs either in the case of recycling, sale or re-use of the product.

If we itemize or insert the individual cost categories into the general LCC model (1), it is possible to express the purpose model by the following relation 6:

$$LCC = C_P + C_O + C_{OM} + C_E + C_D \, , \tag{4}$$

then the following relation applies to said model:

$$LCC = C_P + C_O + C_{OM} \, . \tag{5}$$

In order to evaluate the economic viability of the products, it is not unconditionally necessary to work with all the above-mentioned cost categories. This means that it is sufficient to include in the resulting LCC model (1) for the evaluation of the economic viability of products only those cost categories whose amount is directly affected by the technical sophistication of the product and its level of reliability. The amount of unaccounted costs (cost items) does not affect the LCC analysis and does not affect the reliability of the motor vehicle.

The resulting model does not represent the complete life cycle costs but exclusively the purposefully selected parts of the LCC, which are used for the LCC analysis when comparing the acquisition of a new motor vehicle. This means that the resulting model represents the comparative life cycle costs and can be used to compare the economic benefits of different product variants. The model is rational when comparing motor vehicles only if it is true that motor vehicles of the same types (classes, groups) are compared. It is advisable to consider the proposed model as an example and not as a universal one that can be used for all cases of product acquisition.

2.1. Characteristics of Selected Life Cycle Costs for LCC Analysis

The following costs were included in the selected costs of the proposed model for the analysis of life cycle costs for the acquisition of a new motor vehicle.

1. Acquisition costs (C_P) are the selling price of a motor vehicle which is known at the time of evaluation (selection). The following costs are included in this category 11, 6,

$$C_P = C_{CD} + C_{DD} + C_M + C_S + C_G \, , \tag{6}$$

where C_{CD} – conception and requirements definition costs; C_{DD} – vehicle design and development costs; C_M – manufacturing costs; C_S – cost of sales; C_G – cost of repairs during the guarantee period.

2. Operating costs C_O cover the cost of fuel C_F, operating fluids, oils and lubricants C_{OL} that are supplied during vehicle operation (not during service inspection), tyres C_T, accumulator batteries C_{AB}, vehicle insurance fee and road tax or other mandatory fees C_{IRT}, cost of the motorway tax sticker C_{MT}, mandatory vehicle inspection and emission measurement in special vehicles C_{ETC}, cost of the preparation and training of operators C_{PT}, vehicle superstructure cost C_{VB}. The costs are calculated according to 1:

$$C_O = C_F + C_{OL} + C_T + C_{AB} + C_{IRT} + C_{MT} + C_{ETC} + C_{PT} + C_{VB} \, . \tag{7}$$

a) Fuel costs (C_F) are affected by the average consumption of a given type of motor vehicle. Then the comparative fuel costs (C_F) can be expressed by the relation 1:

$$C_F = \frac{\bar{c}_{aF}}{100} p_F t_l \, , \tag{8}$$

where C_F – total fuel costs (EUR), $\bar{c}_{aF}$ – average fuel consumption (l/100 km), p_F – fuel price (EUR/l), t_l – service life of a motor vehicle (km).

b) Costs for operating fluids, oils and lubricants (C_{OL}) are any costs for operating fluids, oils and lubricants that are replenished during operation and not during service maintenance; it can be expressed by the relation 1:

$$C_{OL} = \frac{\bar{c}_{aOL}}{100} p_{OL} t_l \, , \tag{9}$$

where $\overline{c}_{aOL}$ – average consumption of oil and lubricant (l/100 km); p_{OL} – price of oil and lubricant (EUR/l).

c) The cost of tires (C_T) can be expressed by the relation 1:

$$C_T = \frac{t_l}{\overline{d}_{aT}} n_T p_T , \tag{10}$$

where $\overline{d}_{aT}$ – average life of a motor vehicle tyre (km), n_T – number of tyres on the motor vehicle (pc), p_T – price of one piece of tyre (EUR).

d) Accumulator battery costs (C_{AB}) – can be expressed by the relation 1:

$$C_{AB} = \frac{t_l}{\overline{d}_{aAB}} n_{AB} p_{AB} , \tag{11}$$

where $\overline{d}_{aB}$ – average life of one accumulator battery (km); n_{AB} – number of accumulator batteries in the motor vehicle (pc); p_{AB} – price of an accumulator battery (EUR).

e) Costs arising from laws (C_{IRT}) are the costs of motor vehicle insurance (compulsory liability, accident insurance, or other). Some of them can be omitted in case of the same costs due to the simplification of the model. Otherwise, they can be expressed by the relation 1:

$$C_{IRT} = \left(C_{SI} + C_{AI} + C_{RT} + C_R\right) t_{la} , \tag{12}$$

where C_{SI} – price of mandatory annual insurance of a motor vehicle (EUR); C_{AI} – price of the annual accident insurance of a motor vehicle (EUR); C_{RT} – price of annual road tax (EUR); C_R – price of statutory fee (EUR); t_{la} – operating time of the motor vehicle until decommissioning (years).

f) The cost of obtaining a motorway sticker (C_{MT}) may be omitted if the same type of motor vehicle is compared. Otherwise, the cost of a motorway sticker (C_{MT}) can be expressed by the relation:

$$C_{MT} = c_{MT} t_{la} , \tag{13}$$

where c_{MT} – price of annual motorway sticker for a motor vehicle (EUR).

g) The costs of the mandatory vehicle inspection and emission measurement (C_{ETC}) include the costs incurred for the measurement of emissions of the drive engine unit (C_E) and for the technical inspection of the motor vehicle (C_{TC}). For the proposed model, the costs of the mandatory technical inspections and emission measurements can be expressed by the relation:

$$C_{ETC} = \left(C_E + C_{TC}\right) \frac{y_n}{t_{la}} , \tag{14}$$

where C_E – costs related to the measurement of motor vehicle emissions (EUR); C_{TC} – costs of mandatory technical inspection (EUR); y_n – number of years of legal validity of emission measurement and technical condition for the given type of motor vehicle (years).

h) The costs of preparation and training of operators (C_{PT}) are, for example, the costs of driving school or, for special vehicles, the costs of crew training, etc.; but these costs can be omitted for the purpose of evaluating comparable passenger cars.

i) The cost of superstructure of a motor vehicle (C_{VB}) is the cost of a special-purpose superstructure for special vehicles. The costs without a special-purpose superstructure are not included in the LCC for the analysis of motor vehicles acquisition.

2.2. Maintenance Cost of a Motor Vehicle

The total costs for vehicle maintenance consist of the cost of preventive maintenance and the cost of corrective maintenance 1,1, 6:

$$C_{OM} = C_{OMC} + C_{OMP} . \tag{15}$$

Vehicle maintenance costs include the cost of material and the cost of labour:

$$C_{OM} = \left(C_{OMCM} + C_{OMCL} + C_{OMCF}\right) + \left(C_{OMPM} + C_{OMPL} + C_{OMPF}\right) , \tag{16}$$

where C_{OM} – cumulative maintenance costs; C_{OMC} – corrective maintenance costs; C_{OMP} – preventive maintenance costs; C_{OMCM} – costs of material used for corrective maintenance; C_{OMCL} – costs of labour force for corrective maintenance; C_{OMCF} – costs of workshop equipment used for corrective maintenance; C_{OMPM} – costs of material used for preventive maintenance; C_{OMPL} – costs of labour force for preventive maintenance; C_{OMPF} – costs of workshop equipment used for preventive maintenance.

a) Corrective maintenance costs (C_{OMC}) comprise all costs related to the identification of the causes of failures and the elimination of their consequences. This includes in particular the costs of:

- materials consumed during corrective maintenance;
- work spent on corrective maintenance;
- workshop equipment, training of maintenance specialists.

Corrective maintenance costs (C_{OMC}) can be divided into:

I. corrective maintenance of motor vehicles that are sold without a warranty of quality (C_{OMC^*}),
II. corrective maintenance of motor vehicles that are sold with a warranty of quality ($C_{OMC^{**}}$).

ad I.) The corrective maintenance without a warranty of quality (C_{OMC^*}) includes costs that are apparent from the relation for the comparative costs of corrective maintenance [8]. Then the corrective maintenance costs without a warranty of quality can be expressed by the relation:

$$C_{OMC^*} = \frac{t_l}{MTBF}\left(\bar{c}_m + \bar{c}_{le}\right). \quad (17)$$

Further, $\bar{c}_{le}$ can be calculated according to the following relation:

$$\bar{c}_{le} = \bar{c}_p \bar{t}_{pc}. \quad (18)$$

After substituting into Eq. (17), corrective maintenance without a warranty of quality is calculated as:

$$C_{OMC^*} = \frac{t_l}{MTBF}\left(\bar{c}_m + \left(\bar{c}_p \bar{t}_{pc}\right)\right), \quad (19)$$

where $MTBF$ – mean time of operation between failures (km); $\bar{c}_m$ – average cost of material for repairing a failure (EUR); $\bar{c}_{le}$ – average cost of labour and workshop equipment used for repairing a failure (EUR); $\bar{c}_p$ – average hourly cost of labour and workshop equipment used for maintenance (EUR/hour); $\bar{t}_{pc}$ – mean time of labour-intensity for repairing a failure (hours).

ad II.) Corrective maintenance with a warranty of quality ($C_{OMC^{**}}$) are the costs of corrective maintenance, including the costs of corrective maintenance with a warranty of quality (warranty service). This is a completely standard offer when buying a new motor vehicle. This means that during the warranty period, the seller undertakes to carry out corrective maintenance free of charge. However, this absence of charges is only apparent, as the seller includes warranty costs in the selling price. The comparative costs of the corrective maintenance with the warranty of quality ($C_{OMC^{**}}$) for motor vehicles can be expressed by the relation:

$$C_{OMC^{**}} = \frac{t_l - t_g}{MTBF}\left(\bar{c}_m + \left(\bar{c}_p \bar{t}_{pc}\right)\right), \quad (20)$$

where t_g – guarantee period (km) 8.

b) Preventive maintenance costs (C_{OMP}) are costs that include all costs associated with preventive maintenance performed to reduce degradation and mitigate the likelihood of failure. At present, preventive maintenance is performed at predetermined time intervals (according to the manufacturer's preventive maintenance program) or when a specified number of kilometres are not covered before the next service maintenance, depending on the time. In practice, for passenger cars, it is usually 1 or 2 years, depending on the use of engine oil. This mainly includes the cost of 9:

- material consumed during preventive maintenance;
- work spent on preventive maintenance;
- workshop equipment, training of preventive maintenance specialists.

Preventive maintenance costs (C_{OMP}) can be divided into:

I. preventive maintenance of motor vehicles sold without warranty service (C_{OMP^*});
II. preventive maintenance of motor vehicles sold with warranty service ($C_{OMP^{**}}$).

ad I.) The costs of preventive maintenance without warranty service (C_{OMP^*}) can be expressed by the relation:

$$C_{OMP^*} = \frac{t_l}{MTBM_p}\left(C_{OMPM} + \bar{c}_p \bar{t}_{pm}\right), \quad (21)$$

where $MTBM_p$ – mean operating time between preventive maintenances (km); C_{OMPM} – costs of material used for preventive maintenance (EUR); $\overline{c}_p$ – average hourly cost of labour and workshop equipment used for maintenance (EUR/hour); $\overline{t}_{pm}$ – mean time of labour-intensity per one preventive maintenance (hour) 10.

ad II.) The costs of preventive maintenance with warranty service ($C_{OMP^{**}}$) can be expressed by the relation:

ad III.)

$$C_{OMP^{**}} = \frac{t_l - t_g}{MTBM_p}\left(C_{OMPM} + \overline{c}_p \overline{t}_{pm}\right). \tag{22}$$

3. Costs of improving a motor vehicle (*C_E*) are the costs of upgrading, modifying and innovating motor vehicles. For the purposes of the LCC analysis, which is used to determine the order in which motor vehicles are acquired, these costs are not taken into account.

4. The costs of decommissioning motor vehicles (*C_D*) are the costs associated with the disposal of these vehicles. This item can be an income in the case of the sale of a motor vehicle before the end of its life. In most cases, there is a fee for disposing of motor vehicles. For some equipment, disposal is already included in the purchase price. For the purposes of the LCC analysis, which is used to determine the order in which motor vehicles are acquired, these costs are not taken into account.

2.3. Design of a Model for the Analysis of Selected Life Cycle Costs of a Passenger Motor Vehicle

The model for performing an analysis of selected life cycle costs for the purchase of a new motor vehicle with a warranty of quality is based on the basic relation (4). We will not count the costs of improvement (C_E) and the costs of the decommissioning phase (C_D) for the mentioned model due to the calculations of costs that are unnecessary for the analysis. Then the model can be expressed as follows:

$$LCC = C_P + C_O + C_{OM}\,. \tag{23}$$

Then, the following equations (6), (8), (9), (10), (11), (12), (14), (20) and (22) are substituted into the given relation, and the selected costs can be calculated for individual motor vehicles acquired. The resulting model for calculating the selected LCC costs has the following form:

$$LCC_{ch} = C_p + \frac{\overline{c}_{aF}}{100} p_F t_l + \frac{\overline{c}_{aOL}}{100} p_{OL} t_l + \frac{t_l}{\overline{d}_{aT}} n_T p_T + \frac{t_l}{\overline{d}_{aAB}} n_{AB} p_{AB} + C_{SI} t_{la} + \left(C_E + C_{TC}\right)\frac{y_n}{t_{la}} + \frac{t_l - t_g}{MTBF}\left(\overline{c}_m + \left(\overline{c}_p \overline{t}_{pc}\right)\right) + \frac{t_l - t_g}{MTBM_p}\left(C_{OMPM} + \overline{c}_p \overline{t}_{pm}\right) \tag{24}$$

In this way, the cumulative costs for each passenger motor vehicle are calculated. Since the passenger motor vehicles may have a different service life t_l which is expressed in kilometres, it is recommended to convert this relation to specific costs which are related to one kilometre of use. The selected LCC_{Sch} life cycle specific costs can be expressed by the following relation:

$$LCC_{S_{ch}} = \frac{LCC_{ch}}{t_l}\,. \tag{25}$$

3. Example of a Model for Analysis of Selected Costs of the Life Cycle of Passenger Motor Vehicles

This chapter presents the results of LCC analysis when buying a new passenger car. Five different types of passenger cars from different manufacturers were used to calculate the selected LCC indicators. They were Škoda Kamiq 1.0 TSI 85 kW Style, Kia Stonic 1,0 T-GDi 120k Premium, Hyundai Kona 1.0 Comfort Pe, Dacia Duster 1,3 TCe 110kW/150 k S&S 4x2 and Renault Capture Intens TCe 100. In the calculations, the motor vehicles were marked with the numbers 1 to 5 without exact specification. Table 1 shows the following input data.

From the input values given in Table, the selected cumulative life cycle costs of five types of passenger motor vehicles were calculated. For this calculation, the proposed model with the output formula (24) was used; according to this formula, calculations were performed and Fig. 1 was constructed. Subsequently, from the relation (25), the selected specific life cycle costs of passenger motor vehicles were calculated; they are expressed in Fig. 2.

The above LCC analysis (Fig. 1), which we propose to use when making a decision to buy a new passenger car, shows that the vehicles have approximately the same purchase price. In the example shown, the difference in the purchase price of vehicles is up to 5%. The biggest difference is in the operating costs, which are caused by average consumption, and other operating costs, which are determined according to the relationship (7 – 14). Minor differences between the motor vehicles compared are in the costs of preventive and corrective maintenance, which have been calculated according to the relationship (15 – 22). When buying a new car, we would choose vehicle number 1, which has the lowest life cycle costs.

Table

Basic input data to the LCC model for selected motor vehicles

Input data	Type of vehicle				
	1	2	3	4	5
Purchase price of car C_p (EUR)	18376	18372	18567	18179	18952
Selected life time of cars t_l (km/years)	250000 10	250000 10	250000 10	250000 10	250000 10
Mean time between failures *MTBF* (km)	32000	35000	33000	25000	25000
Average cost of material for repairing a failure $\overline{c}_m$ (EUR)	329	286	387	317	418
Average hourly cost of labour and workshop equipment used for maintenance $\overline{c}_p$ (EUR/hour)	36	35	38	29	29
Mean time of labour-intensity for repairing a failure $\overline{t}_{pc}$ (hour)	3.5	4	4	4	4
Preventive maintenance interval $MTBM_p$ (km/years)	30000/2	15000/1	15000/1	20000/1	20000/1
Material cost for preventive maintenance C_{OMPM} (EUR)	300	219	217	217	286
Mean time of labour-intensity for preventive maintenance $\overline{t}_{pm}$ (hour)	1.5	1.35	1.25	1.3	1.3

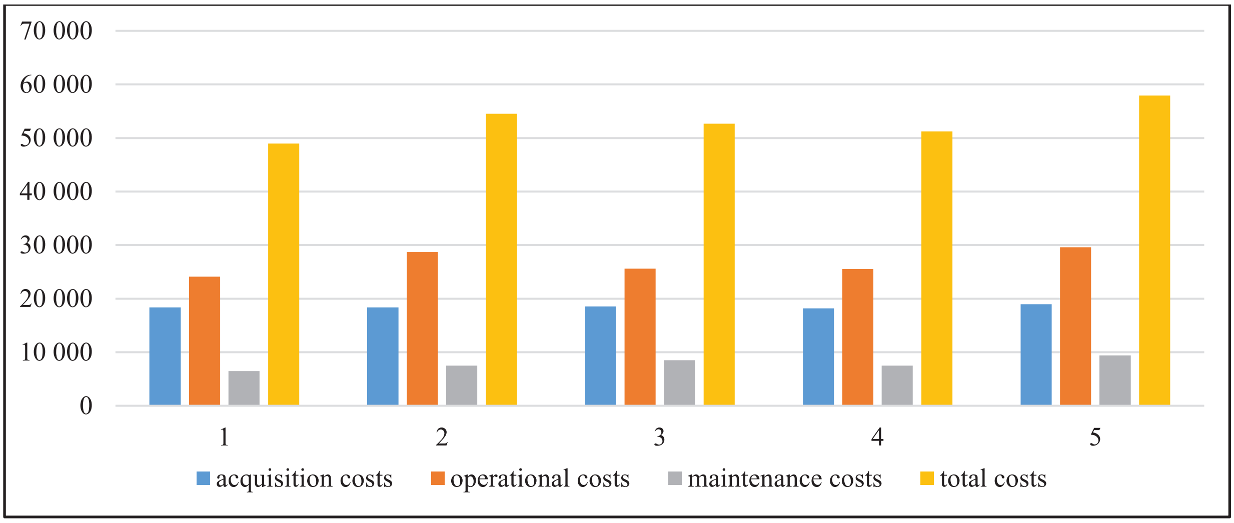

Fig. 1 Selected cumulative life cycle costs of five passenger motor vehicles expressed in (EUR)

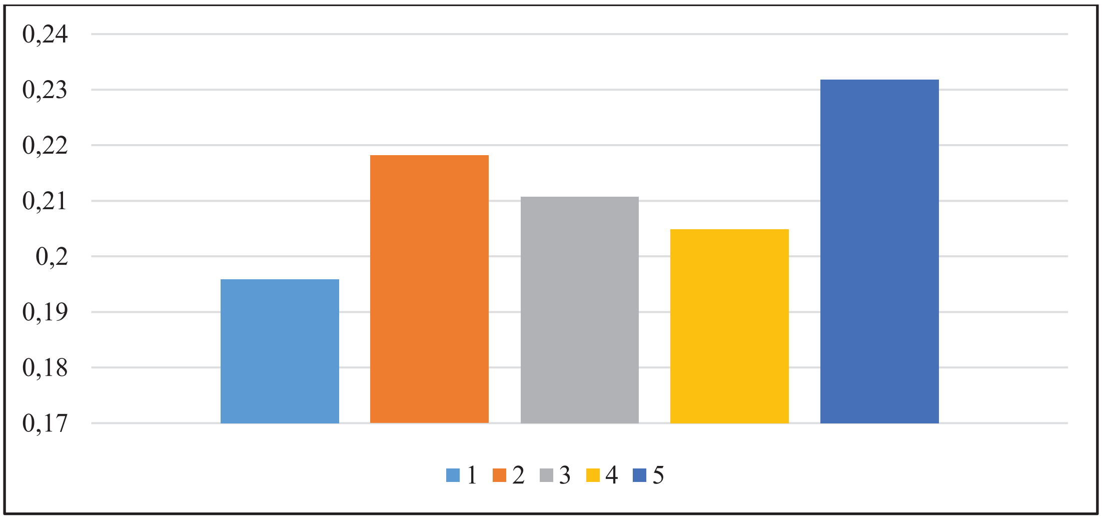

Fig. 2 Selected specific life cycle costs of five motor vehicles expressed in (EUR / km)

To confirm the previous statement, Fig. 2 was created, which expresses the specific costs that are spent per one kilometre of operation of individual vehicles. Even in this case, vehicle number 1 has the lowest specific costs which are related to one kilometre of operation. On the contrary, the highest specific costs are spent on operating vehicle number 5.

Based on the calculation of the proposed LCC model, the general assumption that ownership costs reach up to 70% of the total life cycle costs was confirmed. In our calculations, this value ranged from 62 to 67%. Fig. 3 shows an example for vehicle number 1, where this value was 62%.

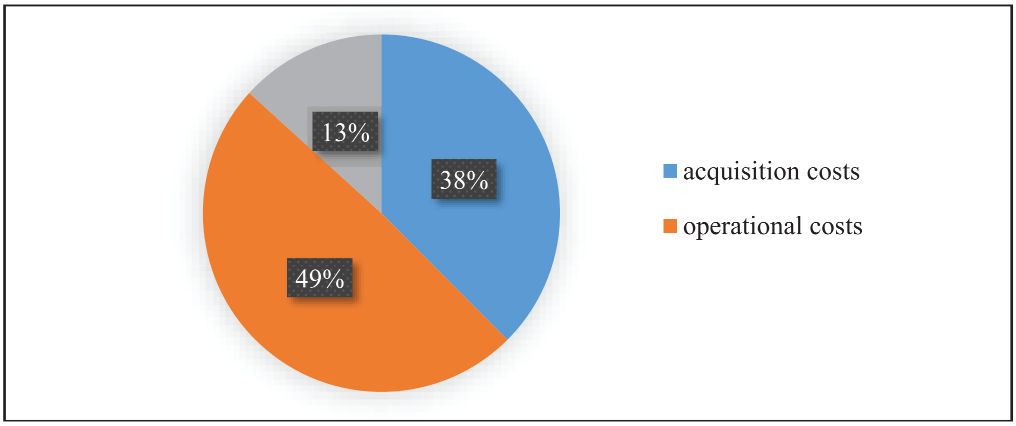

Fig 3 Percentage expression of selected LCC costs for passenger motor vehicles

4. Conclusions

The created purpose-built LCC model makes it possible to compare the expected lifetime costs when purchasing a new motor vehicle. This model can be used to compare different categories of motor vehicles because it is designed for wider use. It can be used for passenger cars, trucks and special vehicles. This article presents the results of a comparison of selected five different brands of passenger cars whose results are described in the third chapter. The above results show that in terms of life cycle costs, the best choice for the customer is option No. 1, where these costs are the lowest. Although it can be seen that the acquisition costs of the said passenger car were the 3rd highest, it would lead the customer without the above analysis to conclude that option 1 is the best, which has not been confirmed by the analysis of total life cycle costs. In this way, the authors confirmed the general statement that the rule that the cheapest acquisition costs represent the best choice in terms of the entire life cycle of a motor vehicle does not usually apply.

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Investigation and Analysis on Fun Buggy Simulation

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Abstract

Plan and examination of Buggy roll confine regularly utilized as a sporting vehicle on rough terrain landscapes have been contemplated. These vehicles are normally changed from their current plan to give execution and wellbeing. In this exploration paper, an endeavor has been made to plan a roll confine for a buggy considering various individuals from the roll confine. In this setting roll confine has been drawn on Solidworks CAD programming and has been dissected utilizing limited examination by applying the diverse limit conditions. The roll confine has been planned considering the AISI 1060-H12 Aluminum and Plain Carbon steel considering three cases like front impact, side impact, rear impact test to guarantee wellbeing of the administrator to endure the impact situation. The principle meaning of this review is to examine buggy job confine according to security perspective of administrator. From these outcomes it very well may be presumed by the both the materials is additionally one of the promising choices for Buggy plan and can be suggested according to security perspective.
KEYWORDS: *automobile engineering, buggy frame, AISI 1060 H-12 Aluminium, plain carbon steel*

1. Introduction

Buggy is one of the common elements is to be performed as the aspects of the automobile industry. In this we can see a lot on the sports concepts, sand racings and more over for a fun creation element of an axis. The buggy is made of many materials such as steel and alloys and many more, but the factor is every material has its own identity of performance. The buggy frame of the component must include all the elements of the products like differential rods, engine bay, suspension system, connecting rods and drive chains to be held on the one component to desire the capacity of the work is performed by the frame [1]. In this analysis, the process of performance of the buggy frame is to be calculated by two identical materials and happening some experiments on the frame to know the strength and capability performance of the frame for better use of the vehicle. This includes the structural analysis and strength analysis of the frame more over the costing structure of the material. Here, the mass of the material frame plays a significant role in to up comes the situation to hold the output of the frame. In this we have used the Solidworks software to create the buggy frame and perform some tests like front impact, side impact, rear impact tests.

2. Buggy Frame Design and Material Properties

The buggy frame is designed in a circular tube formed in Solidworks with a specification of the parameters (Fig. 1) (Tables 1 and 2). The Buggy frame is planned with various cylinders which structure a cylindrical space outline. This assists with circulating burdens and stresses all through the casing and structures an unbending underlying body. It serves the driver with a safe encased 3-D construction and makes underlying scaffolding for every one of the fundamental frameworks.

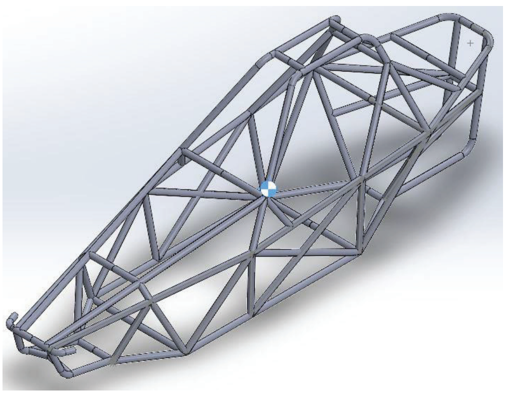


Fig. 1 Center of Gravity of Buggy Frame

Table 1

Frame specifications with Dimensions

Frame Specifications	Dimensions
Length	3041.12 mm
Width	800 mm
Height	1055.16 mm
Mass of AISI 1060-H12 Aluminium	28.44 Kgs
Mass of Plain Carbon Steel	82 Kgs
Center of Gravity (axis)	X = 0.01; Y = 367.51; Z = -1211.18

Table 2

Properties of AISI 1060-H 12 Aluminum and Plain Carbon Steel Materials

Material	AISI 1060-H 12 Aluminum	Plain Carbon Steel
Mass Density (kg/m^3)	2705	7800
Modulus of Elasticity (GPa)	69	210
Yield Strength (MPa)	75	220.59
Ultimate Tensile Strength (MPa)	85	399.82
Poisson's Ratio	0.33	0.28

To guarantee a solid casing without thinking twice about weight, it is consistently helpful to make a casing of interconnecting three-sided areas, as this considers an intelligible burden way for the buggy casing. The heap way is the course that the powers and ensuing anxieties finish a construction. At the point when a lucid burden way doesn't exist inside the design, the powers and stresses respond in a solitary cylinder, producing a high-pressure inclination nearby and fundamentally expanding the likelihood of disappointment. A decent burden way will scatter the heaps and stresses across interconnected individuals all through the Buggy Frame.

3. Mathematical Calculations

The bending stiffness of the frame:

$$K_b = E \cdot I\,, \tag{1}$$

where E – modulus of elasticity; I – area moment of inertia.

The bending strength of the frame:

$$S_b = \frac{\delta_y - I}{c}\,, \tag{2}$$

where δ_y – yield strength; I – area moment of inertia; C – outer diameter/2.

Area of Inertia:

$$I = \frac{\pi\left(D^4 - d^4\right)}{64}\,. \tag{3}$$

Dimensions of pipe used to form the frame i.e., outer diameter D = 26.9 mm, inner diameter d = 20.5 mm, and thickness 3.2 mm. to know the area moment of Inertia substitute the values in Eq. (3).

$$I = \frac{\pi\left(26.9^4 - 20.5^4\right)}{64} = 17033.38 \text{ mm}^4.$$

For AISI 1060-H 12 Aluminum

Bending stiffness, in Eq. (1) the values of Modulus of elasticity is 69 GPa and Area of inertia is 17033.38 mm^4 is calculated:

$$K_b = 69 \cdot 17033.38 = 1175.30 \text{ N/m}^2.$$

Bending strength, substitute the values of yield strength of 75 MPa and Area of inertia of 17033.38 mm^4 in Eq. (2).

$$S_b = 75 \cdot 17033.38/13.4 = 95.3 \text{ Nm}.$$

For Plain Carbon Steel

Bending stiffness, in Eq. (1) the values of modulus of elasticity is 69 GPa and area of inertia is 17033.38 mm^4 is calculated:

$$K_b = 210 \cdot 17033.38 = 3577 \text{ N/m}^2.$$

Bending strength, substitute the values of yield strength of 75 MPa and area of inertia of 17033.38 mm^4 in Eq. (2)

$$S_b = 220.59 \cdot 17033.38/13.4 = 280.4 \text{ Nm}$$

Therefore, load on the frame is to be calculated by force, therefore:

$$F = m \cdot a\,, \tag{4}$$

where m − mass of the vehicle; a − acceleration of the vehicle.

Hereby, acceleration:

$$a = \frac{(v - u)}{t}\,. \tag{5}$$

Let's, assume velocity of vehicle is v = 40 km/h = 11.11 m/s; time t = 0.15 (stop of the vehicle); u – initial velocity. From Eq. (5) we get to know the value of acceleration is:

$$a = \frac{(11.11 - 0)}{0.15} = 74.06 \text{ m/s}^2.$$

Now we know the mass of the vehicle and acceleration values, substitute in Eq. (4) to get the force/ load value.

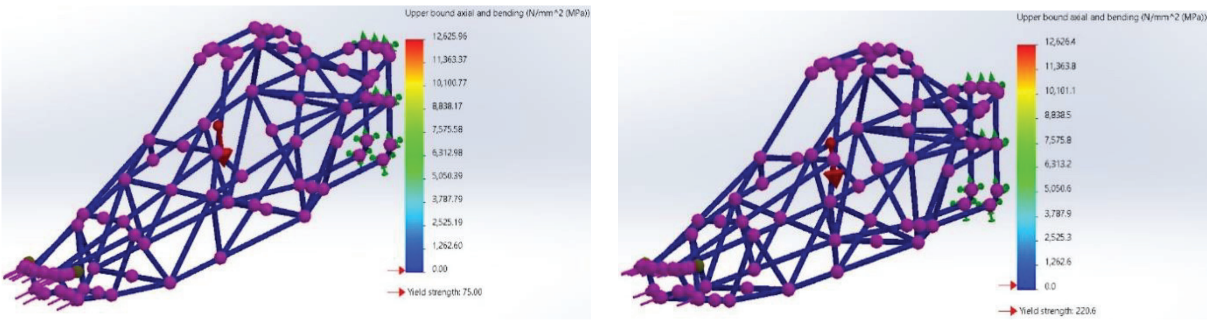
$$F = m \cdot a = 277 \cdot 74.06 = 20514 \text{ N}.$$

The load of 20514N is to be applied on the joints of the frame where the load is equally distributed by the joints in the impact tests in Solidworks Simulation.

4. Results and Discussion

4.1. Front Impact

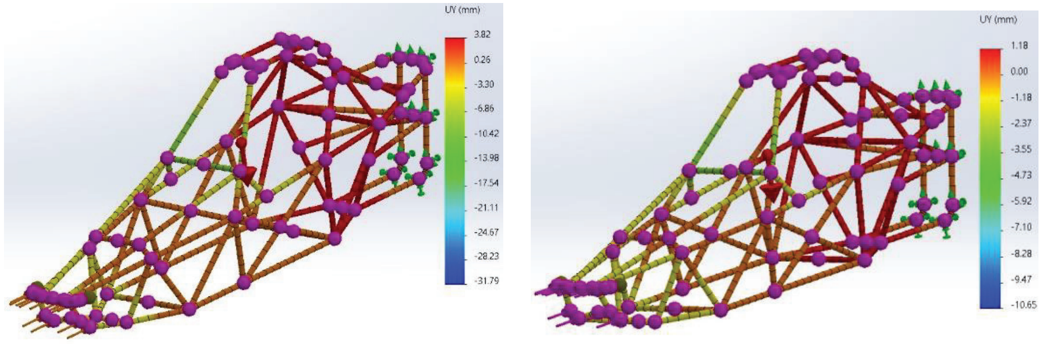
The calculation of the frame is imported on SolidWorks Simulation stress examination. A consistently circulated load of 20514 N is applied to the joints situated at the front most individuals from the casing. The rear joints of the frame are fixed in Degree of Freedom to ensure the study of the load access on the front of the Buggy frame. The relating FEA correlation results of AISI 1060-H12 Aluminium and Plain Carbon Steel of front Impact Stresses and displacement resultant comparison figures are shown below.



a b

Fig. 2 Analog of Front Impact FEA Stress of AISI 1060-H12 Aluminium (a) and Plain Carbon Steel (b)

The load of 20514 N has been applied to the buggy frame for results. The obtained analysis results, it is from the figure we observed that the maximum stress of AISI 1060-H12 Aluminium and Plain Carbon Steel are 12625.9 MPa and 12626.4 MPa from these results of stress, there is a minor difference between both the materials (Fig. 2). Fig. 3 shows the maximum displacement is 3.81 mm and 1.184 mm in the analysis of AISI 1060-H12 Aluminium and Plain Carbon Steel where we get to know that the displacement is less in case of plain carbon steel compared to AISI 1060-H12 Aluminium. The factor of safety is 0.0059 and 0.017 is from the AISI 1060-H12 Aluminium and Plain Carbon Steel is observed. It seems, the plain carbon steel has the high level of factor of safety compared to AISI 1060-H12 Aluminium.



a b

Fig. 3 Analog of Front Impact FEA Displacement of AISI 1060-H12 Aluminium (a) and Plain Carbon Steel (b)

4.2. Side Impact

The calculation of the Buggy frame of side impact is organized by the mass of the vehicle, where it includes the mass of the driver and assumed 277 kgs of vehicle mass i.e., includes the vehicle mass and mass of the driver.

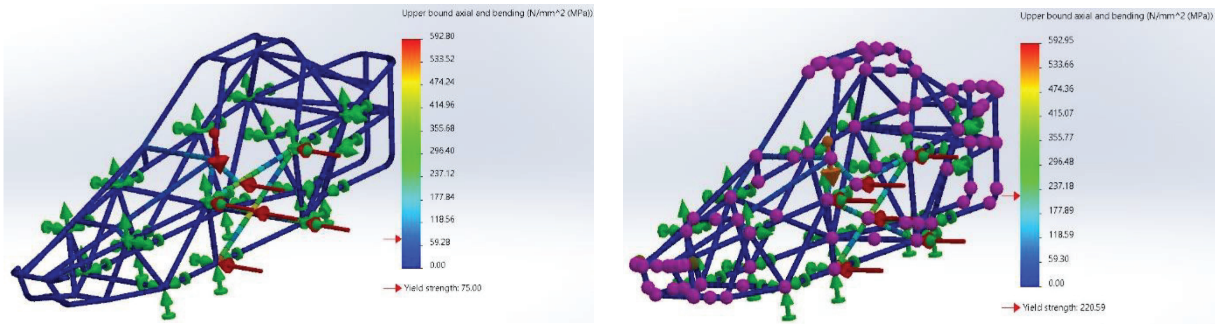


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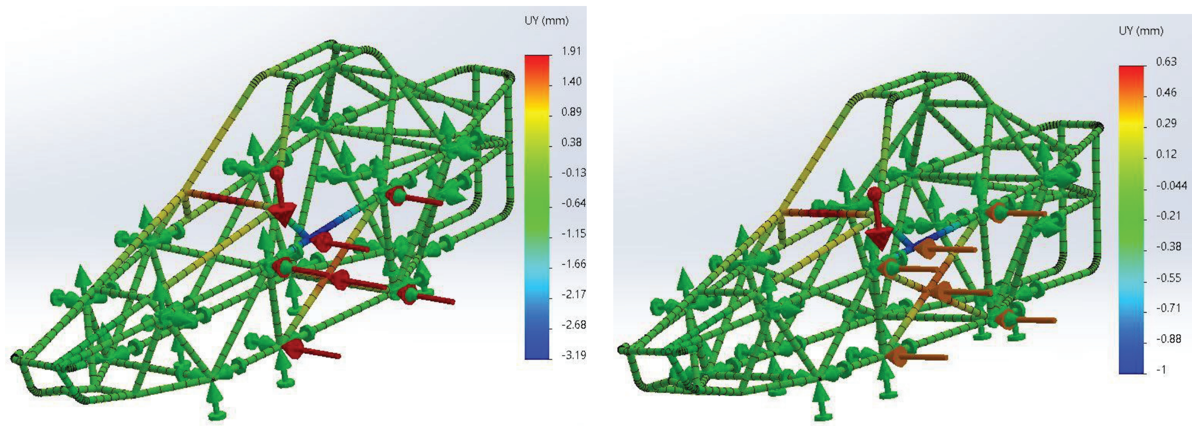
Fig. 4 Analog of Side Impact FEA Stress of AISI 1060-H12 Aluminium (a) and Plain Carbon Steel (b)



a b

Fig. 5 Analog of Side Impact FEA Displacement of AISI 1060-H12 Aluminium (a) and Plain Carbon Steel (b)

A consistently circulated load of 20514 N is applied to the joints situated at the side of the frame. The besides joints of the side frame are fixed in Degree of Freedom to ensure the study of the load access on the side impact of the Buggy frame. The relating FEA correlation results of AISI 1060-H12 Aluminium and Plain Carbon Steel of side Impact Stresses and displacement resultant comparison figures are shown below. The load of 20514 N has been applied to the buggy frame for results. The obtained analysis results, it is from the figure we observed that the maximum stress of AISI 1060-H12 Aluminium and Plain Carbon Steel are 592.8 MPa and 592.9 MPa from these results of stress, there is a similar content between both the materials (Fig. 4). Fig. 5 shows the maximum displacement is 1.90 mm and 0.62 mm in the analysis of AISI 1060-H12 Aluminium and Plain Carbon Steel where we get to know that the displacement has a much variation and has less in case of plain carbon steel compared to AISI 1060-H12 Aluminium. The factor of safety is 0.13 and 0.37 is from the AISI 1060-H12 Aluminium and Plain Carbon Steel is observed. It seems, the plain carbon steel has the high level of factor of safety compared to AISI 1060-H12 Aluminium.

4.3. Rear Impact

The rear impact calculations that the vehicle is to be rear ended by the possibility of the mass, where the engine bay and differential and connecting rods are to be assembled at the rear view of the frame. A consistently circulated load of 20514 N is applied to the joints situated at the rear point of the frame. The front joints of the frame are fixed in Degree of Freedom to ensure the study of the load access on the rear of the Buggy frame. The relating FEA correlation results of AISI 1060-H12 Aluminium and Plain Carbon Steel of front Impact Stresses and displacement resultant comparison figures are shown below. The load of 20514 N has been applied to the buggy frame for results. The obtained analysis results, it is from the figure we observed that the maximum stress of AISI 1060-H12 Aluminium and Plain Carbon Steel are 628.9 MPa and 629.0 MPa from these results of stress, there is a slight difference between both the materials where the numerical has a minor diffusion (Fig. 6). Fig. 7 shows the maximum displacement is 66.69 mm and 19.75 mm in the analysis of AISI 1060-H12 Aluminium and Plain Carbon Steel where we know that the displacement is major in AISI 1060-H12 Aluminium as there is no comparison with plain carbon steel. The factor of safety is 0.12 and 0.35 is from the AISI 1060-H12 Aluminium and Plain Carbon Steel is observed. It seems, the plain carbon steel has a high level of a factor of safety compared to AISI 1060-H12 Aluminium.

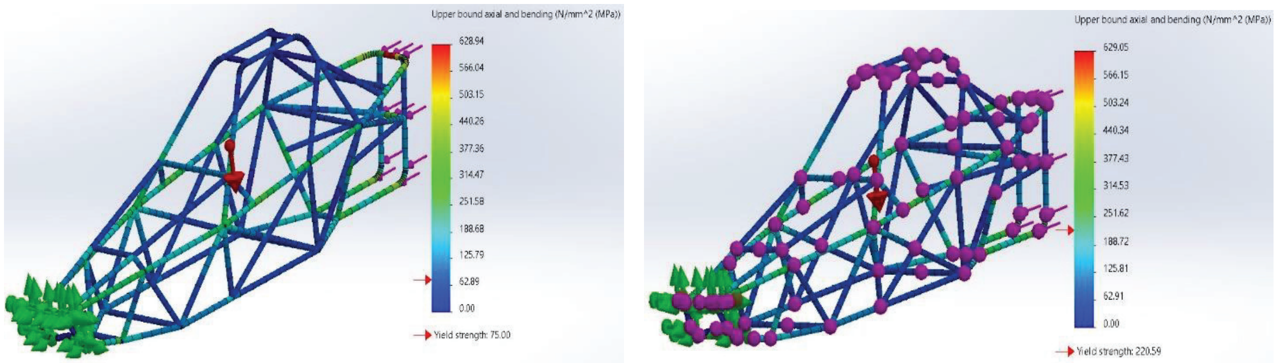


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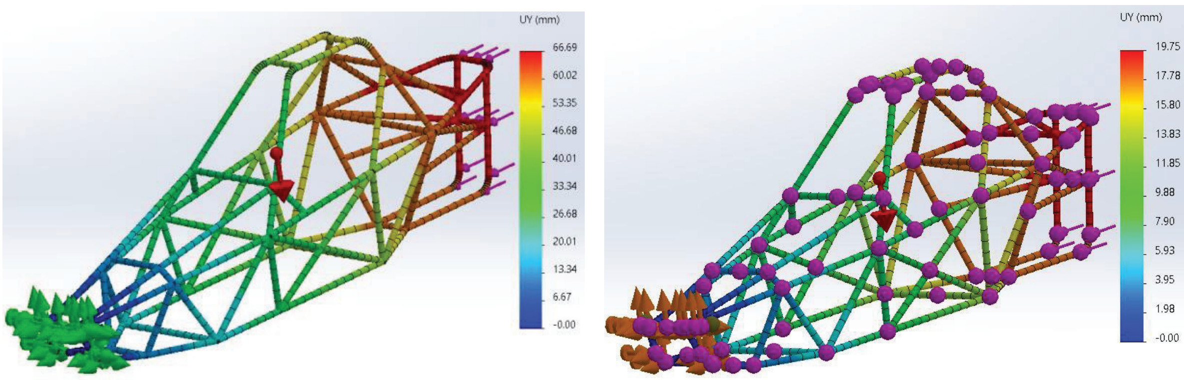
Fig. 6 Analog of Rear Impact FEA Stress of AISI 1060-H12 Aluminium (a) and Plain Carbon Steel (b)



a b

Fig. 7 Analog of Rear Impact FEA Displacement of AISI 1060-H12 Aluminium (a) and Plain Carbon Steel (b)

5. Conclusions

In this research paper, the design and simulation of buggy it has to be studied. By creating a buggy frame in Solidworks with the use of finite element analysis we have performed three tests on the frame. The tests are front impact, side impact and rear impact to know the actual grading of the material frame to be upgraded for the use of the recreational vehicle. The tests have been done with the material AISI 1060 H-12 aluminium and plain carbon steel. From the results we conclude that the materials have the most strength factor which leads to the good conduct of the vehicle frame. Both have a high factor of safety by the design of the buggy frame. Comparatively the AISI 1060 H-12 aluminium material has less mass compared to plain carbon steel. In the automobile aspects both the materials are used in different modules where the cost of AISI 1060 H-12 Aluminium is completely high compared to plain carbon steel. The tubes of plain carbon steel are very quite easy can be got with different gauges and required dimensions and used in manufacturing units all over accessible. By the tests we get to know there is a similarity in stress in all the impacts on the frame and the displacement has a minor differential in the front, side, and rear impacts where we get to notice that the tube gets some deformation through the angle to stable i.e., 3.8,1.90, 66.69 in mm and 1.184, 0.625, 19.75 in mm AISI 1060 H-12 Aluminium and plain carbon steel. Here for the front and side impact slight deformation of the displacement whereas the rear impact has the impact analysis where the major components are to be attached is to seem a wide dimensional point of intersection. By taking the factor of safety conclude that by the difference in the impacts i.e. 0.12,0.13 and 0.37, 0.35 of AISI 1060 H-12 Aluminium and plain carbon steel. By this analysis comparatively both the material frames are safe and usable in all aspects which has good strength, ductility and compression elements and by taking the cost in contact plain carbon steel is less compared to AISI 1060 H-12 Aluminium.

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Statistical Data Processing in R-Studio and WEKA Software for Engine Oil Life Prediction

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Abstract

The article deals with the issue of statistical data processing in the field of tribology based on sophisticated mathematical programs. Specifically, it is a tribodiagnostic monitoring on a Mitsubishi Lancer 1.5 MIVEC passenger car with the aim of predicting the service life of the oil in the engine. The vehicle is regularly monitored since April 2019 and the operating values of the atmosphere and the engine are measured each time the engine is started. Once every two weeks is performed tribological diagnostics for the physical and chemical properties of engine oil. The measured data are correlated to predict the life of the oil fill. The article does not deal directly with the result of oil life, but with the preparatory phase, i.e. the design of the optimal dataset in the R (R-Studio) programming language and the connection with the WEKA machine learning program. These programs offer a large number of mathematical - statistical operations and learning algorithms. The result of dimensioned dataset in R-Studio is a large-scale mathematical matrix (800 starts x 15 parameters) from the first monitored oil filling, whose service life reached 800 engine starts - 10 months - 11.056 km. At the end of each oil cycle, the same dataset is compiled by analogy. A set of high-quality processed datasets from each oil filling is the basic source of data for future prediction of engine oil life or for finding the optimal algorithm for determining its service life.
KEY WORDS: *engine oil, life prediction, algorithms, statics, R-Studio, Weka, time series analysis (TSA)*

1. Introduction

Efforts to economically optimize vehicle operation in connection with engine lubrication have been on the scene among vehicle manufacturers for decades. As vehicle operation and oil degradation are very complicated processes with a number of variable parameters, it has not yet been possible to develop a comprehensive, sufficiently accurate oil detection system built into the vehicle. With the absence of related literature and research in this area, e. g. Experts from the Korean-Swiss team also mention in a scientific article with an extensive search (A predictive algorithm for estimating the quality of vehicle engine oil), which should be quoted at least briefly: „Although many publications have considered predictive maintenance and engine oil relevant maintenance problems, however, they have some limitations. First, there is a lack of research to address the issue of predictive maintenance about engine oil. Even though some works mentioned engine oil analysis, only a few works dealt with its predictive maintenance. Hence, there is no explicit guidance about how the quality of engine oil could be estimated considering its usage mode.“ [5].

2. Description of the Issue

The issue of motor oil life prediction is still a major challenge for research, despite the rapid electrification of vehicle propulsion units. This is a very complex issue where many variable factors enter the process. This paper offers another possible solution to this issue. It focuses on the preparation and processing of collected data for the creation of a predictive model. The aim of this part is to present the possibility of creating statistical datasets in the R-Studio software and correlating with the WEKA machine learning program in the field of tribology.

Characteristics of the measured object are shown in Table 1.

Table 1

Measured object

	Passenger car **Mitsubishi LANCER 1.5 Inform** Type: 10. edition of model Lancer Year of production: 9/2009 Country of origin: Japan Transmission: manual, 5 g. r., 191 km/ h Engine: in-line, 4 - cylinder, atmospheric, petrol, EURO 4, 80 kW, 143 Nm Mileage km at the beginning of measurements (1.4.2019): 146.107 km

Monitored relationships between measured data are shown in Table 2

The experts concluded that the statistical determination of data from daily vehicles failed to show a quantifiable correlation between mileage and engine oil performance, as oil degradation affects a number of factors, such as different engine designs, operating conditions, driving habits, etc. However, they suggest that engine oils with the new specifications have a significant improvement in performance compared to their forerunners [1].

Table 2

Monitored relationships between measured data

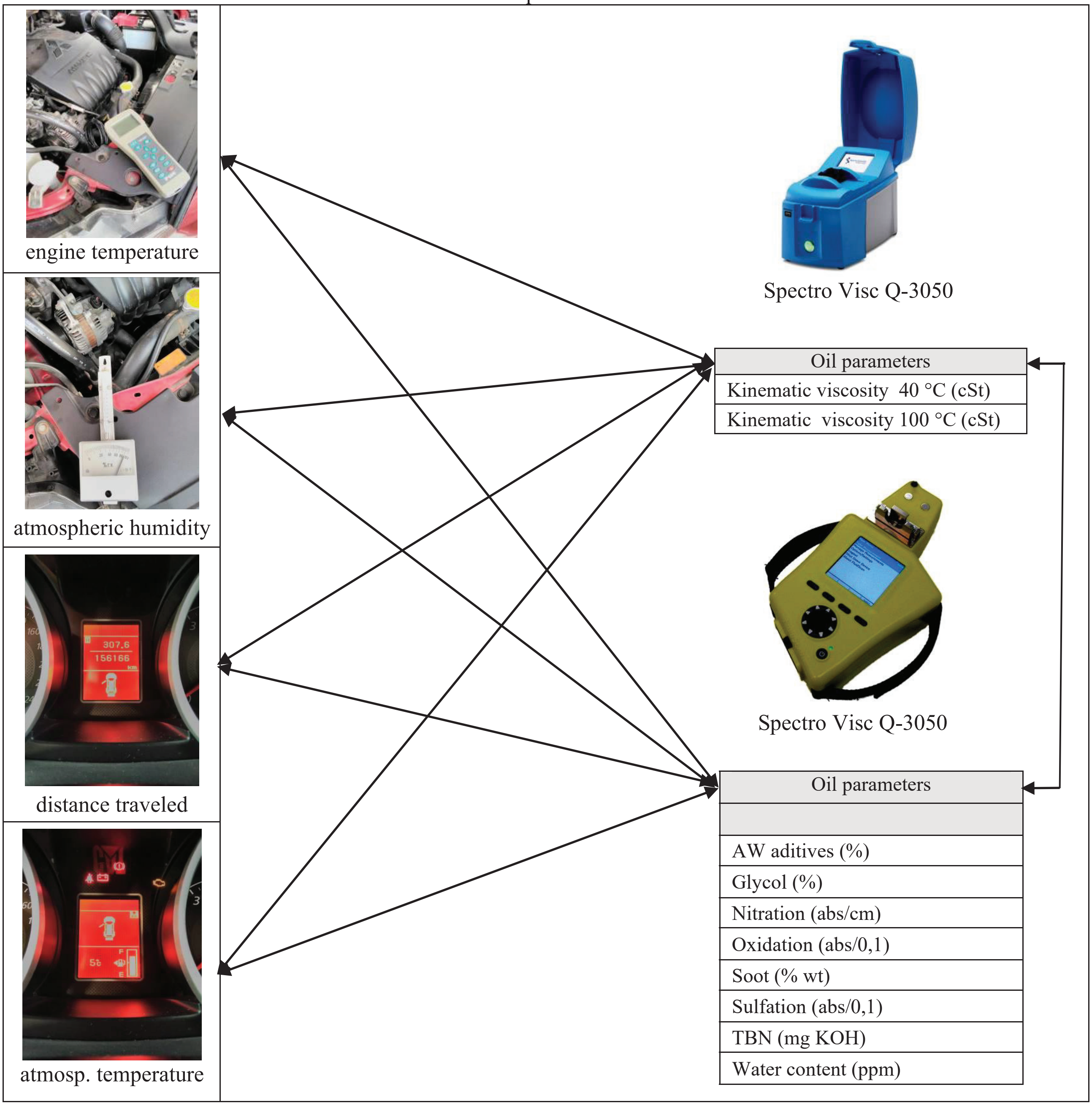

Table 3

Investigated engine oil

	**Used engine oil** Brand: VALVOLINE SynPowerSAE: 5W-40 ACEA: A3/ B3, A3/ B4 API: SL, SM, SN/ CF VW: Standards 50200/ 50500 MB: Approval 229.5 Type of oil: full synthetic, multigrade Country of origine: The Netherlands

3. Data Processing for the Future Predictive Model Through Time Series Analysis (TSA)

The description of the problem shows that the goal is to create a reliable system for predicting the life of engine oil and finding the optimal algorithm. To achieve the goal, the first thing is to create a compact dataset from the measured data. From the previous description (Tables 1, 2, 3) it should be added that this is a data collection during each engine start, where the operating parameters (atmospheric temperature, atmospheric humidity, engine temperature, distance traveled) are manually read. These values are assigned to the oil level, in which a tribodiagnostic analysis is performed every 14 days.

$$y_t, \text{ for } t = 1,...,n;$$

$$\bar{y} = \frac{\frac{1}{2}y_1 + y_2 + \cdots + y_{n-1} + \frac{1}{2}y_n}{n-1}$$

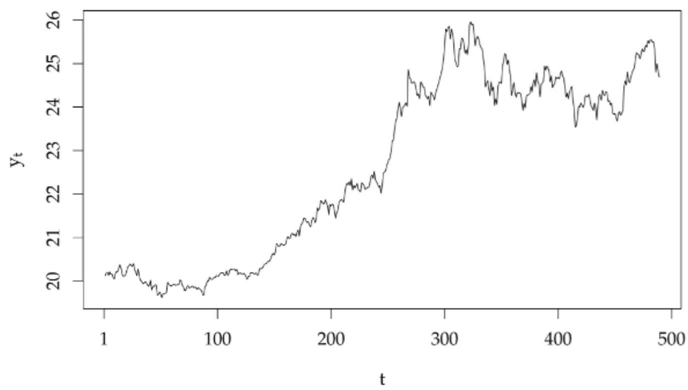

Fig. 1 Example of a simple time series [3]

Several options are available for data processing and subsequent creation of a predictive model. From the analysis of the available options, the decision was made to design a predictive model based on time series analysis (TSA). As the collection of vehicle in-service data has a cyclicality and an ordered chronology, this statistical method proves to be the most appropriate. In addition, this method can also reveal correlations within individual months or seasons, as well as their climatic aspects. The problem was abandoned using fuzzy logic, as this method proves to be the most suitable for process control and latent recognition. The solution of the problem based on artificial intelligence using neural predictors is still left as a backup solution, as it requires a high quantity of input data and conditions of dependencies of the monitored processes. For this case, the length between the time points is the same and a simple chronological average is used $\bar{y}$ (Fig. 1).

The time series analysis can be summarized in five basic steps [3]:

1. Determination of simple (elementary) characteristics;
2. Determination of basic descriptive characteristics;
3. Creation of mathematical - statistical model ;
4. Design of prognostic model;
5. Verification of the accuracy of statistical forecasts [3].

Most predictive models are built on kilometer intervals, ie sampling and analysis of the sample is carried out exactly after the observed kilometer interval (1.000 km, 2.000 km, etc.), regardless of the time duration of the interval. The difference between our system and the others lies, among other things, in the fact that the sensing of parameters is exclusively before engine start (many systems read operating variables continuously during engine load), as cold vehicle starts have the greatest impact on oil degradation.

4. Dataset Design for Predictive Model in R - Studio Environment

The programming language R can be used for simple manipulation of data structures such as lists, tables or matrices. It can statistically process various data structures and subsequently visualize them, e. g. into a graphic form. It contains a large number of functions that make it easier and more efficient to work with various forms of data. It is distributed as an opensource project and therefore can be used by anyone at will [4].

The R language can easily and quickly process various data structures (e. g. vectors, lists, tables, etc.), perform statistical calculations on them and visualize them graphically. These three options are among the main advantages of the R language. The biggest competitor to the R language is Python. Python can do most of the tasks that R can do. So if Python is used instead of R, then the user should not be disappointed with the possibilities offered by this alternative. [4]

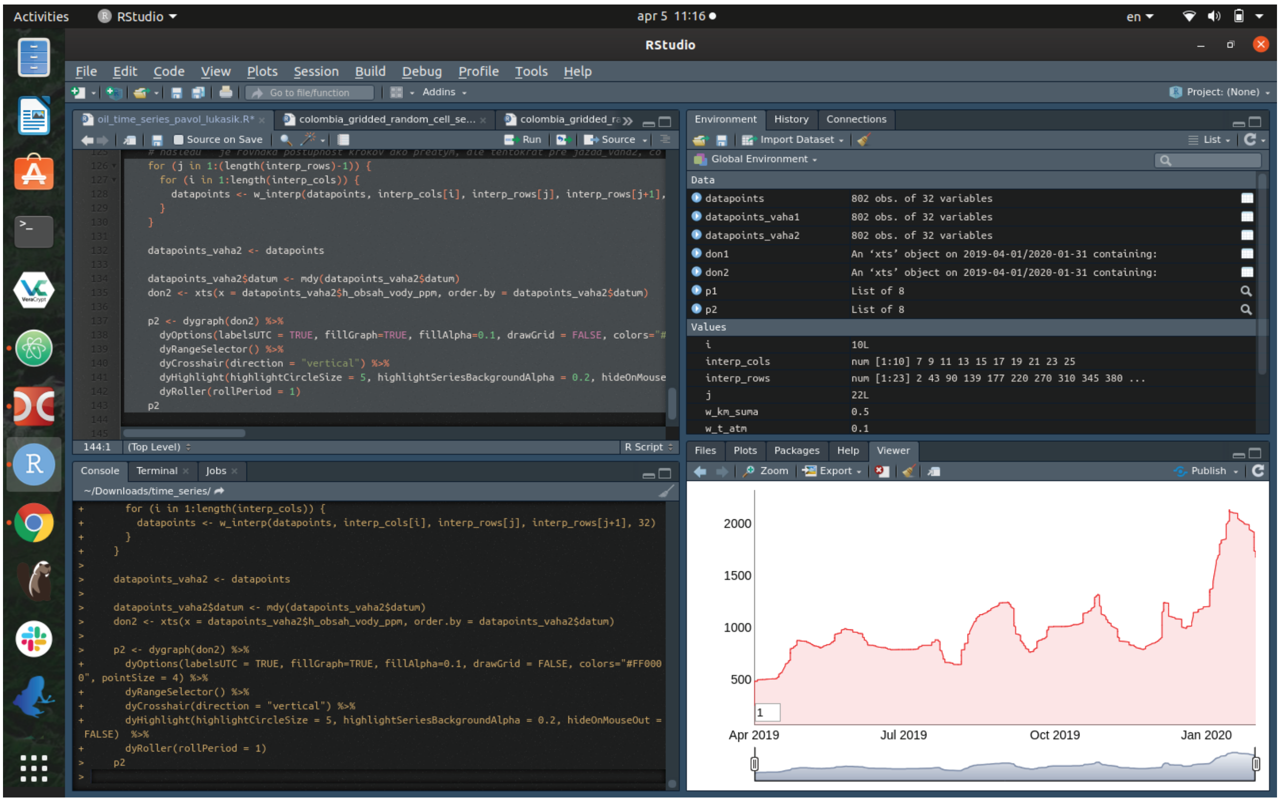

Fig. 2 Working environment in the application R - Studio [Author]

However, there are some differences between R and Python. By comparison, the R language contains more statistical methods and is therefore very popular among statisticians. However, Python is used for more demanding performance calculations - e. g. processing of very large amounts of data, or the use of more complex algorithms. We can see the difference, for example, in the implementation of obtaining summary statistics of the model, where in Python we have to write a 4-line program, while in R we just need to call the function "summary ()". R has been adapted for statistical calculations and graphical output since its inception, while Python was created as a versatile language that can do many things in many areas, and only later, with the help of libraries, did its possibilities in data analysis expand. Therefore, R has an edge in providing possibilities in the field of statistical data processing and powerful packages (ggvis, lattice, and ggplot2) with rich graphical output make it a leader in the field of data analysis and optimization of computational operations [4].

The design of the system itself and the understanding of this issue requires basic knowledge in R - Studio programming (Fig. 2). It is a freely available software application, which is considered one of the most powerful in the field of statistical operations and forecasting procedures. All information about the used packages, functions and their properties are available on the website https://stat.ethz.ch/R-manual/R-devel/library/.

```
   datapoints$jazda_vaha1<-w_km_suma*(1-datapoints$scaled_km_suma)
+w_t_atm*(1-datapoints$scaled_t_atm+w_t_mot*
(1-datapoints$scaled_t_mot+w_vlh_atm* datapoints$scaled_vlh_atm
```

Fig. 3 Writing formula to the R-Studio command line for linear interpolation

In addition to the built-in functions in the program library, there is also the option to create your own functions. An example is the design of a linear interpolation in the R-Studio command line (Fig. 3), which smooths the water content curve (Fig. 4) in the engine oil (since the oil properties are measured every two weeks, the instantaneous daily oil properties are unknown and they can be calculated, for example, by linear interpolation).

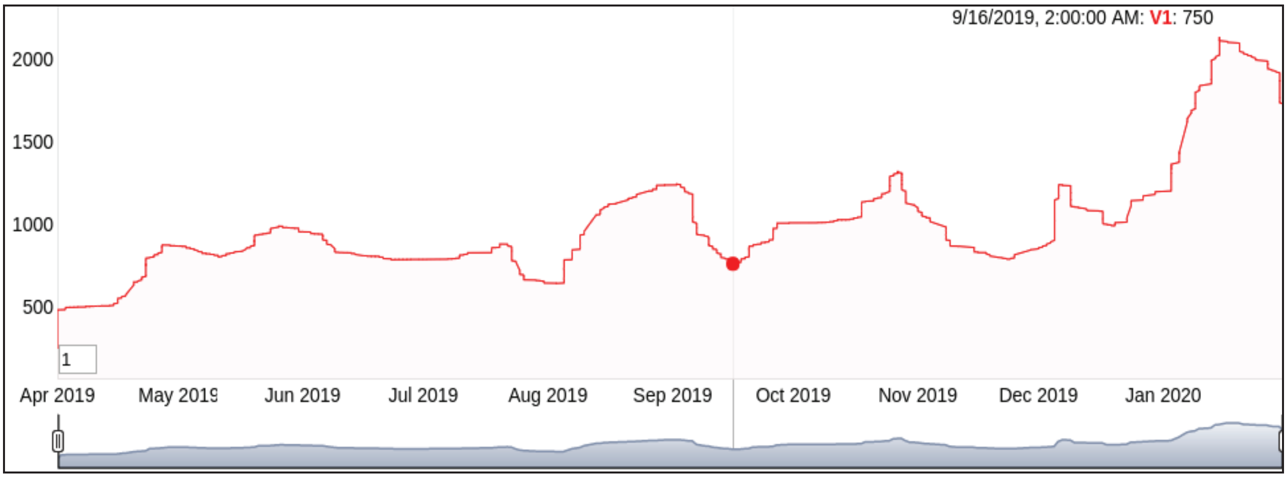

Fig. 4 Example of the time course of the water content in the oil filling with the calculation of values by means of linear interpolation

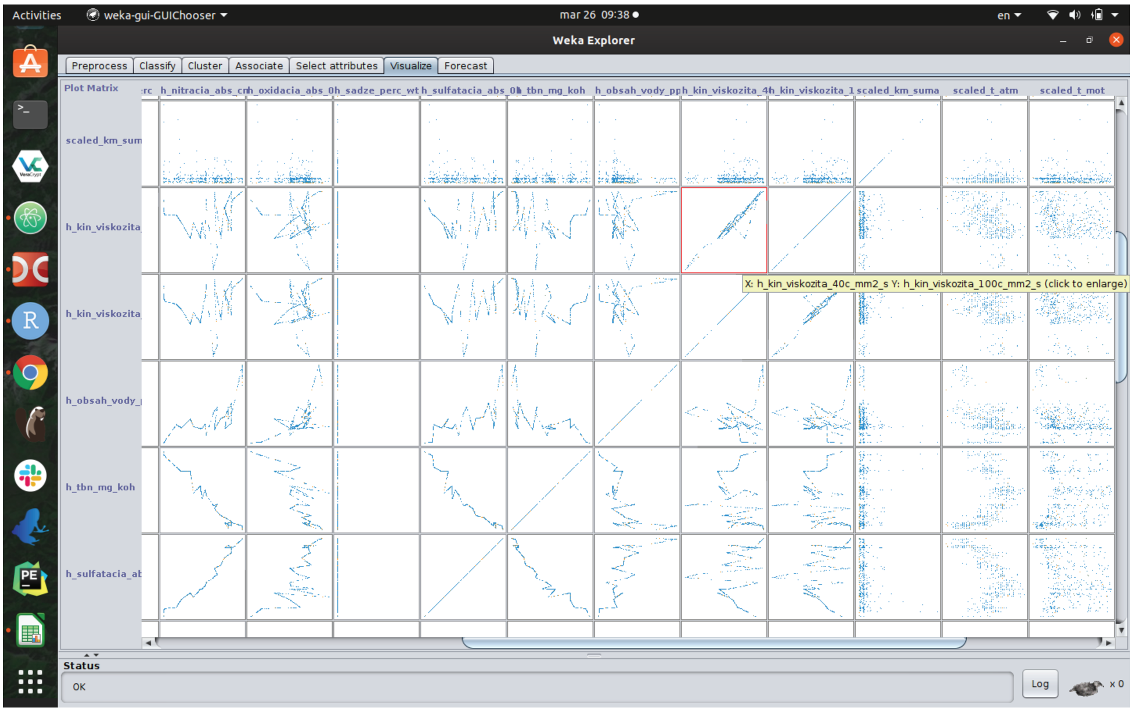

Fig. 5 Part of the matrix of graphs in the WEKA environment - mutual correlations between the investigated oil parameters

5. Results and Discussion

It follows from the above that the Time Series Analysis (TSA) method is proving to be little used and original in the field of monitoring and predicting engine oil life. This method finds its practical use in prognostic models of various industries. We encounter the time series as a chronologically arranged observation on a daily basis, for example in the development of daily temperatures, unemployment rates, the development of exchange rates, electrocardiogram (ECG) values, pandemic prognoses and many others [3].

In addition to dataset design, R-Studio software also offers event forecasts. In addition, it allows cooperation with other software. An example is the WEKA machine learning software. WEKA (Waikato Environment for Knowledge Analysis) is a popular Java-based machine learning software package developed at the University of Waikato, New Zealand. WEKA is free software available under the GNU General Public License [2].

By exporting data from R-Studio to WEKA, it is possible to create a matrix graph (Fig. 5). This matrix graph shows all correlations of the investigated parameters shown in the schematic diagram (Table 2). In such a visual display, the relationship between all examined parameters can be clearly and in detail determined. In this case, it allows an in-depth insight into the degradation processes of the engine oil charge. However, the creation of a matrix graph and prediction of oil life in the WEKA studio is preceded by the thorough preparation of a complex dataset in the R-Studio environment.

6. Conclusions

The aim of this article was to present the preparatory phase for the prediction of engine oil through the analysis of time series. This method is considered to be specific in predicting engine oil life. Attention was also drawn to the exceptional capabilities of the R-Studio and WEKA software. Their great possibilities for statistical data processing as well as for the field of trilogy were pointed out.

In this case, it was a proposal for a dataset from the 1st life stage of motor oil lasting from 1.4.2019 to 1.2.2020 (800 starts, 11.056 km, 10 calendar months). However, for a reliable prediction process, it is necessary to document at least two or more life stages of the oil filling and turn them into quality datasets. At the time of the deadline for this paper (16.5.2021), the vehicle is in the 3rd stage of measurement (examination of the 3rd oil filling, creation of the 3rd dataset) and has a current range of 167.401 km (beginning of measurements on April 1, 2019 at 146.107 km). Suitable conditions have been created for solving the prediction of engine oil life. Using multiple datasets, further modeling of predictive processes is then possible through a suitable algorithm.

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Artificial Neural Network in the Description of the Dependence of Scattering on Barrel Oscillations

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Abstract

A mathematical model of the dependence of scattering on barrel oscillations was defined using an artificial neural network. To ensure the correct operation of the mathematical model, the data obtained by measuring the oscillation of the mouth of the small-caliber barrel together with the corresponding scattering for each mass of the powder charge separately were used. The basis of the mathematical model was a feed-forward neural network. The neural network was built so that the approximating function, whose parameters are optimized, provides values close to the required ones.
KEY WORDS: *artificial neural network; barrel vibration; precision; dispersion*

1. Introduction

Feed-forward neural network is a layered structure. A neural network can be understood as a display (function) whose parameters are optimized so that the display provides values close to the desired ones.

Let $F(x)$ is a function defined on a set *A*, to everyone $x \in A$ assigns a functional value $y = F(x)$ from set *B*:

$$F : A \rightarrow B \,. \tag{1}$$

Let's construct such a function *G* that will apply

$$G : A \rightarrow B \,. \tag{2}$$

Function *G* is a neural network approximating a function *F*. The problem is to determine the parameters of the function *G* so, that the images of this function are "close" to the images of the function $F(x)$.

Let's define a purpose function

$$E(w) = \frac{1}{2}\sum_{i=1}^{r}\left[G(x_i, w) - y_i^*\right]^2 \,. \tag{3}$$

Eq. (3) expresses the sum of the squares of the deviations of the function values *G* from the desired images y_i^* (provided by the approximated function *F*), then the goal is to adapt the function G so, to provide values "similar" to the values of the function *F* in terms of the purpose function defined above.

The process of adaptation, or finding suitable parameters *w*, is called the neural network learning process and is implemented by a learning algorithm [1].

2. Construction of a Neural Model of a Weapon from the Barrel Vibration Point of View

Neural networks are particularly suitable for the construction of "black box" system model types - when only the inputs to the system and its outputs are known, and the structure of the system itself is not known. The output of such a system is a response to the input and is given by the structure of the system and the processes implemented in it, but these facts are unknown and usually mathematically indescribable.

In our case, the inputs to the system are the time courses of the muzzle mouth oscillations and the impact velocity of the projectile, the output is the position of the impact on the shooting target. The "Black box" are events taking place in the weapon during a shot, resulting in a position of impact with considering to the inputs of the process.

If we use input-output sessions (forming the so-called training set) to learn (train) an artificial neural network, after the successful completion of the learning process, the neural network will be able to provide appropriate outputs for the inputs from the training set (Fig. 1).

Fig. 1 General shape of ANN model

This is because the network has identified events in the system leading to the transformation of inputs into corresponding outputs, while the mathematical description of the network structure after its training also represents a mathematical description of the process - its mathematical model in the form of a multiparametric nonlinear function.

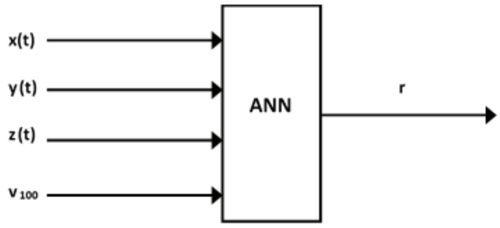


Fig. 2 ANN small arms barrel model

Let $x(t)$, $y(t)$, $z(t)$, v_{100} are process inputs, where $x(t)$ is the time course of the acceleration of the barrel mouth oscillations in the x-axis; $y(t)$ is the time course of the acceleration of the barrel mouth oscillations in the y-axis; $z(t)$ is the time course of the acceleration of the barrel mouth oscillations in the z-axis; v_{100} is the impact velocity of the projectile at a distance of 100 m; x, y, z are the axes of the accelerometer relative to the barrel; $x(t)$, $y(t)$, $z(t)$, are the accelerations of the barrel mouth oscillations measured by the Bruel & Kjaer PULSE system.

The output will be the position of the impact, noticed at the point of impact by the ballistic analyzer.

For calculation purposes, let us define the position of the impact as the distance from the origin of the coordinate system that represents the midpoint of the impact (Fig. 3).

The distance of the point of impact in relation to the beginning of the coordinate system is determined from Eq. (4).

$$r = \sqrt{\left(x_1 + x_0\right)^2 + \left(y_1 + y_0\right)^2} \ . \tag{4}$$

If we perform a defined number of shots for a given gunpowder weights, while recording the above quantities, we will obtain a database, in which the description of events in the monitored process will be recorded. From this database it is possible to gain knowledge about the course of these events in the process of learning the neural network.

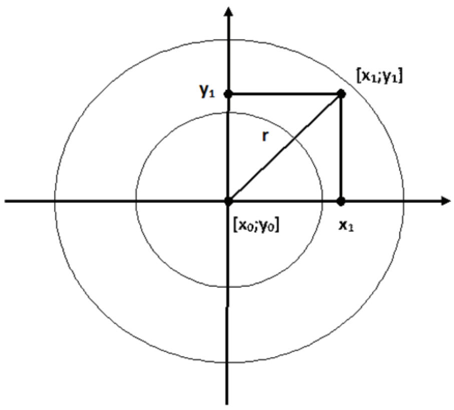


Fig. 3 Definition of the distance r of the impact position from the beginning of the coordinate system

For the following simulation experiments, the same network structure shown in the following figure was used as a process model for all gunpowder weights. It is a feed-forward network with a cascade arrangement, with 52 inputs, two hidden layers (with 10 neurons in each layer) and one output layer with one neuron. The hyperbolic tangent transfer function was used for neurons in hidden layers, the output neuron worked with a linear transfer function. Network training was performed by backpropagation algorithm. Simulations of this network were performed in the Neural Network Toolbox of the MATLAB system (Fig. 4).

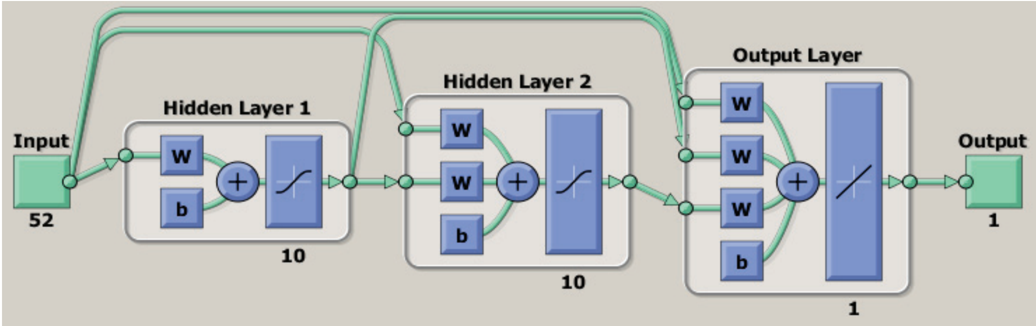


Fig. 4 (92) The structure of ANN realized in MATLAB Neural Network Toolbox

The following graphs show the learning process of the network and the result in the form of agreement of the neural model with the data from the ballistic analyzer - for shots on which learning was performed (training set) and for shots outside the training set, for individual weights of powder charge (Fig. 5-12).

ANN model for the powder charge weight m_ω = 1,5 g

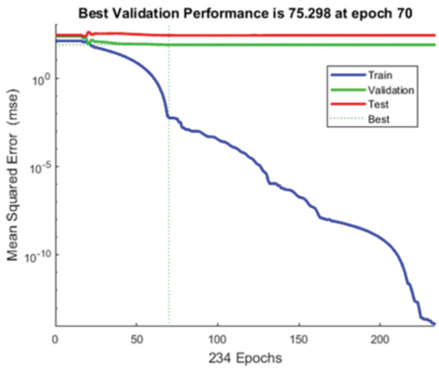
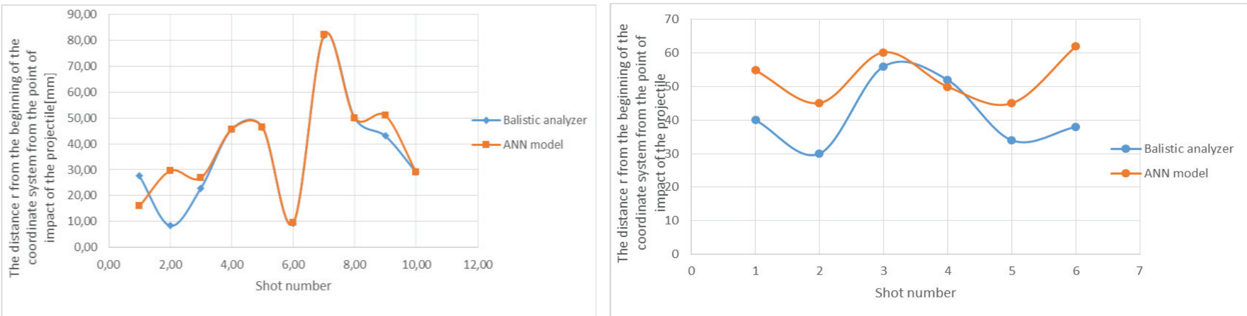


Fig. 5 Learning process ANN for a powder charge weight of 1.5 g



a b

Fig. 6 Compliance of the ANN model with shots for a powder charge weight of 1.5 g: a – within the training set; b – within the test set

ANN model for the powder charge weight m_ω=1,55 g

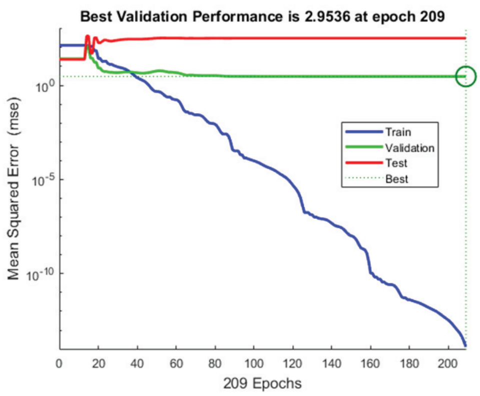
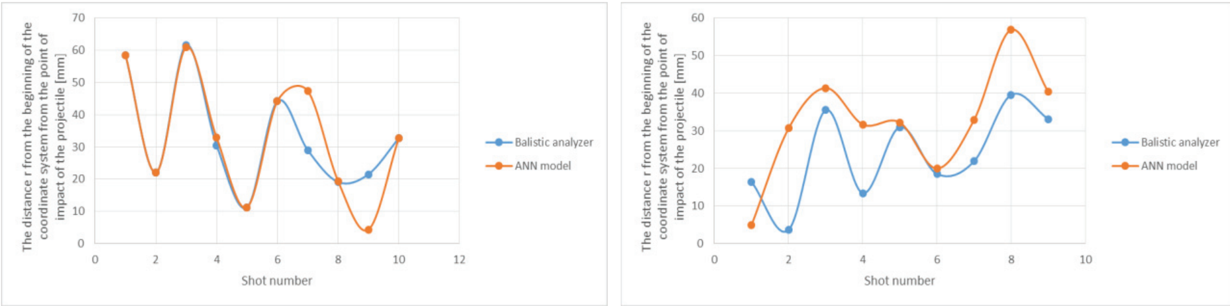


Fig. 7 Learning process ANN for a powder charge weight of 1.55 g



a

b

Fig. 8 Compliance of the ANN model with shots for a powder charge weight of 1.55 g: a – within the training set; b – within the test set

ANN model for the powder charge weight m_ω = 1,6 g

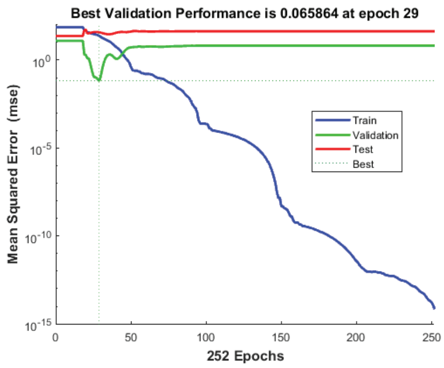
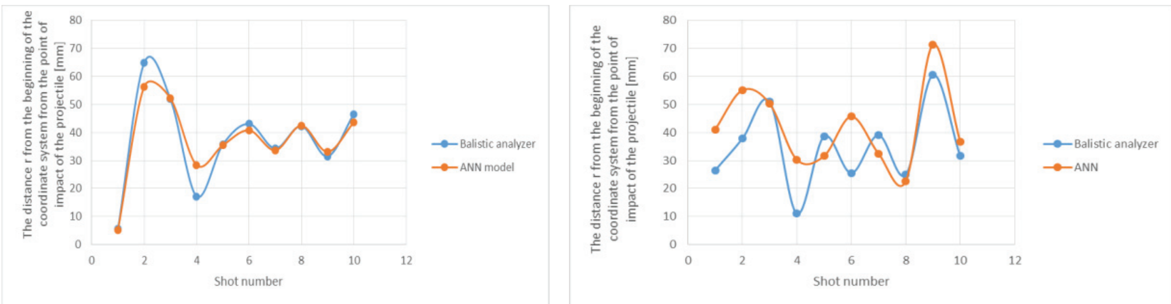


Fig. 9 Learning process ANN for a powder charge weight of 1.6 g



a

b

Fig. 10 Compliance of the ANN model with shots for a powder charge weight of 1.6 g: a – within the training set; b – within the test set

ANN model for the powder charge weight m_ω=1,65 g

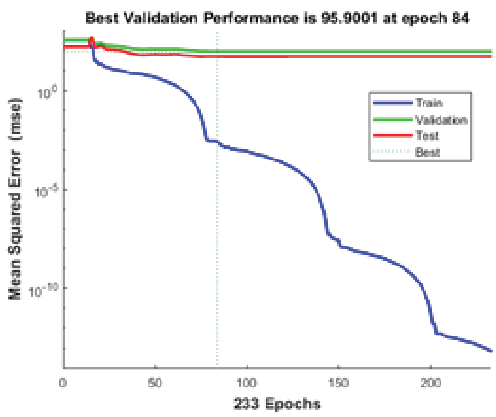
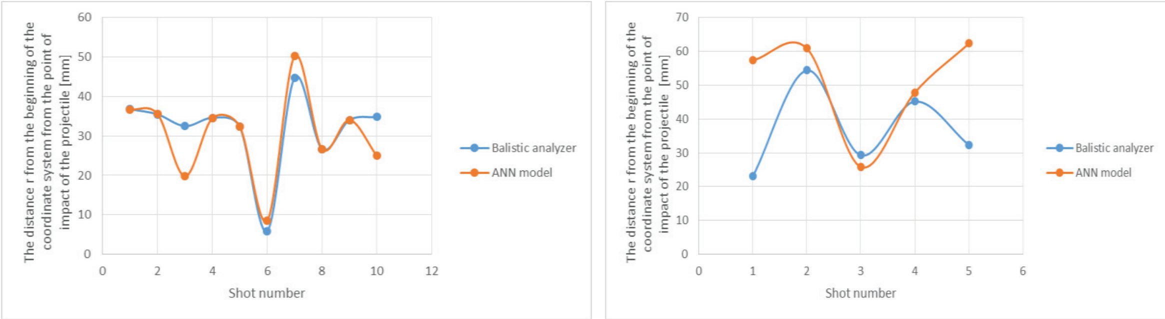


Fig. 11 Learning process ANN for a powder charge weight of 1.65 g



a b

Fig. 12 Compliance of the ANN model with shots for a powder charge weight of 1.65 g: a – within the training set; b – within the test set

3. Conclusions

The course of the learning process, in all the above cases, shows a significant reduction of the learning error numbers, but at the same time leads to a weaker ability to generalize the network. Mainly stagnant testing and validation curves. The network interprets the data from the training data set satisfactorily well, but is no longer able to perform prediction outside this set with sufficient accuracy. The agreement within the test set shows relatively large deviations. This condition is most likely due to the small range of data training set, which is due to the insufficient number of shots in each group of shots with one value of the powder charge weight. The described simulation experiments suggest the possibility of using this method. For the successful use of the method, however, it will be necessary to collect and evaluate a fundamentally larger input database of small-caliber barrel mouth vibration parameters and the associated parameters in the impact plane.

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Low Carbon Mobility - Electromobility

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Abstract

Reducing directly limited exhaust emissions (HC, CO, NOx and particulate matter) is vital and is becoming a major, albeit controversial, motive for the electrification of vehicle propulsion systems. A strict Euro 7 emission standard is being prepared, effective from 2025. If the current proposal is approved, it is likely to mean the end of internal combustion engines, as, for example, the NOx limit should be reduced from the current 80 mg/km to 30 mg/km and the CO limit from the current 95 g/km to 59 g/km. The European Automobile Manufacturers' Association (ACEA) marks these limits in the automotive industry as technically unattainable. The transition to electromobility is inevitable, but such rapid development is not in line with technical possibilities, development or the construction of infrastructure. The EU should adopt a sensible, technically and temporally conceptual solution. The paper discusses various aspects of the massive transition to electromobility.
KEY WORDS: *sustainable development, greenhouse gases, pollutant emissions, life cycle, advantages and disadvantages of electromobility*

1. Introduction

The historically first electric car is considered to be a car assembled in the Netherlands in 1835, about 50 years before the first car with an internal combustion engine. In 1899, a speed of 100 km/h was exceeded for the first time in Belgium with an electric car, and at the beginning of the 20th century, more electric cars drove in the USA than cars with an internal combustion engine. They provided comfort and easy operation. In old days, cars had to be started by a crank, they were noisy and difficult to maintain. The invention of the electric starter, the improvement of the battery design (Thomas Edison) and the mass production of the Ford T model (Henry Ford), which replaced electric cars due to its reliability, driving range and low price, changed everything The first electric car on the Czech territory was manufactured in 1895 (František Křižík), it was powered by a DC electric motor with an output of 3.6 kW, the source was a lead-acid battery with 42 cells.

In December 2015, the Paris Climate Conference approved a new climate agreement with the votes of representatives of 196 UN countries. The basic effort is to keep the annual warming of the Earth significantly below 2°C, or to approach 1.5 ºC. The agreement also commits developed countries to invest billions in aid to developing countries. It sets out the commitments of all parties, including the world's largest producers of greenhouse gas emissions such as China, the USA, Russia, India and others. It is an ambitious effort to reduce global warming. The Green Deal for Europe is a package of measures by the European Commission, launched in December 2019, which should ensure the transition to a sustainable and green economy for EU citizens and companies. The proposed measures include reducing emissions, investing in cutting-edge research and protecting the natural environment of the European continent. The second goal of the agreement is to transform the European economy so that it is sustainable in the long term and can grow without increasing the use of natural resources. The Green Deal for Europe aims to legislate to make Europe the world's first climate-neutral continent by 2050. The European Commission plans to present a pilot European climate legal framework, including a biodiversity strategy to 2030, a new industrial strategy and an EU action plan for the circular economy, a sustainable farmer-to-consumer food production strategy and proposals for a pollution-free Europe. Achieving the targets of the Agreement on climate and power industry by 2030 will require around € 260 billion in additional annual investment, i.e. about 1.5% of EU GDP. At least 25% of the EU's long-term budget should be devoted to climate mesures and further support should be provided by the European Investment Bank. According to the European Commission, the Green Deal for Europe includes the following main elements:

- increasing the EU's climate ambitions for 2030-2050;
- supply of clean, affordable and safe energy;
- activation of industry for clean circular economy;
- construction with efficient use of energy and resources;
- accelerating the transition to sustainable and smart mobility;

- a "farmer-to-consumer" strategy, the creation of a fair, healthy and environmentally-friendly food system;
- protection and restoration of ecosystems and biodiversity;
- ensuring environment free of toxic substances thanks to the ambitious goal of zero pollution.

Note:

The circular economy is a method of production and consumption that processes already manufactured products or resources. This increases their value, prolongs their life and at the same time reduces the amount of waste. The circular economy thus strives for efficient and environmentally-friendly use of resources.

The ambitious Green Deal for Europe plan will also have a major impact on the automotive industry. What new challenges to expect, what can help to perform the challenging transformation; the main goal is to achieve climate (carbon) neutrality in Europe by 2050. This means ensuring that there are no more carbon dioxide emissions on the continent than can be somehow absorbed. This plan will require considerable investment and extensive transformation of industry and other areas, and naturally, it has enthusiastic supporters and sharp critics. A strategy for sustainable and smart mobility is due to be adopted this year. It will present new measures to ensure massive reductions in emissions from transport, the expansion of digitalization in transport, accelerating the production and introduction of alternative fuels, ending subsidies for the use of fossil fuels, promoting the use of rail and water transport at the expense of road transport, etc.

The current emissions legislation forces car manufacturers to produce electrically powered vehicles. The main reason for the introduction of electromobility is the zero production of local emissions and thus the reduction of the local environmental burden. This fact is especially important in cities. However, the share of global emissions, the carbon footprint and the impact on climate change as a whole corresponds exactly to the supply system of the the electric grid providing energy to electric vehicles. The carbon footprint of an electrically powered vehicle may be lower, but unfortunately also higher than that of a vehicle with an internal combustion engine. The advantage of electromobility may be an increase in the energy security (and independence) of the territory. This fact, however, depends on the structure of the electric grid power supply. Electric cars also have lower operating costs; the reason is the lower failure rate compared to conventional cars with internal combustion engines. It results from the fact that the electric motor has much fewer components than the internal combustion engine. The transition to electric cars is selectively supported by various instruments, such as the bonus-malus system, which is designed as a combination of a tax or a fee associated with the acquisition or registration (malus) of a less clean (conventional) vehicle and direct subsidies or tax credit (bonus) provided for cleaner technology. Important tools for the expansion of electric cars are taxes and the construction of charging stations, together with financial support for the purchase of electric cars. In Europe, electric cars currently account for only 4.4% of newly registered cars. In the Czech Republic, the share of electric cars is low, about 3,000 cars, which is only 0.28% of the vehicle fleet, or 0.5% of the vehicle fleet, including plug-in hybrids. The number of charging stations is growing massively, which relatively reduces the problem of the limited range of electric cars. The most powerful electric cars today declare a range of up to 500 km and more. Insufficient infrastructure of charging stations in different parts of the world can also be a problem. Moreover, this infrastructure is not unified, as carmakers or energy companies build stations according to their own standards. The American carmaker Tesla, which is the largest manufacturer of electric cars in the world, has its own charging infrastructure. There are a total of about 500 publicly accessible charging stations in the Czech Republic, but their number is growing rapidly. The disadvantage of electric cars is the long time required to charge the battery in the charging stand, compared to filling the tank in a conventional vehicle. At present, the acquisition costs of electric cars are also higher in comparison with vehicles with internal combustion engines. Examples are given in Table 1.

Table 1

Selected prices of electric cars (in millions of CZK)

City cars	Price	Medium cars	Price	Luxury class	Price
Renault Zoe	from 0.70	Škoda Enyag iV	from 1.15	Audi e-Tron	from 1.89
Mini Cooper SE	from 0.88	VW ID3	from 1.02	Jaguar i-Pace	from 2.13
BMW i3	from 1.05	KIA e-Niro	from 1.10	Tesla MS	from 2.27

2. Positive and Negative Aspects of Electromobility

The direction given by the documents and resolutions of the European Commission mentioned in the introduction is clear - low-carbon mobility. All European vehicle manufacturers have already invested billions of euros in it. This creates the impression, strongly supported by the media and green activists, that exclusively electric vehicles are the future and in the foreseeable future non-electric vehicles will no longer be produced. However, the reality and mainly the technical possibilities are different. Customer preferences are moving in a different direction, towards heavier sport utility vehicles and higher engine power, which results in rising CO_2 emissions. The massive campaign against diesel engines which have lower CO_2 emissions than petrol engines also plays a big negative role, e.g. CO_2 emissions from passenger cars have decreased or stagnated in recent years, Fig. 1 [1].

Electric cars have undeniable driving advantages. This is due to the better acceleration given by the excellent property of the electric motor to provide torque from the lowest speed. The advantage is also simple operation, without clutch and parts of the transmission. As standard, the car can be operated with only one pedal, while the brake pedal is used just for stopping or intensive braking. The most important advantage is the fact that the electric car does not produce any emissions while driving. The energy source of electric cars is an electric accumulator battery, currently usually lithium-ion (Li-ion) with a metal cathode (Cobalt-Nickel-Manganese, etc.), details and selected current information about batteries used in electric cars, at the time of writing the article, are listed in Table 2 [2].

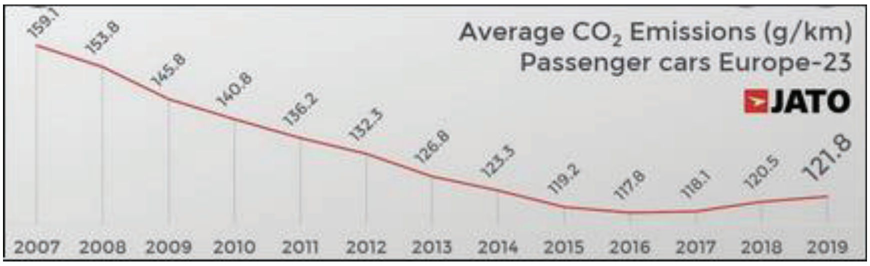

Fig. 1 Development of CO_2 emissions from passenger cars in Europe

Table 2

Batteries used in electric cars

Cathode materials	Electric car (selected manufacturers and models)	Specific capacity (Wh/kg)	Usable capacity (kWh)	Maximum range according to WLTP (km)
Lithium Nickel-Cobalt-Aluminium Oxide (NCA)	Tesla models: S, X, 3	162 – 168	76 – 102.4	487 - 593
Lithium – Manganese Oxid (LMO)	Citroën Zero	107	14.5	150
Lithium – Nickel Manganese – Cobalt Oxide (NMC)	Nisan e+, Peugeot e208, Opel-e, WV e-golf, Hyunday, Audi e-tron, Jaguar, Porsche, MB EQC etc.	103 – 152	32 – 95	232 – 417
Lithium – Cobalt Oxid (LCO)	Smart Fortwo electric	150 – 200	17.6	120 – 135
Lithium – Iron Phosphate (LIP)	Tesla model 3 (in China), BYD Han Ev	65 – 125	106	400 – 500

Note:

The stated maximum combined range according to the WLTP methodology is not achievable by default in actual operation. The actual range of selected electric cars is shown in Table 3.

The advantage of batteries is a high energy density of up to 200 Wh/kg (530 Wh/l), high nominal voltage (3.6 V), the possibility of production in any shape, life of up to 1,200 charging cycles, almost zero self-discharge, etc. The disadvantage is the risk of explosion in case of incorrect use (short circuit, charging to a higher capacity), difficult recycling, irreversible damage in case of complete discharge, etc. Safety in the event of an accident and fire becomes a subject of discussion because conventional fire extinguishers and hitherto common procedures are not enough to extinguish accumulator batteries. Of course, promising alternatives are being developed, such as lithium-sulfur batteries, etc. but they will probably not be usable in the coming years because of their short life span.

We believe that it is very important to understand the context, both the consequences of electricity generation for vehicle drive and the consequences of battery production. Current developments in European legislation are massively pushing manufacturers into the development, production, and sale of purely electric vehicles and do not take into account the total carbon footprint of electric vehicles during their life cycle, i.e. from vehicle production, making batteries as a source of electricity for propulsion to the recycling phase. As a result, it is necessary to produce and sell an increasing number of battery electric cars and possibly plug-in hybrids, which, according to valid measuring methods, will still fall below the set limits, which form the limit for so-called clean vehicles. It can be stated that in the world outside Europe there is also an effort to reduce emissions, but gradually and in the light of technical developments, and without harsh sanctions. There are countries where they take other ways into account and give space to a combination of different solutions. An example is Japan, where next-generation vehicles include hybrids, plug-in hybrids, battery electric cars, "clean" diesels and CNG vehicles [3]. The big question is whether electric cars are really emission-free. We believe that only from a local point of view, i.e. when driving, they definitely are. This is their biggest advantage, especially in an urban environment. Unfortunately, from a global perspective, the impact on the Earth's climate, emissions, mainly CO_2, arise both in the production of electric cars but mainly in the production of batteries and in the production of electricity for their operation. When these commodities are produced far from urban agglomerations, harmful emissions in the air are diluted and do not act as massively as the operation of vehicles. Unfortunately, in the case of greenhouse gases, and their impact on the climate and global warming, it does not matter at all where they originate (city, remote power plant, other countries, etc.).

The range is one of the most monitored parameters of electric cars; every increase is welcomed with great enthusiasm, especially in the media. The range is increasing due to new solutions and battery improvements but is still insufficient compared to cars with internal combustion engines. The range also decreases in the winter depending on the temperature and the need to heat the vehicle. The heating consumption depends on the driving time and not on the distance travelled, e.g. according to [4], [10] the stated and actual distances of selected electric vehicles are shown in Table 3. Actual ranges are significantly smaller than the officially reported ones, which are determined in laboratory conditions according to the exact methodology (WLTP). The battery of an electric vehicle consists of a large number of cells, a cooling and heating system, control electronics, a supporting structure and battery housing. It is a fact that a substantial part of CO_2 emissions occurs during various stages of production (extraction of raw materials, refining of materials, production of electrodes, assembly of cells, installation of batteries including cooling, heating and control systems, control electronics and packaging).

Table 3

Actual range of selected electric cars in km

Car	Stated range	Actual range	Car	Stated range	Actual range
Tesla S 75D	490	328	Renault Zoe	316	235
Jaguar I-Pace	470	407	W e-Golg	231	188
Kia e-Niro	485	407	Nissan Leaf	270	206
Hyundai Kona	482	416	BMW i3	235	195

The battery is a relatively sophisticated device that contains several rare elements (Lithium, Cobalt, Samarium, Neodymium, etc.), as well as Nickel, Copper, Manganese, Aluminum, steel, rubber, plastics and other components. Fig. 2 [17] shows an example of the location of a traction battery in electric vehicles. It was stated in the introduction that an electric car is much simpler from the point of view of propulsion than a vehicle with an internal combustion engine due to the number and complexity of the mechanisms forming the internal combustion engine. As for a rechargeable battery (of an electric car), we can mark the fuel tank as equivalent (in the case of a vehicle powered by an internal combustion engine). In this comparison, the complexity and cost of production, including the materials used, are clearly lower for conventional vehicles.

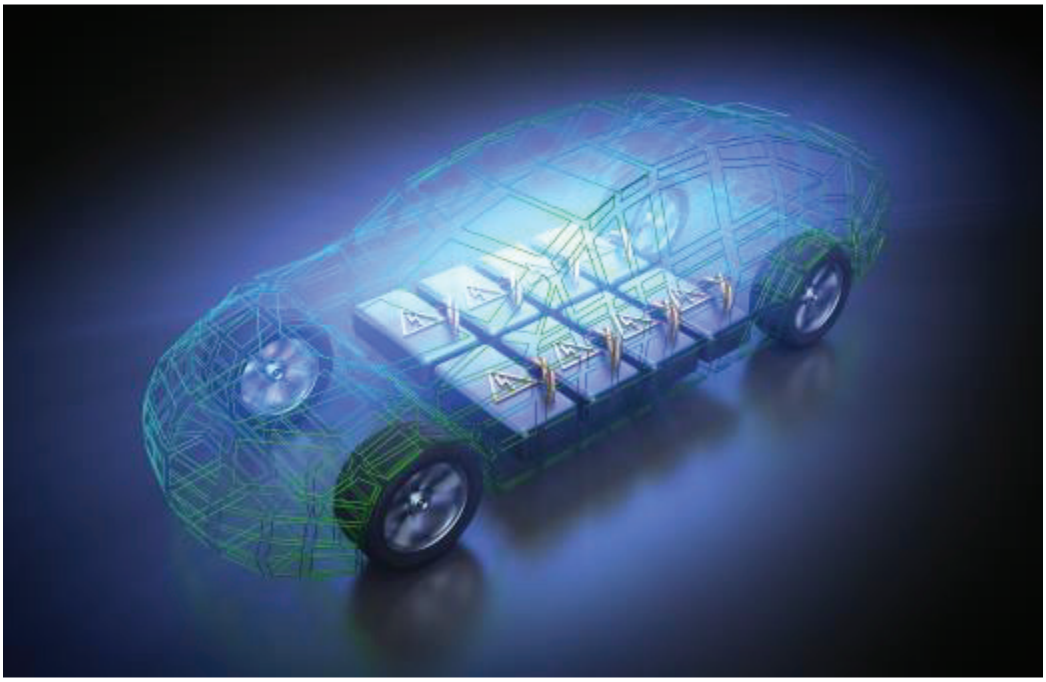

Fig. 2 Example of a traction battery location in an electric car

Emissions that arise during the production of electric cars depend on respective phases of the production and technologies used. The complexity of production and the resulting emissions is assessed by the energy consumed (electricity 40 - 70%, heat, mix of heat and electricity). Consumed electricity can be converted to the amount of produced CO_2 using the so-called emission factor E_f of individual countries. The emission factor indicates how many kgs of CO_2 are produced per 1 kWh of electricity generated, or how many tons of CO_2 per 1 MWh. The value of the emission factor is different for individual countries; examples of the emission factor are given in Table 4. The energy required for the production of batteries for different types of drives is given in Table 5 [1].

The amount of pollutant emitted E_Z is calculated according to the relation: $E_Z = E_f \cdot M$, where M is the number of units to which the emission factor is related, e.g. the mass of fuel burned. The decisive item of emissions in the production of an electric car is the energy consumption for the production of a battery, which is a one-off item but is not negligible. The energy consumed is given in relative values MJ/kWh, i.e. how much energy per 1 kWh of battery capacity, and for a specific battery it is necessary to multiply these values by the battery capacity. However, the results are affected by the energy density of the battery. The energy intensity of production decreases with higher energy density. The energy density of current batteries ranges from 0.10 to 0.16 kWh/kg. The trend is to increase the energy density and capacity of the battery [5]. With the anticipated development of technologies, it can be expected that the electricity consumption for battery production will be in the range of 300 to 500 MJ/kWh, i. e. about 85 to 140 kWh/kWh of battery capacity in the near future. In general, from the point of view of the energy consumed for the production of batteries and the corresponding emissions, the battery electric car appears to be very disadvantageous in comparison with other types of electrified vehicles (hybrids).

Table 4

Examples of emission factor E_f of selected countries (t CO_2/MWh)

Country	E_f	Country	E_f	Country	E_f	Country	E_f
Norway	0.01	Sweden	0.01	France	0.06	Slovakia	0.19
Belgium	0.20	Spain	0.29	Italy	0.35	Netherlands	0.45
Great Britain	0.47	Germany	0.49	Czech Rep.	0.53	Greece	0.66
Poland	0.77	China*	0.76	South Korea*	0.48	Japan*	0.30

Note:

For countries marked with an asterisk, the emission factor values are only estimated. The values of E_f depend on where the sources of electricity come from, e.g. in the Czech Republic in 2020 renewable sources (solar, wind, hydro, geothermal, others) are about 4%, fossil fuels (biomass, coal, natural gas, oil, others) about 57% and nuclear resources 39%. The issue of the energy mix is very complex, e.g. in terms of spatial evaluation, i.e. the area occupied by the source of electricity. If wind power plants were to be the only source, they would cover 15,000 km^2, which is about 20% of the entire territory of the Czech Republic, solar power plants would cover 3,000 km^2, while nuclear power plants would cover only 28 km^2.

Internal combustion engines generate emissions mainly during fuel combustion while driving [15, 16]. CO_2 emissions are directly proportional to consumption and are determined for petrol: emissions = 23.38 • consumption, and for diesel: emissions = 26.83 • consumption [g /km, l/100 km]. Emissions also occur in the extraction and processing of oil and in the production of fuel but are relatively small due to the high energy density of petrol and diesel. The results of the life cycle analysis show that in oil extraction, transport, production, pumping and distribution of petrol or diesel, the share of emissions is about 10% and in operation the remaining 90%. Specifically, the production of a car with an internal combustion engine generates 5 to 10 tons of CO_2 (depending on size, weight and equipment), of which about 20% are emissions from the production of the internal combustion engine itself. The amount of NOX and CO emissions arising in internal combustion engines for various fuels is given in Table 6 [7].

Table 5

Energy requirement for battery production

Type of drive	Battery capacity	Energy for battery production
Mild hybrid	0.5 kWh	150 – 250 MJ → 40 – 70 kWh
Full hybrid	1.5 kWh	450 – 750 MJ → 125 – 210 kWh
Plug-in hybrid	10 – 15 kWh	3000 – 7500 MJ → 830 – 2080 kWh
Battery electric car	30 – 100 kWh	9000 – 13900 MJ → 2500 – 13900 kWh

Table 6

NO_X and CO emissions in internal combustion engines

Type of fuel	NO_X	CO	Unit
Natural gas, liquefied natural gas	4 000	2 300	kg · 10^{-6} · m^{-3} of fuel burned
Gas, biogas	3 000	5 100	kg · 10^{-6} · m^{-3} of fuel burned
Diesel, liquid biofuel	26.8	6.0	kg · t^{-1} of fuel burned

The effort of electric car users is to recharge the batteries as quickly as possible. Unfortunately, the charging time is not achievable compared to refueling with petrol or diesel. When refueling the tank, megawatts of power flow through the hose, e.g. when refueling 30 l of gasoline in 2.5 minutes (energy contained in 1 l of gasoline is about 32 MJ/l) the power is $P = (30 \cdot 32)/150 = 6.4$ MW. No charging cable allows the transmission of such a large electrical power; to achieve such power at a given battery voltage requires a current in the order of thousands of A. The basic issue is the cooling of batteries, or maintaining their optimal temperature of 20 to 40°C, or 50 to 80°C when charging; at higher or lower temperatures, the performance decreases massively [8] and their wear increases. During charging, there are significant energy losses depending on the slow or fast charging, up to 10 to 25% (electrical installation, charger, charging cable, on-board installation, battery), the losses are converted into heat.

The current average consumption of electric cars is between 15 and 25 kWh/100 km [10]. The specific size is a function of a number of factors, such as vehicle weight, nature of the operation, temperature, driving style, driver experience, etc. Economical driving of a small electric car means consumption of about 12 kWh/100 km. Large electric cars exceed a consumption of 30 kWh/100 km when driving hard. Unlike a vehicle with an internal combustion engine, energy can be recovered in electric cars and stored back in the battery during braking. However, the efficiency of energy recovery is relatively low and in practice only an average of 5 to 10% of extra energy can be used. In the winter it is necessary to heat the vehicle, in a conventional car the waste heat of the internal combustion engine is used but the electric car uses energy from the battery. This causes an increase in energy consumption for heating during the year of about 10%.

3. Discussion

In the Czech Republic, acknowledged experts Prof. Macek, FEng., and Dr. Morkus from the Center for Sustainable Mobility carried out a study at the Czech Technical University in Prague [1], which systematically compares current approaches to electromobility including model examples comparing emissions of electric cars and identical vehicles with internal combustion engines. The study gives examples based on the cradle-to-grave approach, i.e. the whole life cycle of the vehicle, where not only the operation of the vehicle (Tank-to-Wheel) but also the production of fuel or electricity (Well-to-Tank) was respected, including losses and emissions from the production of vehicles and batteries. For comparison, one electric car and one equivalent vehicle of similar power with a petrol and diesel engine from the same manufacturer were selected. All data are official figures provided by the manufacturers (power, weight, consumption, battery capacity) [9]. The Škoda Citigo was chosen as the representative of small vehicles, the Hyundai Kona for medium vehicles and the Audi e-tron/Q8 quattro represented large vehicles. The results show that up to approximately 130,000 km, electric cars have higher CO_2 emissions than a car with a petrol engine, and up to approximately 250,000 km, an electric car has higher CO_2 emissions than a car with a diesel engine. Assuming that after the battery warranty expires, i.e. usually after 160,000 km, the battery is replaced, the electric car will almost always be worse in emissions up to about 250,000 km than a petrol car, and a diesel car will practically never be surpassed by the electric car in terms of CO_2 emissions. Even more advantageous is the conventional car running on fuel with a high content of biocomponent with recycled carbon, such as biogas. Based on the fact that under current legislation, only emissions from vehicle operation are taken into account (emission $_{\text{drive}}$) and everything else is neglected, carbon neutrality can be achieved only in theory, not in reality. The above results from the Czech Republic are not generally valid in all countries. The energy mix of individual countries has a massive influence. For example in Norway, most electricity comes from water sources. This will result in equal CO_2 emissions for electric cars and automobiles after about 45,000 km, i.e. after about 2-3 years of operation. The situation is also favorable in France, where the source of most electricity is nuclear power plants.

There is no doubt that it is necessary to reduce emissions from human activities, but the reduction should be effective and gradual. For example, the new US President, Joe Biden, the representative of a country that is the world's second-largest polluter, has set ambitious goals for the environment. According to the declared goals, these are two areas. The US carbon footprint will fall to zero by 2050 and there will be no emissions from power plants by 2030. What awaits America? In particular, the reduction in the emissions produced by their cars involves the replacement of a total of 250 million passenger cars and 12 million petrol or diesel trucks. For example, President Biden quickly convinced GM, which came up with a commitment that by 2035, all their cars will be electric-only. A significant disadvantage of Biden's ambitious statements is the uncertainty of their persistence. The president may issue executive orders at any time, but the next president may revoke them overnight, as happened to President Obama.

Energy (electricity and heat production) has the largest share of CO_2 emissions in Europe, followed by industry, households, transport, natural resources and agriculture. If emissions are to be reduced, this should happen in these areas in particular. The share of transport in CO_2 emissions in Europe is about 12 to 20%, of which the share of road transport is about 72%, while passenger transport accounts for about 60%. Unfortunately, the exact values are not credibly presented but considering the differences, most experts and studies agree that Europe's share of total global CO_2 emissions from human activities is around 10% [11]. These figures show that in Europe, replacing all passenger cars with internal combustion engines with electric cars would cause a negligible change in total world CO_2 production of just 1%. As follows from modelling [1], in the Czech Republic, there would be virtually no reduction in CO_2 emissions without a massive change in electricity production.

It can be stated that the trend of increasing the range of electric cars and shortening the charging time is incorrect, both from the economic and ecological point of view. In general, it leads to increasing emissions, increases the cost of production of electric cars, increases their prices, slows down the replacement of older vehicles with modern ones [12]. The optimal solution to reduce emissions is to quickly replace the vehicle fleet with modern low emission cars. The total CO_2 emissions of electric cars depend on the capacity of the battery, and therefore the larger the battery, the higher the CO_2 emissions during its production. Also, as capacity increases, so does the weight, size and price of batteries, which has the same consequences, namely increased emissions. As charging times decrease, losses increase, so slow charging with low power is optimal if possible at night (lower electricity consumption, lower utilization of power plants and use of a favorable tariff); an essential factor is also longer battery life with slow charging. The idea that a sufficient number of powerful fast charging stations will solve the problem is not realistic. Replacing internal combustion cars with electric cars without changing electricity sources, when considering the entire life cycle of the vehicle, will not lead to a real reduction in CO_2 emissions in the Czech Republic. EU emissions regulations only take into account a one-sided view without broader context, which is massively supported by lobbyists, politicians, green activists, massive media campaigns and, unfortunately, some representatives of the automotive industry who fear delays and market losses after investing huge sums in electric car development. The automotive industry rightly expects a return on investment and a profit. This leads to a very difficult situation when it is impossible to back away from the electromobility trend and previous wrong decisions. The situation is not easy, as almost 15 million jobs in Europe depend on the prosperity of the car industry. Due to the high development costs of electric cars and the decline in sales due to the pandemic, manufacturers have to save, which leads to redundancies and the risk of losing the competitiveness of the European automotive industry.

Cars with low-emission internal combustion engines, various types of hybrids, battery electric cars and, in the short term, also cars running on hydrogen, should be used in areas where it is most advantageous. The electric car is definitely not a universal or the most advantageous solution. It turns out that it would make more sense to produce modern cars with low-emission internal combustion engines, as well as mild and full hybrids, which use relatively small batteries and massively reduce consumption and emissions. At the same time, they do not need any charging infrastructure. In urban traffic, they can only run on electricity with zero emissions, the necessary range, excellent dynamics, low noise [13], etc. A repeated argument in favor of electric cars is the fact that electric motors are significantly simpler than internal combustion engines. It is usually not stated that batteries are much more complex than a fuel tank with the same stored energy capacity. Also, the efficiency of the electric motor is higher than the efficiency of the internal combustion engine; the efficiency of the internal combustion engine is usually 30% and the electric motor 90%. However, this information only applies to a relatively narrow range of torques and speeds.

Fuel for the internal combustion engine can be refueled with virtually 100% efficiency. For electric drives, the charging efficiency of the battery, the efficiency of its discharge during operation and the efficiency of the inverter must be taken into account. Average efficiency depends on the type of traffic, vehicle load and driving style of the driver. It is around 25% for petrol engines [3], about 30% for diesel engines and close to 60% for electric drives [14]. If we also take into account the efficiency of fuel production and electricity production, there is no longer any difference between the efficiency of internal combustion engine propulsion and electric motor propulsion. But there is another difference: the consumption of an internal combustion engine is lower when driving long distances or on the highway, but it is higher when driving in the city. The situation is the opposite for electric motors, lower consumption is due to recuperation in the city; outside the city it increases with speed and driving dynamics. This is the main reason why electric cars are convenient for city driving and not suitable for long-distance driving. Fig. 3 shows the newly introduced harmonized range of labels under the EU Directive for electric vehicles and charging stations and alternative fuel infrastructure.

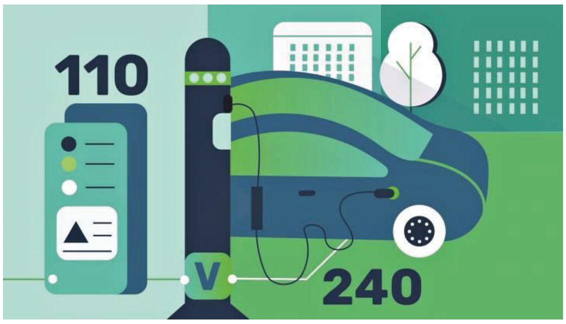

Fig. 3 A new harmonized range of labels under the EU Directive for electric vehicles and charging stations and alternative fuel infrastructure.

Another reason in favour of electromobility is the fact that the operation of electric cars is cheaper. This fact only applies conditionally if the users have the possibility to recharge the vehicle with low power at home in the garage but if they recharge at a public charging station, the prices are higher than for petrol engines [15]. If vehicles with internal combustion engines were to be replaced in bulk by electric cars, it would be necessary for the state to compensate for lost taxes on fuel probably by higher taxation of electricity. For the electric car, some maintenance activities are eliminated and it is stated that maintenance costs will be significantly lower. However, for example, the technical condition and warranty terms of the batteries are conditioned by regular maintenance, which, especially with high-voltage batteries, means relatively complex and expensive service. Cars with electric drives should be used in the short term wherever they are clearly suitable and their operation is economical and emission-free. It is a relatively large number of applications starting with cars that run mainly in city traffic (supply, city public transport, cars of city authorities, city police, vehicles of taxi services, rental and car-sharing companies, other family cars, etc.) and of course electric scooters and electric bicycles. Quick decommissioning and replacement of cars with petrol or diesel electric cars, which will be enforced by emission regulations, is easy but only if the number of electric cars is small. There will be problems with bulk expansion.

4. Conclusions

The information provided in this article is alarming and the solution to the problems will be out of reality, which mainly concerns the provision of the required amount of energy. However, the solution is not fast and requires a longer time, probably the connection of electric cars to the system of smart grids. Routine recharging of batteries requires slow recharging with relatively low power, during parking (night rate electricity, garage, company car park, etc.). The charging infrastructure should be built in this way and fast charging stations should be an accessory in truck car parks, near motorways, in places where it is difficult to create a slow charging infrastructure. For the next 5 to 10 years, it seems to be an acceptable solution to diversify the types of vehicle propulsion (i.e. to electricity, liquid fuels, hybrid propulsion, CNG, hydrogen, etc.), depending on the purpose of use and the type of operation of the vehicle. In order for electromobility to be meaningful and to improve the environment, it seems vital that at the same time, sources of electricity with minimal emissions are built which will realistically cover the consumption of electric vehicles, without the occupation of agricultural land.

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Accidents of Emergency Vehicles

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Abstract

The article deals with the statistical evaluation of traffic accidents of vehicles with the right to use the beacon while driving. The statistics are focused on the area of Slovakia and are divided by regions. The statistics show the number of accidents of vehicles with special warning signs and vehicles with priority right. Based on the cooperation with Falck company (the operator of ambulance vehicles in Slovakia) data was obtained on driver training practices. Selected elements of the internal standard of Falck and the Slovak regulations are a part of the article. Demonstration of the road traffic accidents of ambulances captured by a camera is the part of the research focused on the accidents of these vehicles at the intersection. The paper is part of the EU project SENECA with the cooperation of University of Zilina and Technion institute in Haifa.
KEY WORDS: *emergency vehicles, traffic accident, PC Crash*

1. Transport Accident Statistics of Emergency Vehicles with Right of Way

In Slovak republic, there is according Fig. 1 decreasing trend of transport accidents of emergency vehicles with right of way. One of the reasons for such a trend could be the higher education level of emergency vehicle drivers or more tightened internal regulations of companies responsible for the operation of emergency vehicles. In the next chapter, internal regulation of organizations operating the ambulance emergency vehicles will be analysed and compared with current legislation in the Slovak republic. It will be described how the regulation has been modified in order to improve ambulance emergency vehicle drivers' behaviour.

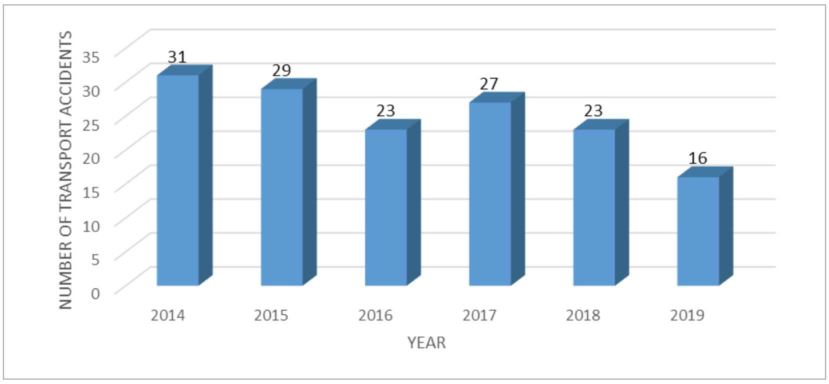

Fig. 1 Number of transport accidents of emergency vehicles with right of way in period 2014 – 2019 [1]

2. Legislation for Emergency Vehicles with Right of Way in Slovak Republic

The driving of emergency vehicles with the right of way in Slovak republic is regulated by law no. 8/2009 Z. z. o cestnej premávke. § 40 ods. 1) law no. 8/2009 Z. z. says, that emergency vehicle driver is not obligated to comply with responsibilities and prohibitions mentioned in this law (excluding police force orders in connection with their authorization, the driver must have a special driving license, must not be under influence of alcohol or drugs, must not be tired or ill) and is obligated to act in a careful way not to endanger other traffic participants. § 2 ods. 2 písm. o) zákona č. 8/2009 Z. z. says, that not endanger others means acting in such a responsible way, that will not create any kind of danger towards other traffic participants [2]. The term "not to endanger" is working experts quite often as it is one of the criteria in offender determination. Emergency vehicles with the right of way in duty must use audible and visual signals. If one of them is not activated, the vehicle is not considered to be the one with the right of way. According § 40 ods. 8) zákona č. 8/2009 Z. z. o cestnej premávke - the driver of other vehicle is obligated to enable safe and fluent drive for emergency vehicle and if necessary even stop the vehicle in order not to be an obstacle [2]. It is often observed that transiting emergency vehicles on a long route does not have an audible signal on. The reason for that is the serious audio discomfort of passengers. In provision § 40 ods. 9) zákona č. 8/2009 Z. z. o cestnej premávke says, that in case of increased traffic density in one way causing a traffic jam, the emergency vehicle driver is allowed to use roadside or another part of the road which is not designated for vehicle driving, but there is a requirement to act in the responsible and careful way in order not to endanger other traffic participants. According to the § 40 ods. 6) zákona č. 8/2009 Z. z. o cestnej premávke - the emergency vehicle driver must be older than 21 years and must have at least 2 years long practice in the driving of vehicle of the same category [2].

3. Internal Regulation for Ambulance Emergency Vehicle Driving

Internal regulations of any company must satisfy at least the national laws of the country. On the other hand, the internal regulations are allowed to be stricter and require extra duties. In the following points, the complementary requirements are listed up which are stricter in comparison with national law.

- Unjustified usage of emergency audible and visual signals are prohibited.
- Driver is allowed to use emergency audible and visual signals only in necessary cases and with approval of the leader.
- Emergency audible and visual signals to be used only for the necessary period of time to fulfill the task, to be activated in advance in order to enable other traffic participants to be aware of an emergency vehicle and allow its safe and fluent drive.
- With activated audio and visual signals are the driver is obligated to respect the speed limit of the vehicle and road however the limit can be overreached by 20 km/h (Excluding highway, where is driver obligated to keep speed limit 130 km/h). Driving over the speed limit must be also approved by the leader of the emergency action.
- Driver of ambulance emergency vehicle is obligated to stop the vehicle on crossroad red traffic light, also in case of traffic situation where is not obvious his right of way. He must stop in a position, where is a clear view and is allowed to continue with the vehicle only in case there is not any danger to do so [3].

4. Transport Accident Statistics of an Emergency Vehicle with the Right of Way in Period 2014-2019

Transport accidents of emergency vehicles with the right of way are very specific and causes of accidents are mostly different than causes in the case of standard traffic vehicles. The important fact is that emergency vehicles with the right of way are not obligated to follow the road traffic rules. Many drivers are used to driving according to repeated experiences, rely on other’s traffic participants' discipline and do not pay the required attention for driving the vehicle. Listening to loud music during driving is also one of the reasons for the delayed detection of an emergency vehicle. Similarly using of mobile phone could lead to limited attention for traffic situation. Green light on the traffic light or driving on the main road often gives false certainty to the driver, that there is no chance of a sudden obstacle and his attention is significantly decreased a reaction is slower. In following part will be described transport accidents of emergency vehicles with right of way in Slovak republic in period 2014 – 2019. In this period of time, it has been recorded 149 transport accidents.

From total transport accidents number of an emergency vehicle with the right of way 72% of accidents were registered in the city and 28% out of the city as you can see in Fig. 2. It is caused by the fact, that probability of accident occurrence is higher as there is higher traffic density. There is also more crossroads and collision points where an accident can happened. Transport accidents occurrence probability on roads out of the city is lower, however consequences of such accidents are mostly much more serious than those in the city.

From Fig. 3 is obvious that 50% of the accidents were collisions with road traffic vehicles. 20% of accidents were collisions with parked or not moving vehicles. The third largest group are other accidents which are not classified in any of the previous category. Accident with the collision of pedestrian has 5% portion.

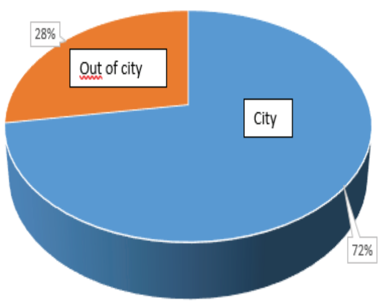

Fig. 2 Emergency vehicles accidents proportion according to place in period 2014 -2019 [1]

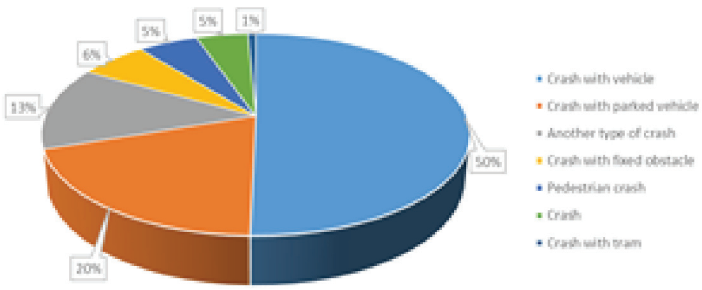

Fig. 3 Emergency vehicles accidents proportion according to type in period 2014 -2019 [1]

In following Fig. 4 is shown that 95% of accidents happened under good surrounding view conditions. In other 5% the surrounding view conditions were limited due to visual obstacles around the accident place as are the buildings or fences. To this group also belong reasons such as limited view due to nature of road profile with peaks or sloping type of the road. Mentioned influences on driver view conditions have a significant impact on the accident cause, however, their portion in this group is quite low.

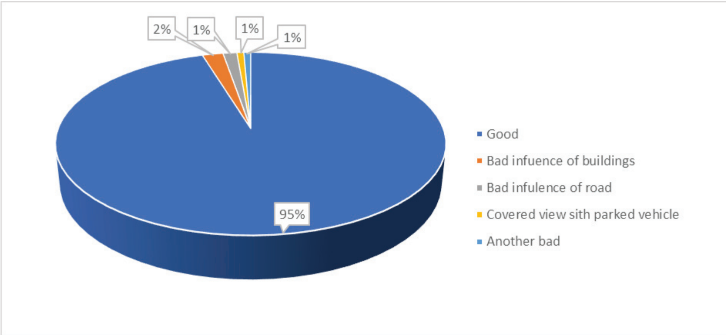

Fig. 4 Emergency vehicles accidents proportion according to view condition at the place of accident 2014 -2019 [1]

Fig. 5 represents the vehicles accidents portion according to the traffic organization method. It concludes that not all vehicle accidents happen at crossroads. In fact, if roads are without traffic signs or traffic lights, traffic organization and right of way should follow general rules of traffic. Directly the statistics are followed up by Chart no. 5, which evaluates the number of accidents that happened on crossroads of direct roads or in other important parts of the road such as curves or direct parts of the road just before the curve.

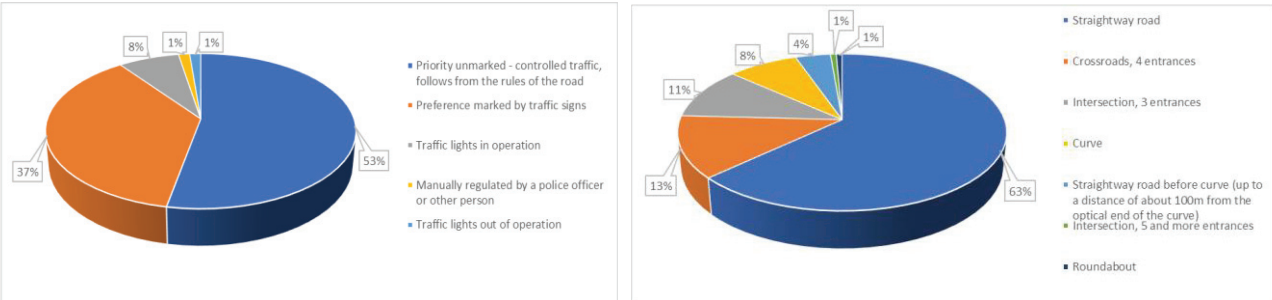

Fig. 5 Emergency vehicles accidents proportion according to traffic organization method 2014 -2019 [1]

The next indicator (Fig. 6) of transport accidents statistics of emergency vehicles with right of way is visibility condition at the accident scene. By 70% of accidents was decreased visibility by actual weather condition and accident happened during the day. Only 15% of accidents were registered during the night with public lights on, where visibility was not affected by weather conditions. It means that these accidents were recorded in the city area.

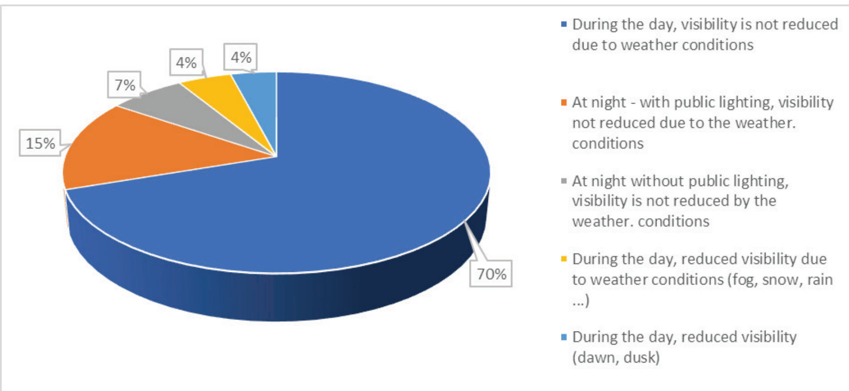

Fig. 6 Emergency vehicles accidents proportion according to visibility condition at accident site: 2014 -2019 [1]

Graph of accident proportion according to the type of collision of moving vehicles represents possibilities of collisions of an emergency vehicle with another participant vehicle. In the category of not moving vehicles collisions, the other vehicle must have been stopped, or there was another obstacle as a tree, traffic sign or another subject. This sample represents 49% of the total number of accidents. In other cases, it is about vehicle collision and concerned vehicle's position at the time of the crash (Fig. 7).

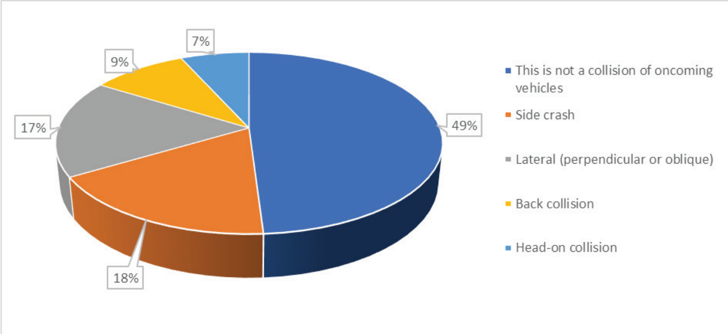

Fig. 7 Emergency vehicles accidents proportion according to type of collision in period 2014 -2019 [1]

In Fig. 8 are statistically evaluated accidents in connection with road surface conditions at the accident scenes. 72% of the accidents were registered on the dry and clean surface of the road. 24% of the accidents happened on the wet surfaces of the road. The rest of the accidents were those on roads covered by snow or ice.

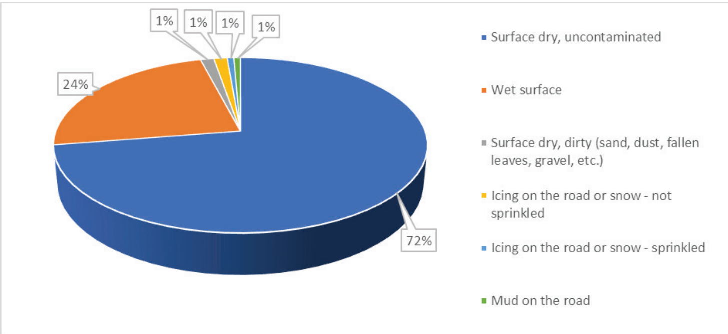

Fig. 8 Emergency vehicles accidents proportion according to road surface condition in period 2014 - 2019 [1]

Regarding weather conditions, 83% of accidents were recorded under standard weather conditions, which means without the decreased level of visibility or other negative factors. Second highest portion of accidents were those in rainy weather, which represents 9% of the total number of accidents. The rest of 8% are accidents under other weather conditions such as fog or snowing (Fig. 9).

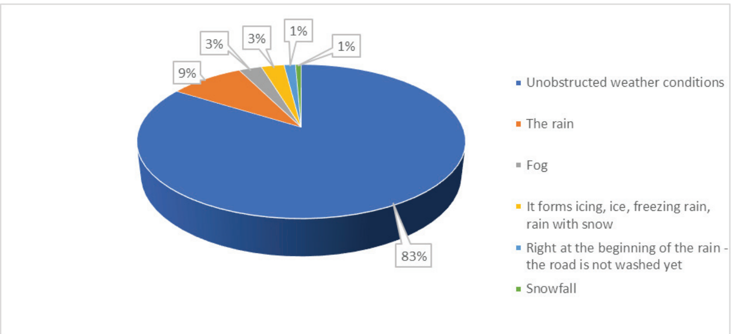

Fig. 9 Emergency vehicles accidents proportion according to weather condition at accident site 2014 – 2019 [1]

The most frequent type of road where accidents occurred was a two-lane road (62%). Four-lane road with separating strip (10%). 9% of the accidents happened on unidentified types of road related to the categories in Fig. 10.

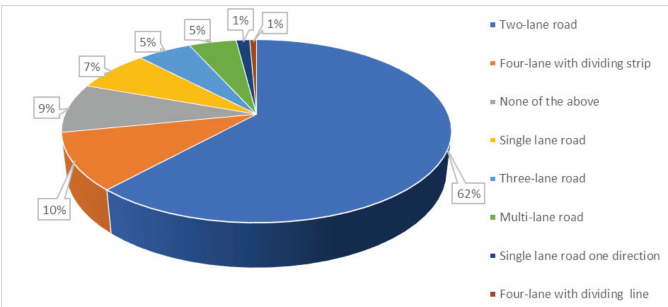

Fig. 10 Emergency vehicles accidents proportion according to road type in period 2014 – 2019 [1]

From presented accident statistics of emergency vehicles with right of way in period 2014 – 2019 results the facts of most frequently registered accidents:

– In the city (72%);
– Collision with moving road vehicle (50%);
– Under good surrounding view conditions (95%);
– Traffic organization without traffic lights or signs, managed just by traffic rules (53%);
– In the straight road section (63%);
– During day time, under normal weather conditions (70%);
– Collision of not-moving vehicles (49%);
– Road surface dry and clean (72%);
– Not under difficult weather condition (83%);
– On two-lane road (83%).

5. Database of Transport Accidents

In the time period 2016 - 2020 was recorded 10 real traffic AV accidents were by company Falck, which is a provider of AV services (Fig. 11). All accident video materials have been provided to the Institute of Forensic research and education for further investigation. A complex overview of accident circumstances is mentioned in the table. The article has described a simulation of one accident event. Complex analysis of all accidents will be published after detailed investigation.

Accident	Day time	Visibility	Direction of motion	Colided object	Traffic light	Signal on traffic light	Weather condition	Location	Speed limit	Driving line	Sun bliding	Obstruction	Siren	Traffic dansity	Type of crrosing road	Agresivity
no. 1	night	umele osvetleno	forward	pedestrian	yes	red	dry	city	up to 50	4	yes	no	no	0	+	no
no. 2	day	cloudy	turning	vehicle	no	-	wet	city	up to 50	2	no	no	no	1	y	no
no. 3	day	cloudy	forward	vehicle	yes	red	dryd	city	up to 70	4+2	no	no	yes	1	+	no
no. 4	day	cloudy	turning	vehicle	yes	red	dry	city	up to 50	4+2	no	no	yes	3	+	no
no. 5	day	sunny	forward	vehicle	no	-	dry	city	up to 50	2	no	yes	no	0	+	no
no. 6	day	cloudy	forward	vehicle	no	-	dry	city	up to 70	2	no	yes	yes	3	T	no
no. 7	day	sunny	forward	pedestrian	no	-	dry	city	up to 50	2	no	no	yes	0	T	no
no. 8	day	cloudy	forward	vehicle	no	-	dry	city	up to 50	2	no	no	no	0	T	no
no. 9	day	cloudy	forward	vehicle	no	-	dry	city	up to 50	2	no	no	n/a	2	T	no
no. 10	Day	janso	forward	vehicle	no	-	dry	city	up to 50	2+1	no	no	no	1	T	yes

Fig. 11 Database of transport accidents [authors]

6. Analysis of Accident Event of Ambulance Vehicle with the Right of Way Driving on Crossroads– Case No. 3.

6.1. 3D Model for Transport Accident Documentation Purposes

Introduction Photogrammetry and its use within the modern forensic analysis were for a long time on a rapid decline. Practical use of photogrammetry by general forensic experts usually degraded to a simple plane rectification of a given image with the use of four known points and their relations. In spite of the wide range of proven or newly developed methods for photogrammetric reconstruction, the necessary knowledge of fundamental photogrammetric principles and rather time consuming processing leads to a decrease in its usage. However, the rapid development of image processing software, increasing quality of available photographic documentation and lowering demands on technical equipment used for reconstruction seem to be able to change this situation. Modern photogrammetric software, which is based on multi-image digital correlation, enables to process and interpret a wide range of information that is captured within the images with almost no or very limited requirements to the knowledge of fundamental photogrammetric principles. Furthermore, users are able to process and reconstruct even highly complex accident scenes via a user-friendly interface in a significantly less time-demanding and complex way. Although the road surface can be measured by several different techniques, the photogrammetric approach seems to be a suitable approach for the purposes of traffic accident forensics. The main advantages are low acquisition costs, flexibility and speed of measurements and sufficient resulting accuracy. It can be argued that the laser scanner will be able to capture data in higher or similar details with significantly higher accuracy. However, there is a significant ideological difference that plays a significant role in transportation forensics. Most of the traffic accidents are resolved on site and are not further analysed in greater depth. The necessity of forensic assessment arises usually only in a few cases and with a certain time delay. Thus, the implementation of laser scanning would be unnecessary and inefficient in most cases. On the other side, photogrammetric approaches introduce a possibility to utilize photographic documentation in two ways. The photographs enable us to easily and effectively capture the situation and conditions at the accident site by themselves and only if necessary serve as a base for spatial reconstruction. Thus, it increases the documentation effectiveness without the need for significant investments or change of current procedures. Additionally, adverse weather conditions, such as rain or snowfall can significantly affect the resulting accuracy and quality of laser scanning outputs. A prime example of a suitable photogrammetric tool is PhotoScan (newly rebranded as Metashape) which is produced by the Russian company Agisoft LLC. A wide range of articles already discussed and assessed its potential for accident scene reconstruction, documentation of various marks, deformations or as a tool for creation of accurate and detailed orthophotos of the accident scene. The results show high potential, flexibility, sufficient accuracy of the outputs, applicability and lower time and cost demands.

However, most of these studies or practical tests were focused on the application of digital image correlation under ideal conditions. Situations where the weather was optimal, light conditions were sufficient or the reconstructed object was suitable for the automatic processing. Yet, traffic accidents occur not only under these ideal conditions. Therefore, this article aims to show, how the processing is affected by adverse conditions of the environment, whether there are any possibilities to improve the resulting outputs and if the results are still suitable for the purposes of forensic analysis. Discussed recommendations are based on the research of authors and their practical experiences which were obtained throughout their daily work (two of the authors are policemen at the traffic department of Slovak republic and two are doing photogrammetric processing for the purposes of forensic testimonies). The recommendations are shown in two study cases. The study cases were captured under significant adverse conditions (night time, heavy snowing) with an aim to show the possibilities and potential limits of this approach. Digital image correlation Modern photogrammetric software enables the automatic processing of acquired images. The software is based on digital image correlation where the identification and referencing of common features (points, edges, patterns) within the images is done automatically through and advanced image recognition algorithms. Thus, there is no more a necessity to perform the time demanding to the reference images by the user. This approach leads to a significant reduction of processing time of the reconstruction and a decrease of the requirements onto the user’s knowledge. However, it also means that the outputs are no longer selective measurements of the points of interest. The measurements lead, similarly to 3D scanning, to an aggregation of all points which the software was able to identify within the image (a dense point cloud). The digital image correlation principle lies in the identification of common significant features between multiple images. The image correlation automatically identifies and uniquely connects the same elements of a scanned object (points, patterns, edges) to two or more images capturing a given object. If we were looking for an image of a homology point (represented by one pixel in one image) within only one pixel, we would find hundreds of thousands of identical pixels in the other image. Therefore, it is assumed that each point has a unique neighborhood to a certain extent, through which we can identify the position of the homology point in the second image. The larger the point, the higher the probability of finding the correct point, but the computational demands will increase. The automatic matching of pixels is one of the earliest problems of computer vision and is still one of its most studied topics. Conformity analysis is a prerequisite for understanding the images of the space explored and is closely related to human visual perception. While digital imaging of suitably structured scenes (eg by targeting or projected patterns) can overcome human capabilities (measurement accuracy, processing speed), analysis of general spatial scenes still represents the subject of intense research. This implies limiting conditions for the deployment of this approach and the requirements for the method of scanning the object of reconstruction, such as the high overlap of the images taken and their continuity. Matching methods are based on a game-archiving strategy. The necessary calibration and data orientation for input images is usually calculated or estimated in advance. Pre-processing involves improving image quality (smoothing, removing noise, or adjusting contrast) and reduction of the resolution (creating pyramids).

6.2. 3D Point Cloud for Transport Accident Reconstruction Purposes

For transport accidents reconstruction software is effective to obtain digital inputs from accident scenes such as digital photos, digital video sequences and 3D digital models of the point cloud. 3D point clouds are able to provide high quality sources of information from the accident scene. Reconstruction of real circumstances at the accident scenes is an irreplaceable part of forensic expert investigation results. By reconstruction of accident of emergency vehicle with the right of way, it was additionally executed scanning of the real accident scene for reliable simulation of reality and precise results of the investigation.

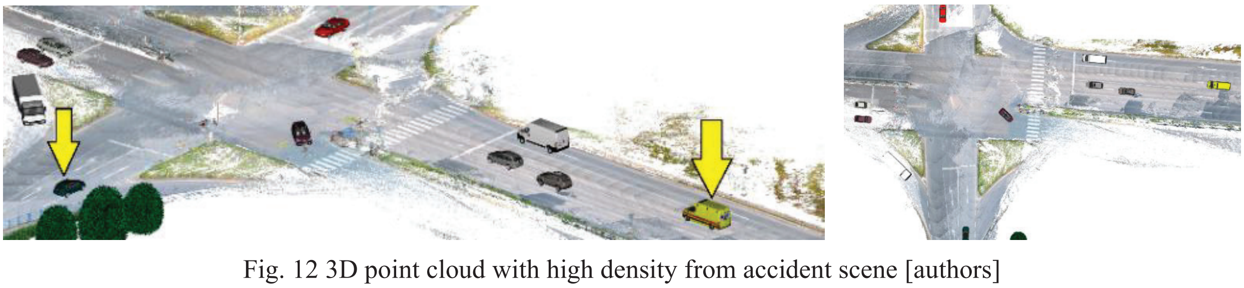

Fig. 12 3D point cloud with high density from accident scene [authors]

Transport accident happened in the city of Martin (Slovak Republic) on the junction with a traffic light and with side crossing minor road in right angle (Fig. 12). Emergency ambulance vehicle drove on the main road but with red traffic light on. According to the video sequence the driver did not change significantly the speed or direction of driving during approaching the junction. The video sequence was made from a dash-board video recording device, which was provided for investigation purposes. In the picture (Fig. 13) it is possible to see the position of other vehicles approaching the junction on the green traffic light and the emergency vehicle approaching on a red traffic light.

Fig. 13 Screen shot video sequence from ambulance vehicle by approaching to junction [authors]

From the video sequence and from the simulation it is possible to notice that in time 32 seconds is approaching from left side vehicle Peugeot (Fig. 14). Emergency ambulance vehicle was driving at speed 86 km/h and vehicle Peugeot at speed 55 km/h. In the Slovak Republic, there is a speed limit within a village or city 50 km/h.

Fig. 14 Record from dash board video device and from simulation 32 seconds before collision [authors]

Fig. 15, 16 and 17 are clearly seen continually approaching vehicle Peugeot 508, which was not in a visually hidden area. The emergency ambulance vehicle driver was at the necessary height to see continually approaching vehicle Peugeot 508 without any difficulties or complicated head movement. This vehicle could also notice the passenger of the driver, who was seating in the vehicle and was informing the driver about the possibility to cross the junction without any dangerous difficulties according to the video sequence. According to the analysis of the accident event the driver of the emergency ambulance vehicle and driver of Peugeot did not change significantly the speed and direction of driving as they did not register each other and did not pay appropriate attention. The driver of the emergency ambulance vehicle did not react to the red traffic light at the junction and continued without any vehicle dynamic changes.

Fig. 15 Record of Dash board video device and simulation 2,4 seconds before collision [authors]

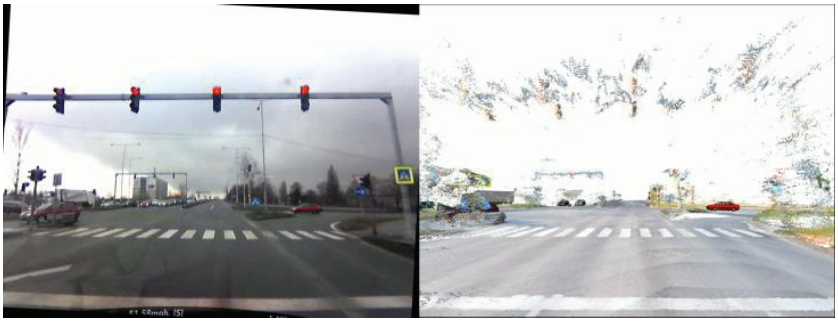

Fig. 16 Record of Dash board video device and simulation 1.6 seconds before collision [authors]

Fig. 17 Record of Dash board video device and simulation 1 second before collision [authors]

In Fig. 18 is displayed ground plan 2D result of accident process of ambulance vehicle and Peugeot 508 vehicle. Emergency ambulance vehicle had just before entering the junction area free driving lane and the driver has not been forced to decrease the speed.

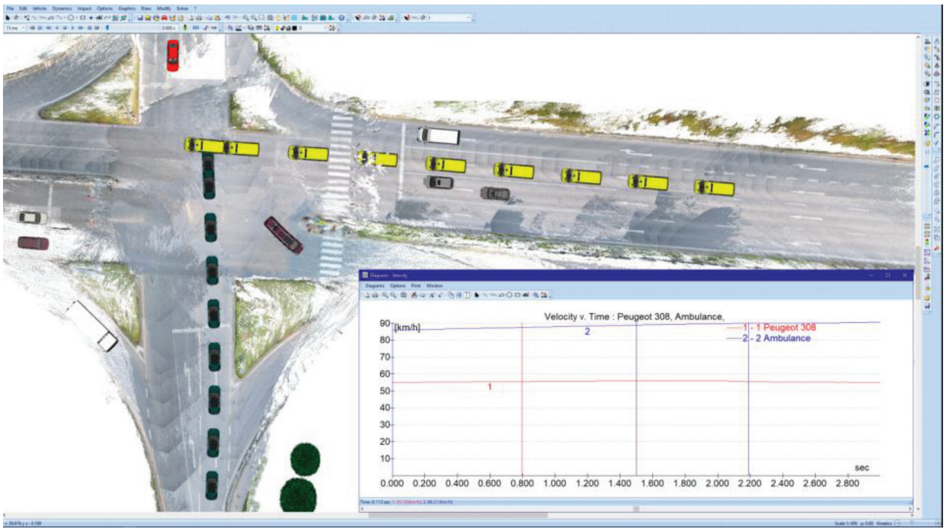

Fig. 18 2D ground plan view of accident scene in software PC-Crash [authors]

7. Conclusions

According to executed analysis it is obvious that the emergency ambulance vehicle drivers violated the internal regulation of the company. The vehicles would not get in collision and accidents would not happen if the driver would have kept the regulation which says that it is required to stop the ambulance vehicle before entering the junction with red traffic light on in order to get a proper view and afterward accelerate the vehicle only in case there is not any danger for driving. The next ambulance vehicle driver's error was, that he did not pay enough attention while driving as he either didn't notice red traffic light or overlooked an approaching vehicle from the left which had green traffic light on.

In the video sequence there is also recorded proper function of audible and visual emergency signals of vehicle, however, driver in Peugeot approaching to the junction on the green traffic light did not expect vehicle coming from the direction where the red traffic light was on. Slovak legislation determines the term that drivers should appropriately rely on other traffic participants' rules keeping. It also mentions the severity of traffic rules violations as a less serious and serious violation. In fact, this helps to support the Peugeot driver because driving at a red traffic light is a serious violation of traffic rules and that's why it is not requested to expect such violation of rules from other traffic participant's side

Slovak legislation does not specify exactly when emergency vehicle drivers have right of way and when is necessary to stop the vehicle before entering the junction. Their duty is only not to endanger all other traffic participants, which seems to be insufficient. As a result of the inaccurate definition of traffic obligation could be also described accident when an ambulance vehicle drove on the red traffic light at a speed of 90 km/h. The next important point is the intensity of the emergency vehicle audible signal, which appears to be too low as it was not noticed by the driver of the Peugeot vehicle.

Acknowledgement

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On the Question of Choosing the Optimal Strength Criterion of Soils and Rocks

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Abstract

Based on the analysis of solutions to the classical problems of soil mechanics and geomechanics on determining the critical height and angle of the slope, as well as active and passive pressure on the enclosing structures, to identify the optimal strength criteria and the limits of their application, which allow predicting the destruction of ideally free-flowing, ideally plastic rocks, as well as rocks characterized by internal friction and specific cohesion, which is necessary for calculating the strength and stability of underground and open mine workings in the supercritical region - after the destruction of the near-contour region.
The areas of application of some criteria for the strength of soils and rocks are outlined and substantiated. It is shown that, in contrast to the known strength criteria of Z.T. Benyavsky, Hoek - Brown and A.N. Shashenko Coulomb - Mohr strength criterion and our proposed modification of the strength criterion of A.N. Shashenko allow predicting the destruction of ideally - free flowing, ideally - plastic rocks, as well as rocks characterized by internal friction and specific cohesion.
KEY WORDS: *Mohr - Coulomb strength criteria, modified strength criterion A.N. Shashenko, ideally - loose soil; ideally plastic soil; soil, specific adhesion; internal friction angle.*

1. Introduction

Currently, the following strength criteria are most widely used in soil and rock mechanics [1-5, 11, 12]: Mora - Coulomb; Z.T. Benyavsky; Hoeka - Brown; A.N. Shashenko (including modified); Cod - Hill; Mises - Botkin; J. Watt; D.N. Rasskazova; other criteria incl. combined (taking into account several mechanisms of destruction, for example, tension and shear).

Each of these criteria describes well the behavior of the material (in the considered case of soil and rock) in a certain narrow range of pressures and physical and mechanical properties. At the same time, it is not clear how general and universal each of them is.

We also note that this article deliberately does not separate the terms "soils" and "rocks" in view of the fact that "From the point of view of construction, soil is called any rock used in construction as the foundation of a structure, the environment in which the structure is being erected, or material for construction ".

Based on the analysis of solutions to the classical problems of soil mechanics and geomechanics about determining the critical height and angle of the slope, identify the optimal strength criteria and the limits of their application, which allow predicting the destruction of ideally free-flowing, ideally plastic rocks, as well as rocks characterized by internal friction and specific cohesion ... This is necessary for calculating the strength and stability of aboveground, underground and open mine workings in the supercritical region - after the destruction of the near-contour region [1-15].

The research task was formulated as follows:

a. The strength characteristics of the soil or rock are known - specific cohesion c and the angle of internal friction φ or the compressive strength of the rock R_c and tension R_p.

b. The specific gravity of the soil (rock) γ is known.

c. It is required to identify the most acceptable strength criterion for solving problems of soil and rock mechanics. To do this, you need to do the following:

1) Reveal the features of using various strength criteria in the conditions of a one-dimensional and spatial problem.

2) Establish the possibility of describing, using one or another criterion of strength, properties of materials

with: specific adhesion; dry friction; specific adhesion and dry friction at the same time.

3) Compare the results of solving such classical problems of geomechanics, obtained using various strength criteria:

– determination of the critical angle of the slope from ideally loose soil;
– determination of the critical height of the vertical slope for soil with specific adhesion and internal friction.

2. Research

Due to the limited scope of the article, it contains the results of considering the most frequently used criteria.

In the course of theoretical studies, obtained by solving the above problems, the results were compared with the solutions obtained using the Mohr - Coulomb strength criterion. This is due to the fact that this strength criterion is the simplest and most widely used in solving problems of soil mechanics and geomechanics.

In addition, to ensure the concentration of attention on the problem under consideration and the convenience of presenting the material of the research, soils and rocks with an undisturbed structure were deliberately considered.

Stage 1. Features of the use of strength criteria in the conditions of one-dimensional and spatial problems.

1.1. Mohr - Coulomb strength criteria for the one-dimensional and spatial cases are known and have the form [1-5]:

– for the spatial case:

$$\frac{\sigma_1-\sigma_3}{\sigma_1+\sigma_3+2\cdot c\cdot ctg(\varphi)}\le sin(\varphi);\ \sigma_1\ge\sigma_2\ge\sigma_3; \tag{1}$$

– for the one-dimensional case:

$$\tau\le\sigma\cdot tg(\varphi)+c, \tag{2}$$

where τ is the shear stress; σ is normal; $\sigma_1,\sigma_2,\sigma_3$ are the principal normal stresses for the case of the spatial problem; φ is the angle of internal friction; c − specific cohesion.

First, we investigate condition (1). When the specific cohesion is equal to zero (c = 0), we have:

$$\left.\frac{\sigma_1-\sigma_3}{\sigma_1+\sigma_3}\le \sin(\varphi);\ \sigma_1\ge\sigma_2\ge\sigma_3\right\}. \tag{3}$$

Analysis of Eq. (3) allowed us to conclude that the Mohr - Coulomb strength condition (1) is applicable for ideally loose soils.

Next, we multiply both sides of inequality (1) by the denominator and set φ = 0. We have:

$$\sigma_1-\sigma_3\le 2\cdot c. \tag{4}$$

Thus, the Mohr - Coulomb spatial strength criterion is also applicable for ideally plastic soils.

Similar conclusions can be made by analyzing the one-dimensional version of the Mohr - Coulomb law - for c = 0 we have:

$$\tau\le\sigma\cdot tg(\varphi), \tag{5}$$

and at φ = 0:

$$\tau\le c. \tag{6}$$

Thus, the Mohr - Coulomb strength condition makes it possible to predict the destruction of such media:

– perfectly free-flowing;
– perfect plastic;
– environments with internal friction and specific adhesion at the same time.

In this case, according to [4, 5], using the Mohr - Coulomb law of strength, underestimated values of active pressure on the holding structures and overestimated values of passive pressure are obtained.

1.2. Strength criterion Z.T. Benyavsky for the spatial case has the form [1, 3, 6]:

$$\left.\sigma_1\le A\cdot(R_c)^{0,25}\cdot(\sigma_3)^{0,75}+R_c;\ \sigma_1\ge\sigma_2\ge\sigma_3\right\}, \tag{7}$$

where $A \in (0, .., 20)$ is an empirical constant.

In order to pass to the strength constants c and φ, let us take into account that in (7) tensile stresses should be taken with a minus sign, and compressive stresses with a plus sign. In addition, we use the well-known equalities (Florin V.A. Fundamentals of soil mechanics, v.1.- L.-M .: Gosstroyizdat, 1959, [4, 5]):

$$\left. R_c = -2 \cdot c \cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right); \;\; \psi = \frac{R_r}{R_c} = -\frac{1}{tg^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)} \right\}. \tag{8}$$

We have:

$$\left. \sigma_1 \le \left[2 \cdot c \cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\right]^{0,25} \cdot \sigma_3^{0,75} + 2 \cdot c \cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right); \sigma_1 \ge \sigma_2 \ge \sigma_3 \right\}. \tag{9}$$

In order to obtain a one-dimensional version of the strength condition Z.T. Benyavsky, we take into account the well-known relations [1, 3, 6]:

$$\left. \sigma = \frac{\sigma_1+\sigma_3 \cdot}{2}; \;\; \tau = \frac{\sigma_1-\sigma_3}{2} \right\}. \tag{10}$$

We have:

$$\tau \le -\sigma + A \cdot (\tau-\sigma)^{0,75} \cdot \left[2 \cdot c \cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\right]^{0,25} + 2 \cdot c \cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right). \tag{11}$$

Next, we investigate inequality (9). With $c = 0$ we have: $\sigma_1 \le 0$; $\sigma_1 \ge \sigma_2 \ge \sigma_3$. Thus, the application of the strength criterion Z.T. Benyavsky when solving the spatial problem is unacceptable for predicting the strength of ideally free-flowing soils, since (12) does not depend on the angle of internal friction φ.

For $\varphi = 0$ we have:

$$\left. \sigma_1 - A \cdot (2 \cdot c)^{0,25} \cdot \sigma_3^{0,75} - 2 \cdot c \le 0; \; \sigma_1 \ge \sigma_2 \ge \sigma_3 \right\}. \tag{12}$$

Thus, the criterion of Z.T. Benyavsky (9) is quite acceptable for predicting the strength of ideally cohesive soils.

Next, we investigate equality (11). For $c = 0$ we have:

$$\tau \le -\sigma . \tag{13}$$

Thus, in one-dimensional problems, the criterion of Z.T. Benyavsky at $c = 0$ does not depend on the angle of internal friction φ and therefore is unacceptable for predicting the strength of ideally loose soils.

In addition, for $\varphi = 0$ we have:

$$\tau \le -\sigma + A \cdot (\tau-\sigma)^{0,75} \cdot (2 \cdot c)^{0,25} + 2 \cdot c . \tag{14}$$

In this case, the criterion Z.T. Benyavsky (11) is quite acceptable for predicting the strength of perfectly cohesive soils.

The foregoing allowed us to conclude that the strength criteria of Z.T. Benyavsky for spatial (9) and one-dimensional (11) problems allow us to predict the destruction of such media:

- perfect plastic;
- a medium that has both internal friction and specific adhesion.

Moreover, this criterion is absolutely unacceptable for predicting the strength of ideally free flowing media. In addition, relations (9) and (11) have a rather complicated form, which is also their disadvantage.

1.3. The Hoek - Brown strength criterion for soil and rock with undisturbed structure in the spatial case has the form [1, 3, 6]:

$$\left. \sigma_1 \le \sigma_3 + R_c \cdot \sqrt{m \cdot \sigma_3 / R_c + 1}; \sigma_1 \ge \sigma_2 \ge \sigma_3 \right\}, \tag{15}$$

where $m \in (0, .., 33)$ is an empirical constant.

In order to pass to the strength constants c and φ, let us take into account that in (15) tensile stresses should be taken with a minus sign, and compressive stresses with a plus sign. In addition, we use the well-known equalities (8). We have

$$\left.\sigma_1 \le \sigma_3 + 2\cdot c\cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\sqrt{\frac{m\cdot\sigma_3}{2\cdot c}\cdot ctg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)+1};\ \sigma_1 \ge \sigma_2 \ge \sigma_3\right\}. \tag{16}$$

In order to pass to the use of the Hoek - Brown criterion in a one-dimensional problem, we use relations (16) and (10). Then:

$$\left.\tau \le -\frac{1}{4}\cdot m\cdot c\cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)+\frac{1}{4}\cdot\sqrt{c^2\cdot\left(m^2+16\right)\cdot tg^2\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)+8\cdot\sigma\cdot c\cdot m\cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)}\right\}. \tag{17}$$

Next, we investigate the application of the Hoek-Brown strength criterion (16) when solving spatial problems. For $c = 0$ we have:

$$\tau \le 0\,. \tag{18}$$

Thus, the option of using the Hoek - Brown strength criterion when solving the spatial problem is unacceptable for predicting the strength of ideally free-flowing soils.

For $\varphi = 0$ we have:

$$\left.\tau \le -\frac{1}{4}\cdot m\cdot c+\frac{1}{4}\cdot\sqrt{c^2\cdot\left(m^2+16\right)+8\cdot\sigma\cdot c\cdot m.}\right\}. \tag{19}$$

Thus, the Hoek - Brown criterion (17) is quite acceptable for predicting the strength of ideally cohesive soils.

The foregoing allowed us to conclude that the Hoek - Brown strength criteria for spatial (16) and one-dimensional (17) problems allow predicting the destruction of such media:

– perfect plastic;
– characterized by internal friction and specific adhesion.

Moreover, this criterion is absolutely unacceptable for predicting the strength of ideally free-flowing media.

1.4. Strength criterion A.N. Shashenko for soil and rock with undisturbed structure in the spatial case has the form [1-3, 6]:

$$\left.-(1-\psi)\cdot(\sigma_1+\sigma_3)+\sqrt{\left[(1-\psi)^2\cdot(\sigma_1+\sigma_3)^2+4\cdot\psi\cdot(\sigma_1-\sigma_3)\right]}-2\cdot\psi\cdot R_c \le 0;\ \sigma_1 \ge \sigma_2 \ge \sigma_3\right\}. \tag{20}$$

In order to pass to the strength constants c and φ, let us take into account that in (20) tensile stresses should be taken with a minus sign, and compressive ones with a plus sign, and the parameter $\psi = \frac{R_r}{R_c}$ − in absolute value. Taking into account equalities (8), we have:

$$\left.\left(\sigma_1-\sigma_3\right)-2\cdot\sqrt{c^2+c\cdot\left(\sigma_1+\sigma_3\right)\cdot tg(\varphi)} \le 0;\ \sigma_1 \ge \sigma_2 \ge \sigma_3\right\}. \tag{21}$$

Using (10) and (21), we arrive at the one-dimensional case of the strength criterion of A.N. Shashenko. We have:

$$\tau \le \sqrt{2\cdot c\cdot\sigma\cdot tg(\varphi)+c^2}\,. \tag{22}$$

Next, we investigate the spatial version of using the strength criterion of A.N. Shashenko (21). For $c = 0$ we have:

$$\left.\left(\sigma_1-\sigma_3\right) \le 0;\ \sigma_1 \ge \sigma_2 \ge \sigma_3\right\}. \tag{23}$$

It follows from (23) that the spatial version of the application of the strength criterion A.N. Shashenko (21) is unacceptable for predicting the strength of ideally free-flowing soils, since (23) does not depend on the angle of internal friction. For $\varphi = 0$ we have:

$$-2 \cdot c \pm (\sigma_1 - \sigma_3) \leq 0;\ \sigma_1 \geq \sigma_2 \geq \sigma_3 \} . \quad (24)$$

It follows from (24) that the spatial variant of using the criterion of A.N. Shashenko (21) is quite acceptable for predicting the strength of ideally cohesive soils.

Next, let us analyze a one-dimensional version of the application of the strength criterion A. Shashenko (22). For $c = 0$ we have:

$$\tau \leq 0 . \quad (25)$$

It follows from (25) that the one-dimensional case of the strength criterion of A.N. Shashenko is unacceptable for predicting the strength of ideally free-flowing media. For $\varphi = 0$ we have:

$$\tau \pm c \leq 0 . \quad (26)$$

It follows from (26) that the one-dimensional case of the strength criterion of A.N. Shashenko is quite acceptable for predicting the strength of ideally plastic media.

In general, the analysis of one-dimensional and spatial strength criteria by A.N. Shashenko made it possible to draw the following conclusions:

1. When solving spatial problems, the strength criterion of A.N. Shashenko (21) allows predicting the destruction of such media: ideal-plastic; possessing internal friction and specific adhesion at the same time. At the same time, the use of the spatial strength criterion of A.N. Shashenko is impossible.
2. When solving one-dimensional problems, the strength criterion of A.N. Shashenko (22) makes it possible to predict the destruction of such media: - ideal-plastic; having internal friction and specific adhesion at the same time. At the same time, its use for predicting the strength of ideally free-flowing media is impossible.

It should also be noted that the strength criterion of A.N. Shashenko makes it relatively easy to take into account the nonlinearity of the Coulomb - Mohr envelope. In this regard, it makes sense to modify it in such a way that it would be possible to predict the strength of ideally - free flowing, ideally - plastic media, as well as media with internal friction and adhesion.

1.5. In order to modify the strength criterion A.N. Shashenko, we expand (22) in a Taylor series in the vicinity of some natural state $\tau(\sigma_0, c_0)$ and keep only linear terms in the expansion. We have:

$$\tau \approx \sqrt{2 \cdot c \cdot \sigma_0 \cdot tg(\varphi) + c^2} + \frac{tg(\varphi) \cdot (\sigma - \sigma_0) \cdot c}{\sqrt{2 \cdot c \cdot \sigma_0 \cdot tg(\varphi) + c^2}} . \quad (27)$$

Putting in (27) $\sigma_0 = 0$, we arrive at the form of writing the Coulomb - Mohr strength criterion for the one-dimensional case:

$$\tau \approx \sigma \cdot tg(\varphi) + c . \quad (28)$$

In conclusion, we note that the following asymptotic estimates also take place:

$$\lim_{\sigma \to 0}(\tau) = c;\ \lim_{c \to 0}(\tau) = \sigma \cdot tg(\varphi) \} . \quad (29)$$

It follows from (27), (28) and (29) that at low stresses the strength laws of A.N. Shashenko and Kulona - Mora are the same.This fact was used by us to modify the strength criterion of A.N. Shashenko. Let us find such a minimum value of the specific cohesion of the soil (rock) at which the breaking shear stresses, calculated using the Coulomb strength criteria for loose soil and A.N. Shashenko for cohesive soil, coincide. In this case, we use the known actual values of the angle of internal friction of the soil φ and the normal stress σ_0. acting at the point under consideration. In view of the above, the solution to the problem is reduced to solving an algebraic equation of the form: $\sqrt{2 \cdot c_{res} \cdot \sigma_0 \cdot tg(\varphi) + c_{res}^2} - \sigma_0 \cdot tg(\varphi) = 0$, from where:

$$c_{res} = (\sqrt{2} - 1) \cdot \sigma_0 \cdot tg(\varphi) . \quad (30)$$

Here c_{res} is the reduced specific cohesion, and σ_0 is the maximum normal stress.

Further, we require that at low values of the specific cohesion of the rock $c_{fact} < c_{res}$, its destruction occurs in accordance with the Coulomb - Mohr strength criterion. If the inequality $c_{res} < c_{fact}$ takes place, then the fracture occurs in accordance with the classical strength criterion of A.N. Shashenko.

In view of the above, the modified strength criterion by A.N. Shashenko looks like:

$$\left.\begin{array}{r}\text{one dimensional case: } \tau = \sqrt{2 \cdot c \cdot \sigma \cdot tg(\varphi) + c^2}; \\ \text{spatial case: } (\sigma_1 - \sigma_3) - 2 \cdot \sqrt{c^2 + c \cdot (\sigma_1 + \sigma_3) \cdot tg(\varphi)} \le 0;\ \sigma_1 \ge \sigma_2 \ge \sigma_3; \\ \text{where: } c = c_{fact} \cdot U(c_{fact} - c_{rez}) + c_{rez} \cdot \left[1 - U(c_{fact} - c_{rez})\right],\end{array}\right\} \tag{31}$$

where $U(x)$ – is the Heaviside unit step function [10]; c_{res} – the minimum specific cohesion that should be taken into account (reduced specific cohesion); c_{fact} – actual value of specific cohesion. In particular, the last equality (31) means that if the reduced specific cohesion c_{res} is greater than the actual one, then the specific cohesion c_{res} should be taken into account; otherwise, the actual specific cohesion should be taken c_{res}.

Next, we will consider solutions to some problems in soil mechanics and geomechanics obtained using the strength criteria discussed above.

Stage 2. Features of the use of strength criteria when determining the critical angle of the slope from loose soil (Fig. 1, a). This problem occurs when constructing embankments, dumps, soil cushions, dams, reclamation of soil, etc.

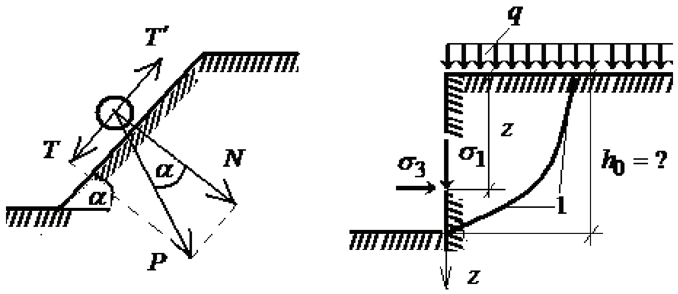

Fig. 1 Scheme for determining the stability of the slope: a – from loose soil; b – from soil with specific adhesion and internal friction

The research task was formulated as follows:

A. The criterion of rock (or soil) strength is known.
B. The rock (or soil) is absolutely free-flowing (ie, the specific cohesion is zero).
C. It is required to determine the critical angle of the slope, the design scheme of which is shown in Fig. 1, a.

2.1. Coulomb-Mohr strength criterion.

Consider a rock particle with weight P located on the slope. Let us decompose the weight P into the perpendicular surface of the slope N and the parallel shear force T. Next, we find the holding force T'. In addition, we equate the shearing and holding forces. We have:

$$\left.\begin{array}{c}N = P \cdot \cos(\alpha);\ T = P \cdot \sin(\alpha);\ T' = N \cdot tg(\alpha) = P \cdot \cos(\alpha) \cdot tg(\alpha); \\ T = T';\ P \cdot \sin(\alpha) - P \cdot \cos(\alpha) \cdot tg(\varphi) = 0; \\ \alpha = \varphi.\end{array}\right\} \tag{32}$$

2.2. Strength criterion Z.T. Benyavsky.

In this case, for loose soil from condition (11) we have:

$$T' \le -N. \tag{33}$$

Repeating the reasoning presented in section 2.1, we find:

$$\left.\begin{array}{c}N = P \cdot \cos(\alpha);\ T = P \cdot \sin(\alpha);\ T' = -N = -P \cdot \cos(\alpha); \\ T = T' \Rightarrow P \cdot \sin(\alpha) + P \cdot \cos(\alpha) = 0;\ \alpha = -arctg(1) = \dfrac{-\pi}{4}.\end{array}\right\}. \tag{34}$$

This result contradicts the experimental data. Therefore, the strength criterion Z.T. Benevsky is unacceptable for calculating slopes from loose soil.

2.3. Hoek - Brown Strength Criterion.

In this case, for loose soil from condition (18) we have:

$$T' \le 0\,. \tag{35}$$

Repeating the reasoning presented in section 2.1., we find:

$$\left.\begin{array}{c} N = P\cdot\cos(\alpha);\; T = P\cdot\sin(\alpha);\; T' = 0; \\ T = T' \Rightarrow P\cdot\sin(\alpha) - 0 = 0;\; \alpha = \arcsin(0) = 0. \end{array}\right\} \tag{36}$$

Therefore, the Hoek-Brown strength criterion is unacceptable for calculating slopes from loose soil.

2.4. Strength criterion A.N. Shashenko.

In this case, for loose soil from condition (25) we have:

$$T' \le 0\,. \tag{37}$$

Repeating the reasoning presented in Section 2.3, we find

$$\alpha = arcsin(0) = 0\,. \tag{38}$$

Therefore, the strength criterion of A.N. Shashenko is unacceptable for calculating slopes from loose soil.

2.5. Modified strength criterion by A.N. Shashenko.

In this case, for loose soil from condition (31), we should put $c = c_{rez}$. As a result, we come to the Coulomb - Mohr strength criterion (Section 2.1), due to which:

$$\alpha = \varphi\,. \tag{39}$$

The data presented in paragraph 2 made it possible to conclude that for absolutely free-flowing rock (soil) the results obtained using the Coulomb - Mohr strength criteria and the modified A.N. Shashenko.

In this case, the strength criteria Z.T. Benyavsky, Hoek - Brown and A.N. Shashenko for calculating slopes from loose soil is absolutely unacceptable.

Stage 3. Features of the use of strength criteria when solving problems of ensuring the stability of vertical slopes. This problem arises when constructing trenches, foundation pits, open workings with vertical walls, etc.

The research task was formulated as follows:

A. The criterion of rock (or soil) strength is known.

B. Rock (or soil) has internal friction and specific adhesion.

C. It is required to determine the critical height of the slope, the design scheme of which is shown in Fig. 1, b, based on the fact that in this case the main normal stress σ_3 is equal to zero, and the main normal stress is: $\sigma_1 = \gamma\cdot z + q$

3.1. Coulomb-Mohr strength criterion. Putting in (1) $\sigma_3 = 0$ and solving the thus obtained inequality with respect to the principal stress σ_1 we find:

$$\left.\sigma_1 \le \frac{2\cdot c\cdot\cos(\varphi)}{1-\sin(\varphi)}\right\}. \tag{40}$$

Taking into account that in this case $\sigma_1 = \gamma\cdot z + q$ we finally find:

$$h_{\max} = z_{\max} \le \frac{2\cdot c}{\gamma}\cdot\frac{\cos(\varphi)}{1-\sin(\varphi)} - \frac{q}{\gamma}. \tag{41}$$

Analysis (41) made it possible to draw the following conclusions:

1. When the specific adhesion is equal to zero (*c*=0), the critical slope height is equal to zero $h_{max} \le 0$.
2. When the angle of internal friction is equal to zero (φ=0), the critical height of the vertical slope is equal to $h_{max} = \frac{2\cdot c}{\gamma} - \frac{q}{\gamma}$. Thus, solution (41) is acceptable for perfectly connected (plastic) rocks and rocks with specific cohesion and internal friction. The solution to problem (41) is known from the literature and is presented, for example, in [4, 5].

3.2. Strength criterion Z.T. Benyavsky. Putting $\sigma_3 = 0$ in (7) and solving the inequality thus obtained with respect to the principal stress σ_1, we find $\sigma_1 \le R_c$. Taking into account (8) and explanations for formulas (7), we arrive at the equality $\sigma_1 \le 2\cdot c\cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)$. Since on the interval $\varphi \in \left(0,\frac{\pi}{4}\right)$ (this is the range of variation of the angle of internal friction of the rock), we will come to (40) and (41) in succession. Thus, the use of the strength criterion Z.T. Benyavsky (7) to solve this problem made it possible to obtain exactly the same results as using the Coulomb - Mohr strength criterion (1). Therefore, the strength criterion Z.T. Benyavsky is quite acceptable for determining the critical height of vertical slopes.

3.3. Hoek - Brown Strength Criterion. Putting $\sigma_3 = 0$ in (15) and solving the thus obtained inequality with respect to the principal stress σ_1, we find $\sigma_1 \le R_c$. Taking into account (8) and explanations for formulas (7), we arrive at the equality $\sigma_1 \le 2\cdot c\cdot tg\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)$. Since on the interval $\varphi \in \left(0,\frac{\pi}{4}\right)$ we come to (40) and (41) in succession. Thus, the use of the Hoek - Brown strength criterion (15) for solving this problem made it possible to obtain exactly the same results as the use of the Coulomb - Mohr strength criterion (1).

3.4. Strength criterion A.N. Shashenko. Putting $\sigma_3 = 0$ in (21) and solving the thus obtained inequality with respect to the principal stress σ_1, find $\sigma_1 \le 2\cdot c\cdot(\sin(\varphi)+1)/\cos(\varphi) = 2\cdot c\cdot\cos(\varphi)/(1-\sin(\varphi))$.

Thus, the use of the strength criterion of A.N. Shashenko (21) to solve this problem made it possible to obtain exactly the same results as using the Coulomb - Mohr strength criterion (1). Therefore, the strength criterion of A.N. Shashenko is quite acceptable for determining the critical height of vertical slopes.

3.5. Modified strength criterion by A.N. Shashenko. In this case, the results of solving the problem are completely identical to the data presented in Section 3.4. Therefore, the modified strength criterion by A.N. Shashenko is quite acceptable for determining the critical height of vertical slopes.

3. Conclusions

In general, it was concluded that all the strength criteria considered at stage 3 in relation to solving the problem of the stability of a vertical slope are quite acceptable and give the same result.

1. Using the strength criteria of Coulomb - Mora, Z.T. Benyavsky, Hoek - Brown, A.N. Shashenko and our proposed modification of the strength criterion A.N. Shashenko obtained analytical solutions to the following problems:
   1.1. Determination of the critical slope height from ideally free-flowing rock.
   1.2. Determination of the critical slope height from ideally plastic rock.
   1.3. Determination of the critical slope height from rock with specific adhesion and internal friction.

Using the strength criteria Z.T. Benyavsky, Hoek - Brown, A.N. Shashenko and the modified strength criterion A.N. Shashenko solutions of the listed problems were obtained for the first time.

2. The generalization of the well-known strength criterion by A.N. Shashenko in case of perfect loose soil. The modification is based on the fact that the asymptotic expansion of the classical strength criterion by A.N. Shashenko in the region of low pressures completely coincides with the Coulomb - Mohr strength criterion.
3. It is shown that using all the listed strength criteria is only possible to solve one problem - to determine the critical height of the vertical slope (slope).
4. It has been established that the use of the strength criteria Z.T. Benyavsky, Hoek - Brown and A.N. Shashenko to determine the critical angle of the slopes from ideally free-flowing rock is absolutely impossible.
5. It is shown that the strength criteria of Coulomb - Mohr and A.N. Shashenko (modified) are acceptable for solving all of the above problems.
6. It is shown that the results of solving the considered problems obtained using the modified strength criterion A.N. Shashenko and Coulona - Mora practically coincide at: low stress values; small values of the angles of internal friction; zero and low values of specific cohesion; very high specific cohesion values.

In this case, at large values of stress, there is a significant discrepancy.

In general, it was concluded that when designing overground and underground transport communications, attention should be paid to nonlinear strength criteria, of which the most promising is the modified strength criterion of A. Shashenko.

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The Use of Chernoff Faces to Depict Losses in the Number of Passengers Transported by Air in Australia

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Abstract

The article uses Chernoff faces to depict air passenger losses in Australia - caused by the 2020 COVID-19 infectious disease pandemic. The research began with an analysis and evaluation of the number of passengers transported by air in Australia from January 2010 to January 2021. In order to show the economic losses, the forecast of the considered time series from January 2010 to December 2019 for 2020 was conducted.
KEYWORDS: *air transport, multivariate comparative analysis, Chernoff faces, forecasting, COVID-19, economic security*

1. Introduction

By 2019, passenger air transport had been one of the fastest growing in the world. It was and is considered generally accessible, safe, reliable and comfortable. The infectious disease COVID-19 has led to a global slowdown in the passenger air transport sector worldwide including in Australia.

The aim of the study is to illustrate the losses in the number of passengers transported by air in Australia - caused by the infectious disease COVID-19 in 2020 - using the face of Chernoff.

In the article, the analysis of the literature on issues related to air transport, multidimensional comparative analysis, Chernoff faces, forecasting, COVID-19 and economic security was used for the research.

The study consists of an introduction, three substantive points, a summary and conclusions.

2. Analysis of the Literature on the Subject of Research

The analysis of the literature shows that transport focuses on the movement of resources in the supply chain [2]. One of the modes of transport is air transport. The air transport sector stimulates the economic growth of individual countries. It provides employment in many areas, including: airports, transport, fuel supplies, insurance, tourist offices [9, 13]. The subject of the study is air passenger transport in Australia. By 2019, this sector had shown a trend of dynamic growth. Since 2020, there has been a slowdown caused by the infectious disease COVID-19.

On January 25, 2020, the first case of the infectious disease COVID-19 was recorded in Australia [19]. It involved a man who came to Australia from Wuhan, a Chinese city where the infection was first detected [11].

On March 11, 2020, the infectious disease COVID-19 was declared a pandemic [10].

The beginning of the pandemic led to the introduction by respective countries of the world [12], including Australia, many restrictions such as: maintaining social distancing, avoiding large gatherings, following the hygiene rules for washing and disinfecting hands and wearing face masks [16].

An analysis of the literature shows that the travel restrictions related to the COVID-19 outbreak have caused severe disruptions to domestic air travel since April 2020. In January 2021, Australia's domestic commercial aviation carried 1.9 million passengers (including charter operations) which is a decrease of 64.4 percent compared to January 2020 [18]. The decline in economic growth caused by the slowdown in passenger air transport was also observed in other countries of the world [5].

The Australian government has made major changes to the way the country admits passengers requiring them to test for COVID-19 before flying to Australia or, in exceptional cases, directly at the airport upon arrival [15].

The latest data indicate that in Australia a total of 909 people died from COVID-19 and 29 273 were infected [20].

The COVID-19 crisis has led to a shift in Australian fiscal policy. In 2020 the federal government predicted a return from persistent deficits to modest surpluses, about 1 percent of national income. However, in response to the crisis, the federal government has sharply increased government spending, in particular on the JobKeeper wage payment program and the JobSeeker unemployment benefit program. Together with a modest drop in tax revenues, this led to a budget deficit of 10 percent of national income which means a return of 11 percent (or around $ 600 billion) [14].

The study presents the losses in the transport of people by air in Australia caused by the COVID-19 pandemic in 2020. To achieve this goal, multidimensional comparative analyzes were used. This analysis is a group of statistical methods by means of which at least two variables describing each object are subject to simultaneous analysis [6]. In the study, Chernoff faces were used to show the considered data and to examine the similarities and differences between the dependent variables (years). [M. Rabiej, 2018, s. 27]. This type of picture chart creates a separate category. Cases are visualized by faces here - in such a way that the relative values of the variables are represented by the size or position of the various elements of the human face. Due to its unique features, this technique is considered by some researchers to be the most advanced multidimensional exploratory technique which reveals hidden systems of interrelationships between variables impossible to detect in any other way. Additionally, to show losses in the number of passengers transported by air in Australia during the COVID-19 pandemic, forecasting was used [1, 3, 4, 7] of the time series of the mentioned data from January 2010 to December 2019 for 2020. The results of the research are summarized in the Chernoff faces chart.

The evaluation obtained from the conducted research is important in terms of maintaining the economic security of the passenger air transport sector in Australia. Economic security means certainty of the survival and development of the economic system of the state and international organizations including the guarantee of an adequate standard of living for citizens [8].

The next substantive point is devoted to a multidimensional comparative analysis of the number of passengers transported by air in Australia.

3. Multidimensional Comparative Analysis of the Number of Passengers Transported by Air in Australia

The research began with a time series analysis of the number of passengers transported by air in Australia from January 2010 to December 2020. The first step was to draw a line graph (Fig. 1).

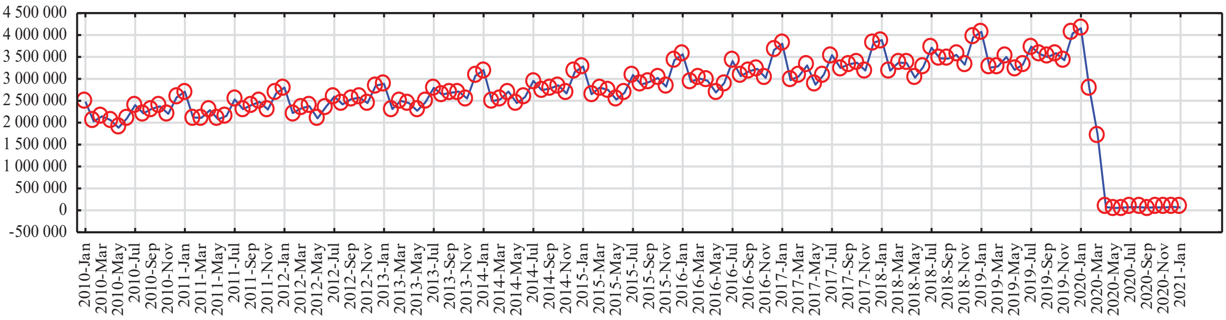

Fig. 1 A line graph of the number of passengers transported by air in Australia from January 2010 to January 2021. Source: own study based on data obtained from [17]

The data presented in Fig. 1 shows that from January 2010 to January 2020 a growing trend and seasonality in the number of passengers transported by air in Australia were visible. Since February 2020 large drops in the number of passengers have been visible. The lowest results were observed from March 2020 to January 2021. The arithmetic mean of the considered data is 2 666 049 passengers. The standard deviation from the arithmetic mean amounted to 899,746 passengers. The number of N elements of the time series under consideration is 133 variables. The minimum value of the series in question is 52 989 passengers and the maximum value is 4 154 051. The quartile of the 25th series in question is 2 379 244 passengers and quartile of the 75th series is 3 250 087 passengers. The analysis clearly shows that the COVID-19 pandemic in Australia has led to a huge decrease in the number of passengers transported by air since February 2020.

The next stage of the research is to conduct a multidimensional comparative analysis through the use of Chernoff faces.

When analyzing Chernoff faces (Fig. 2), it was assumed that each face is data on the number of passengers transported by air in Australia in one year (2010-2020). It was assumed that:

– face width represents the variable for the number of passengers by air in Australia in January;
– ear level refers to the variable number of passengers transported in Australia in February;
– half of the face height is data on the number of passengers in Australia in March;
– the eccentricity of the upper half of the face refers to the number of passengers transported in Australia in April;
– the eccentricity of the lower half of the face was assigned to the number of passengers transported in Australia in May;
– nose length is data on the number of passengers in Australia in June;
– the position of the center of the mouth corresponds to the data on the number of passengers transported in Australia in July;
– lip curvature is data on the number of passengers transported in Australia in August;
– mouth length is data on the number of passengers in Australia in September;
– ear height refers to the number of passengers carried in Australia in October;
– the distance between the eyes is data on the number of passengers flown in Australia in November;
– eye slant is data on the number of passengers flown in Australia in December.

The information presented in Fig. 2 shows that from January 2010 to December 2019 a growing trend in the number of passengers transported by air is visible. The trend has been clearly visible through the increase since 2010 of individual facial features such as: nose length, distance between the eyes, ear level, mouth length and other features that have been encoded. The repeatability of facial features with their increasing tendency may be a reason for the existence of seasonality. In 2020, during the outbreak of the COVID-19 pandemic, large drops in the number of passengers transported by air in Australia were observed. The face labeled 2020 differs significantly from the rest. Its individual features are much smaller than those observed in previous years. This demonstrates the large drops in the number of passengers transported by air in Australia in 2020. Only in January 2020, 4,154,051 passengers were transported which is reflected in the wide face in 2020.

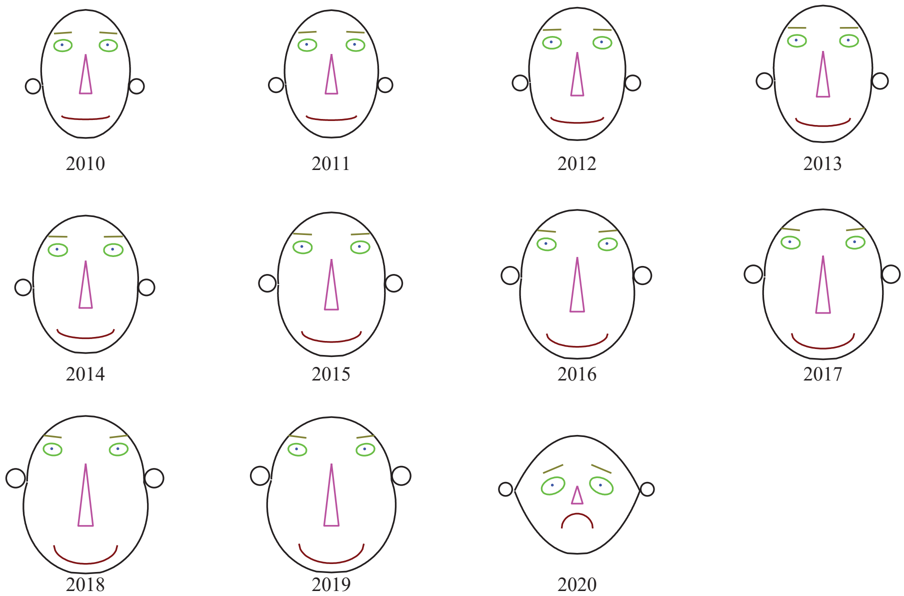

Fig. 2 Chernoff faces - the number of passengers transported by air in Australia from January 2010 to December 2020 Source: own study based on data obtained from [17]

In 2010 a total of 26,790,315 passengers were transported by air in Australia. The arithmetic mean, considering the months, in 2010 was 2,232,526 passengers. The median, on the other hand, was at the level of 2 209 694 passengers. In the following years until 2019, increases were observed, which were as follows: 2011 (28 155 009), 2012 (29 608 992), 2013 (31 344 516), 2014 (33 133 088), 2015 (34 866 649), 2016 (37 616 753), 2017 (39 615 707), 2018 (41 575 313) and 2019 (42 508 455). In 2020, as a result of the COVID-19 pandemic, the number of passengers transported by air in Australia decreased to 9,302,204 passengers. In 2010-2019, the highest standard deviation was 301,566 (2017). In 2020, however, there was an increase in the standard deviation to the level of 1,379,611 passengers.

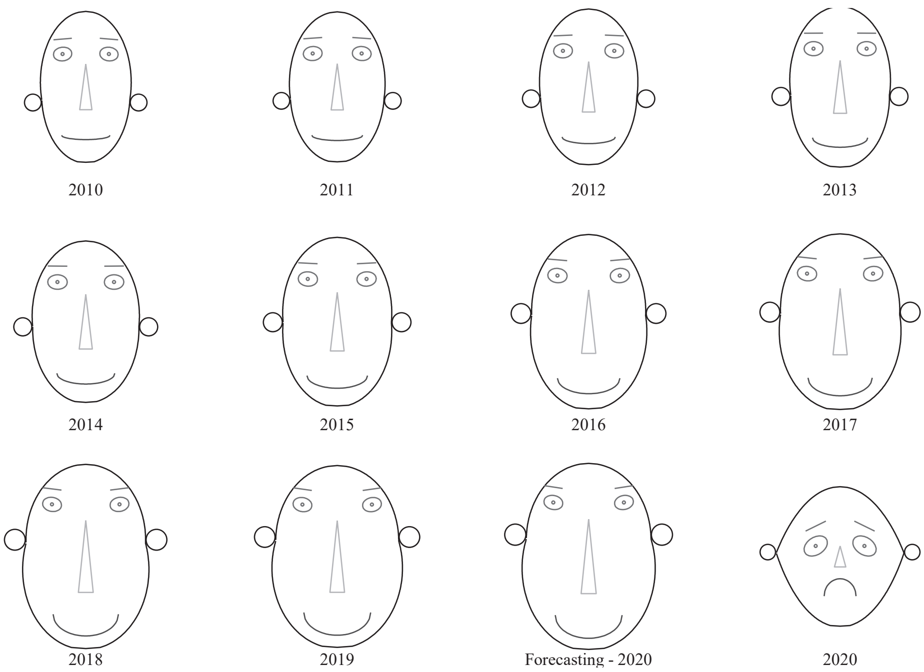

Fig. 3 Chernoff faces - the number of passengers transported by air transport in Australia from January 2010 to December 2020 with a forecast for 2020. Source: own study based on data obtained from [17]

The next stage of the analysis was an attempt to determine the losses suffered by Australia in the transportation of passengers by air. To show them, a multi-dimensional data analysis in the form of Chernoff faces was used. The Holt – Winters' method of the time series forecasting of the number of passengers transported from January 2010 to December 2019 for 2020 (12 periods) was used. The results of the research with raw data from January 2010 to December 2020, together with the forecast for 2020, are summarized in Fig. 3.

The data presented in Fig. 3 shows that in 2020, if the COVID-19 infectious disease had not appeared, the number of passengers transported by air in Australia would have increased to 43,413,959 passengers. It should be emphasized that the face labeled Forecasting-2020 is the largest of all those observed faces. Therefore, in order to count the losses caused by the COVID-19 pandemic, the observed values should be subtracted from the forecasted values (Forecasting-2020). The results of the difference are presented in Fig. 4.

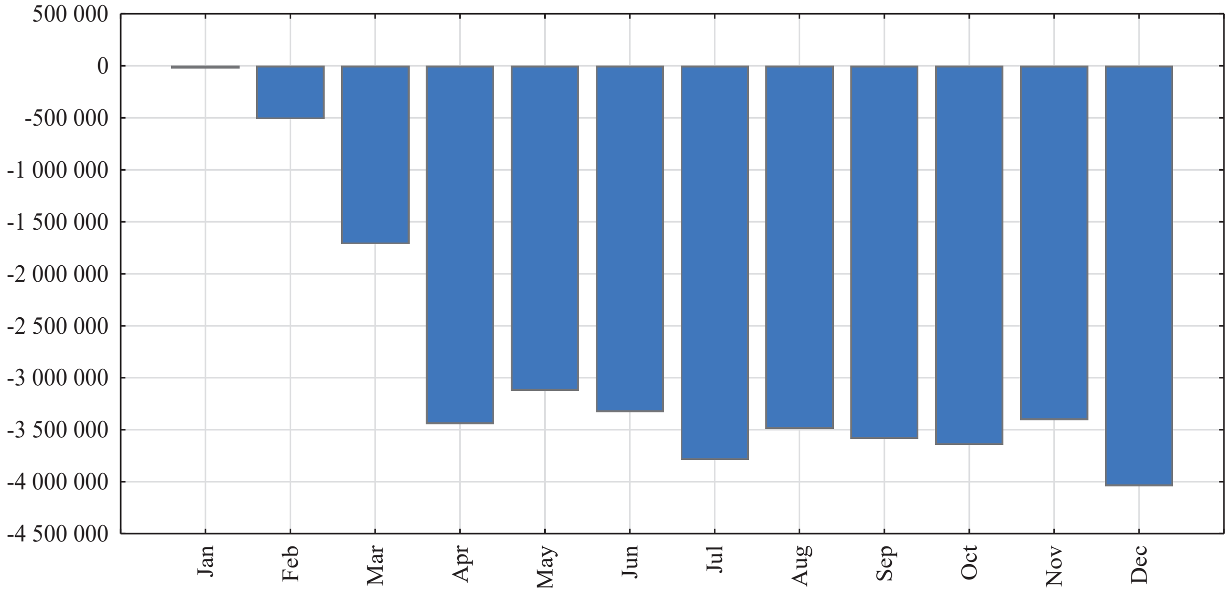

Fig. 4 Graph of the difference of the identical periods of the number of passengers transported by air in Australia between the actually transported passengers and the forecast for the period from January to December 2020 [17]

Fig. 4 shows that in each month of 2020 Australia suffered losses in the number of passengers transported by air. Losses in respective months of 2020 are as follows: January (26,390), February (511,489), March (1,715,041), April (3,444,254), May (3,121,286), June (3,790,615), July (3,790,615), August (3,490,824), September (3,586,670), October (3,646,824), November (3,406,810) and December (4,041,930). Total losses for the number of untransported passengers in air transport in Australia in 2020 are estimated at around 34 111 755 passengers.

4. Conclusions

The research shows that the COVID-19 pandemic has led to a decline in the number of passengers transported by air in Australia in 2020. This has been shown by applying a multivariate comparative analysis using a chart called Chernoff faces. The conducted research shows that if the infectious disease COVID-19 did not appear in 2020, the number of passengers transported by air in Australia would increase to the level of 43,413,959 passengers. In fact, 9,302,204 passengers were transported in 2020. Total losses in the number of untransported passengers by air in Australia in 2020 are estimated at around 34,111,755 passengers.

On the other hand, losses in the number of passengers transported in particular months of 2020 are as follows: January (26,390), February (511,489), March (1,715,041), April (3,444,254), May (3,121,286), June (3,790,615), July (3,790,615), August (3,490,824), September (3,586,670), October (3,646,824), November (3,406,810) and December (4,041,930).

The passenger air transport sector in the world, including Australia, was affected by the COVID-19 pandemic which is directly manifested by huge drops in the number of passengers transported in dynamic terms. There is a need for government financial assistance to airline companies. The survival of this industry without financial support would probably be unrealistic. The lost financial outlays will be difficult to make up for. Therefore, there is a need for further financial support for this industry coordinated by international organizations and institutions responsible for the economic security of countries and the world.

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