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Sustainability: Research and Solutions

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PREFACE

23rd international scientific conference TRANSPORT MEANS 2019 will be held on 02-04 October, 2019 in HOTEL „GABIJA“, Palanga (Lithuania), Vytauto str. 40. It continues long tradition and reflects the most relevant scientific and practical problems of transport engineering.

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

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

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

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

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

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

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

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

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Prof. V. Ostaševičius
Computer Forecasting of Exploitation Parameters of Railway Traffic Control Devices

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Abstract

The article presents issues concerning computer forecasting (estimation) of exploitation parameters of railway traffic control devices with the use of simulation techniques. In forecasting exploitation parameters of railway traffic control devices, was based on solutions used to secure railway crossings, so-called automatic of the level crossing devices. Conducting a simulation of the exploitation process of the level crossing automation devices will allow us to analyze the relationship between tasks, equipment and organization of the operation of these objects. Shaping the exploitation process takes into account the tests of reliability of railway traffic control systems in natural conditions of use and renewal. For the purposes of the article, a number of experimental studies were carried out to examine the reliability of selected railway traffic control objects and determine the values of valence-normative indicators defining the operation of these objects and the entire system, with fixed tasks and known equipment. They also enable difficult exploitation decisions to be taken regarding the choice of means and methods for maintaining devices belonging to the railway traffic control system.

KEY WORDS: railway transport, railway traffic control, railway level crossing automation devices, exploitation process, reliability, model, computer simulation

1. Introduction

The article presents the analyzes concerning the exploitation parameters forecasting of railway traffic control devices on the example of the level crossing automation system. This system should be understood as technical means of function implementing in reference to controlling protective devices at the level crossing in the process of moving railway vehicles as well as methods and means of their maintenance.

The possibilities of exploitation parameters forecasting of railway traffic control devices are presented on the example of computer modeling regarding the exploitation process of the level crossing automation system. These considerations may be important as the basis for improving both the construction of the railway traffic control devices and their production process. In addition, they allow to obtain the reliable information which is necessary to implement the decision process. It regards to the proper organization of the repair teams and the estimation of exploitation costs. The information gathering concerning the technical condition of devices can be used for the modern management of their maintenance strategy based on a proper prevention and also on predictive maintenance of railway traffic.

2. Structure and Operation of Typical Level Crossing Automation System

The construction and operation of the level crossing automation system will be presented on the example of a typical solution of automatic crossing signaling (Fig. 1).

Fig. 1. Typical arrangement of devices in the level crossing automation system [own elaboration based on 4], where CD – a cabinet with control devices; TS – the track sensors enabling and disabling signaling at the level crossings; SL – the traffic signal lights on the level crossings with turnpikes.
The warning activation occurs when the train approaches to the level crossing zone. At an appropriately
determined distance from the level crossing, there are track sensors $TS_1$ and $TS_2$ turning on the signaling. The train
approaching to the level crossing is activated by one of them. The signal from the sensors regarding the train
approaching to the level crossing is sent to the control devices ($CD$). It causes switching on the traffic signal lights $SL_1$
and $SL_2$ as well as acoustic and also closing of road barriers drives. The release of the activated signalling and opening
of the road barriers drives occur upon the impact completion of a moving train on the switching off track sensor $TS_3$. If
there is expected only one-way traffic on one railway track, the track sensor $TS_3$ is unnecessary.

The warning should be switched on no later than 30 seconds and not earlier than 90 seconds before the train
arrival. The signaling should be switched off about 5 seconds from the moment of the last axle of the train passes over.
In case of diversified train speeds, some systems of level crossing automatic signaling allow to balance the switch-on
and time based on the detection of the travel speed through the track sensor. It prevents the premature warning activation for
drivers of vehicles approaching the level crossing [1, 4, 13].

3. Exploitation Process of the Level Crossing Automation System

The concept of the level crossing devices exploitation means all activities that must be performed from the
moment of their manufacturing in order to keep them in constant readiness for work as long as possible. These activities
are aimed at ensuring the highest reliability of the device and securing a proper service [3, 5, 12].

The exploitation process of the level crossing automation system ($EPLCAS$) can be presented in the form [7]:

$$EPLCAS = <UP, RP, DP>, \quad (1)$$

where: $UP$ – the process of using devices – it is the phase of the exploitation process, in which the level crossing
automation system performs its functions or it is ready for their implementation; $RP$ – the renewal process – it is the
phase of the exploitation process consisting in maintaining and restoring the functional efficiency state of the level
crossing automation devices; $DP$ – the decision-making process – it is the phase of the exploitation process consisting
in influencing the $UP$ and $RP$ processes in such way that they take into account the superior objectives of the railway
transport system.

The above processes can be specified more precisely based on their sub processes [7]:

$$UP = <TP, EP>, \quad (2)$$

where $TP$ – the traffic process determined by the intensity of railway and road traffic (mathematical product of road and
railway vehicles crossing the intersection within 24 hours) and the topology of the railway level crossing; $EP$ – the
executive process understood as the impact of the level crossing automation system on the traffic intensity on it.

$$RP = <SP, RTP>, \quad (3)$$

where $SP$ – the service process of the level crossing automation devices (maintaining them in functional readiness); $RTP$ – the repairs technologies process (a collection of necessary repair technologies).

$$DP = <PDU, PDR>, \quad (4)$$

where $PDU$ – a process that generates decisions for the state of devices use (for $UP$); $PDR$ – a process that generates
decisions for the state of devices renewal (for $RP$).

![Fig. 2. Algorithm of the exploitation process controlling of the level crossing automation system [own elaboration based on 4, 16]](image-url)
The management of the railway traffic control system exploitation process, including the level crossing automation system, can be carried out according to the general algorithm from Fig. 2.

On the basis of information obtained in the exploitation process, an assessment is made in reference to the reliability indicators of the railway traffic control devices (the level crossing automation devices). The study of change trends in calculated indicators is carried out. If they show positive tendencies (increase in safety and reliability, efficiency, etc.), the causes of these changes are popularized. If there are no change tendencies, no additional exploitation operations are performed. In case of negative tendencies (increase in the number of failures, reduction in the level of safety and reliability, etc.), the appropriate measures are taken to prevent these changes [4, 15, 16].

4. Reliability Model of the Level Crossing Automation System

The level crossing automation system belongs to the group of simple reliability systems and it has a parallel-serial structure, i.e. parallel to circuits and devices whereas serial to single elements included in individual devices, in accordance with Fig. 3. In the reliability model of the system with such structure, it is assumed that the system works correctly even if there functions one of the devices with a serial structure. The reliability function of the system with a parallel-serial structure \( R(t) \) is described by dependence (5) [5, 8, 13]:

\[
R(t) = 1 - \prod_{i=1}^{m} \left[ 1 - \prod_{j=1}^{n} r_{ij}(t) \right],
\]

where \( r_{ij}(t) \) – the reliability function of the \( j \)-th serial element in the \( i \)-th parallel device for \( i = 1, 2, ..., m; j = 1, 2, ..., n \).

5. Mathematical Model of the Level Crossing Automation System

In order to build a model of the level crossing automation system, it should be assumed that this system can be presented by means of disjoint \( S_i \) subsystems and that there is a certain number of objects belonging to the level crossing automation system in each of these subsystems. The model of the level crossing automation system includes also the real topographic data from the railway network.

Based on the above, it should be assumed that the \( S \) system, where the objects are the real devices of the level crossing automation system, can be presented by \( S_i \) subsystems that meet mathematical equations [4, 7]:

\[
\begin{align*}
\bigcup_{i=1}^{I} S_i &= S; \\
\bigcap_{i=1}^{I} S_i &= \emptyset,
\end{align*}
\]

where \( S \) – the level crossing automation system; \( S_i \) (for \( i = 1, 2, ..., I \)) – the level crossing automation subsystems; \( I \) - the number of specified subsystems.

Based on the presented dependencies, it is possible to consider the system of random variables (e.g. mean times between failure MTBF, mean repair times MRT) that characterize the reliability parameters of the subsystems specified in the \( S \) system. They take into account the operation of each element occurring in the block device of each \( i \)-th subsystem. If the distribution of these random variables is known, the equations of random variables can be replaced by the dependencies of the distribution function. Each of the distribution of random variables describes the probability of the correct operation time of each element in each device [7, 11, 16].

The reliability model regarding the exploitation process of the level crossing automation system considers also very important renewal process next to the process of using the devices.
6. Simulation Model of the Level Crossing Automation System

The creation of systems that simulate the operation of real systems is currently the main motive for the research development of the railway traffic control devices models. These models allow to study the interrelationships between tasks, equipment and organization of the activities with accuracy comparable to the observed real object (preferably using modern computer techniques).

The modern simulation models are based on the complicated formal models. These models include significant amounts of factors, they reflect complex structural relationships and internal couplings. They consist also of a large number of elements. An important feature of the simulation method is making multiple tests (experiments) with the tested model in order to obtain the data allowing for material mapping of the technical conditions regarding tested models.

Taking into account the model of the level crossing automation system simulation process (similar to the other railway traffic control systems) from Fig. 4, the following experiments can be carried out [1, 2, 3]:

- evaluation of the exploitation process that allows adjustment of necessary resources for tasks and vice versa;
- estimation of the exploitation process reliability which enables the determination of exploitation parameters, including value-normative indicators defining the operation of the level crossing automation objects with specific tasks and the adopted equipment;
- taking important exploitation decisions which allow to make the right choice of means and maintenance methods of the objects building the level crossing automation system [13, 15].

![Fig. 4 Decision algorithm in the exploitation process of the level crossing automatic system [own elaboration based]](image)

The algorithm presented in Fig. 4 enables making decisions which will steer the course of the level crossing automation system exploitation process depending on its technical condition and the obtained quality indicators (appropriate exploitation parameters). The model has adaptive character and can be widely used [9, 11].


Exploitation tests of the level crossing automation system were carried out on the E-30 railway route in Poland on the section Opole – Wrocław – Zgorzelec with the length of 327.294 km. The analyzed fragment of the E-30 route has been divided into subsystems, which creates 5 selected railway lines with a known configuration of the railway traffic control devices. In the simulation model of the level crossing automation system distinguished one type of devices (the level crossing) and six types of elements: traffic signal lights, road barriers drives, track sensors, controlling circuits, power systems and others (interfaces, transmission network, cables, etc.) [4].

The level crossing automation system is a 4-level system with a dispersed structure and hierarchical controlling. The simulation model takes into accounts the relationships between system levels, subsystems, devices and elements. There are several repair technologies associated with each element. Therefore, the model of the level crossing automation system can be expanded with an additional level of repair technology. It will be the basic decision-making level regarding the choice of renewal technology for the damaged element [3, 10, 11].


A computer application has been developed to evaluate the exploitation parameters of the railway traffic control devices including the level crossing devices. It allows to [4, 6, 7]:

- create the database with the structure and exploitation of the level crossing automation system;
- simulate the failure and repair processes;
- analyse, verify and statistical evaluate the real data obtained during exploitation tests and simulation results (Fig. 5).

A random number generator was used in the simulation process to provide the procedure of drawing new values depending on previously identified probability distributions of these quantities. There was applied a simulation model based on the “subsequent events” method.

In the simulation model, there were preliminarily made statistical hypotheses about unknown values of failure
time duration parameters and time of failure-free operation of all objects distinguished, statistical hypotheses regarding
the distribution of damage in individual subsystems and devices of the level crossing automation system as well as
hypotheses regarding their unknown type (shape). The λ-Kolmogorov and Chi-quarter tests were used to verify the
compatibility of empirical distributions with the most popular hypothetical distributions used in the theory of reliability,
I.e. exponential, normal and logarithm-normal. The parametric Student’s t-test was used to verify the average values of
the compared probability distributions [4, 7, 10, 11, 14].

Fig. 5 Screen of a simulation program presenting the statistical analysis results of data regarding failure elements such
as “controlling circuits” [own elaboration]

8. Results Obtained During Computer Forecasting of the Level Crossing Automation Devices Exploitation
Parameters

As a analysis result of data collected from the railway network selected fragment (E-30 railway route in Poland)
in 2017, there were obtained information such as: system structure description, names of objects appearing in it,
histograms of the damages number in distinguished objects, histograms of damage durations and histograms of the time
of failure-free operation, coefficients of devices and elements readiness, information on the number of repair
technologies, etc.

The results of exploitation parameters obtained by various methods were verified, i.e. on the basis of statistical
analysis and computer simulation in order to provide more comprehensive analysis and evaluation of the level crossing
automation system exploitation process 12, 13, 16].

Fig. 6 Percentage schedule of the level crossing automation units damages for [own elaboration]: a - given statistical
data in 2017 year; b - simulation data

Fig. 6 shows the percentage share of individual elements damages of the level crossing automation system in the
total number of all damages in 2017. Among the distinguished types of elements, the least damage was noted for traffic
signal lights (2%), while the highest for road barriers drives (59%).

In the analysis of the level crossing automation devices exploitation process there are useful the average duration
of damage and average time of the entire level crossing failure-free operation, as well as the times of damage and times
of failure-free operation of its individual elements types. Elements of other type (interfaces, transmission network,
cables, etc.) are in the longest state of inability – 21 hours per year, traffic signal lights (6.5 hours per year) are in the
shortest. The determined average values of the failure-free operation times indicate that the power systems worked for
the longest without breakdown – 2452 hours per year, i.e. continuously for 102 days, while the shortest times of failure-
free operation – control circuits – 98.5 hours per year.

9. Conclusions

In order to make a forecast of the railway traffic control devices exploitation parameters, there was carried out
computer modelling of these devices, including the level crossing automation devices. A computer application was
developed to evaluate the exploitation parameters of devices for securing traffic at the level crossings. Thanks to this,
there was created the possibility to analyse and evaluate the level crossing automation system exploitation process (its
use and renewal) with the given description of this system equipment and a given description of repair technologies
reertoire.
Forecasting the reliability of the railway traffic control devices allows to determine the values of reliability indicators based on working conditions and environmental impact. However, this requires knowledge of the system reliability model, working conditions and environmental conditions, the reliability characteristics of the components and used software.

The hierarchical system in the form of a tree used in the model of the level crossing automation system maps the infrastructure of this system exploitation process in the topographic sense (assignment of the railway traffic control devices to individual subsystems, components to devices, etc.) and in the technical sense (device types, their number, complexity, etc.).

The presented results of computer forecasting of exploitation parameters of the railway traffic control devices show how the system exploitation process is going on over a longer period of time. They can be a useful tool for assessing the technical condition of the system and its subassemblies under natural exploitation conditions. They enable assessment of the manufacturer’s technical level and are a source of service planning (preventive inspections, maintenance, adjustments, etc.) and repairs (replacements, upgrades, renovations, etc.) of the railway traffic control devices, eg they will determine the number and frequency of preventive inspections, the number and type of necessary spare parts, global exploitation costs, etc.

References

The Graph Theory Application in the Praxis of Flight Path Planning

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Abstract

The article is focused on the graph theory application in the praxis of aviation - especially the flight routes planning and airways optimization. The article analyses the theoretical-practical findings of the graph matrix and consequently examines how to apply it into air transportation. The main aim of the article is to highlight the possible practical methods of using the graph and matrix theory in the optimizing of air tracks and routes and minimizing errors during tactical flight planning. The result of the exploration is an overview and response to the issue of graph theory application in aviation. The graph and matrix theory helps to ensure the effective, safe, economic and ecological air traffic flow management, optimize the tactical flight planning, minimize the unexpected situations and prevent the possible air traffic congestions and delays.

The result of the article demonstrates that graph and matrix theory is one of the possible solutions in the air traffic flow management and tactical flight planning issue.

KEY WORDS: air traffic flow management, CPM method, flight path planning, flight routes, graph theory.

1. Introduction

Graph theory is a mathematical field, and it is a special part of the combinatorial analysis, which closely relates to applied mathematics and operational analysis. It deals with the study of mathematical form - graph. The term of the graph can be defined from a mathematical and, from a normal point of view, in two ways:

1. graph as a way of displaying (for example, some dependencies of variables);
2. graph as a certain mathematical form, which is a model of some real system.

The importance of the graph theory is best described by the second definition.

The graph can be characterized as a form, showing relationships between elements of a system through a set of vertices and edges. The roots of the graph theory date back to the 18th century, when in 1736 the Swiss mathematician Leonard Euler solved the oldest and best-known graph issue, the Königsberg bridge problem. This already solved mathematical problem is based on a real place and a real situation. The German city (now it is Russian Kaliningrad) was situated on the river Pregel, which created two islands. The islands were connected with the other cities by seven bridges. The question was whether it was possible to take a walk through the island in such a way as to cross over every bridge only once. It was Euler who first solved the issue and stated that it is not possible. He reworded the problem based on his graph theory method and proved that in the created graph, there is no Eulerian move.

Fig. 1 The Königsberg bridge issue [2]

Only Eulerian graphs have one-stroke draw property. This above-mentioned issue is referred to as the beginning of graph theory. In summary, the graph optimization algorithms based on the graph theory is a very useful technique of transport system theory, which uses its own access and procedures for solving optimization problems.

The main goal of these optimization tasks is to search for a minimal graph frame, search for optimal routes and ways in the graph (minimal, maximal, shortest, longest, cheapest, etc. track or airways), determine sequences and maximal flows in tracks, design new routes, tracks and other. The graph theory is also studied and discussed in works [1, 3].

The application of acquired knowledge is part of the aviation training of pilots and air traffic controllers, as well...
as the flight planning dispatchers, which has a 65-year tradition in Košice, in the Slovak Republic. The core elements of education and training of pilots as a part of the Knowledge Alliance of Aviation Education are:

- the know-how, the past and present Civil and Military aviation maintenance, repair and operation’s experience;
- the results of the theoretical work and the scientific and research activities in the field of: University Academic subjects, Social and Human Sciences, the Simulation and modelling of Security issues, the Applied Technical Sciences, the Applied Civil and Military / Air Force management, education and training etc. within the Expert Database of Civil and Military Aviation Experience in progress (the selected theoretical framework of Knowledge Alliance within the Simulation and modelling of Security issues is in the works of authors [4 - 8], the selected theoretical framework of Knowledge Alliance within the Applied Technical Sciences is in the next works of authors [9 - 12], the another selected theoretical framework of Knowledge Alliance within the Applied Civil and Military / Air Force management, education and training is in the works of authors [13]).

2. Basic Knowledge and Concepts in Graph Theory Important for Graph Travel

Each graph consists of certain parts that it is need to know for proper graph handling. The basic elements of graphs are a set of nodes or vertices and edges. It means that a graph is a collection of vertices and edges.

**Vertices** are elements of the set \( U \) and are places, where at least one of the following occurs:

- elements enter or exit the system, or gathers;
- it creates, cancels or manipulates ensembles.

**Edges** or lines are pairs of vertices in an undirected graph, arranged pairs of vertices in an oriented graph and a set of vertices in Multigraph. We can mark them as “\( h_{ij} \)” or as a disordered pair \([u_i, u_j]\). They are elements of the set \( U \) (Fig. 2).

![Fig. 2 Vertex-edge [own source]](image)

The **orientated edge** is given by the starting and ending vertex, indicated by an arrow in the graph. It is an ordered pair \((u_i, u_j)\).

**Parallels edges** are at least two edges, which connect the same pair of vertices.

**Multiple edges** are at least two parallel edges that start and end at the same vertices. They differ from parallel ones in that they are all oriented or non-oriented (Fig. 3).

![Fig. 3 Parallel and multiple edges [own source]](image)

**Adjacent edges** are two edges that have a common vertex.

**Adjacent vertices** are two vertices, between which is an edge that connects them.

A **loop** is an edge that starts and ends in the same vertex. It is incidents with one vertex (Fig. 4).

**The sequence** is an alternating sequence of consecutive vertices and edges that starts and ends at a vertex. There are two types of sequences: open and closed.

An **open sequence** is a sequence in which the initial and final vertex is different, \( u_1 \neq u_n \).

A **closed sequence** is a sequence in which the initial and final vertex is identical, \( u_1 = u_n \). It means, that a closed path is a cycle.
A cycle is a closed path and has at least one edge. No vertex is repeated except the initial one which is at the same time final. It's a loop.

A stroke is a sequence in which no edge is repeated.

A path is a walk with no repeated vertices.

A relation is a relationship of two graph elements with the same dimension (edge-edge, vertex-vertex).

An incident is a relationship between two elements of different dimension (edge-vertex). Vertex $u_i \in U$ is incident with the edge $h_{ij} \in H$ of the graph $G = [U, H]$ if the edge $h_{ij}$ starts or ends in the vertex $u_i$ [1-3].

3. The Uses of the Graph Theory in the Praxis of Aviation

The practical application of graph theory in transport can have the following tasks divided into two main groups:

– designing transport networks and selecting subnetworks;
– tasks of traffic flow.

The first group means the construction of completely new, non-existent network and the selection of a certain subnetwork that meets certain criteria. In the second category, it is mainly the selection of the optimal track, path in an existing network. The path optimisation means the selection such track, which corresponds to the expected parameters when we use a track - the cheapest, shortest, fastest route. We look for optimal routes in the network in order to minimize the cost of making a trip (referred to as minimum route distances). Similarly, as the graph theory, the operational and system analysis deals with the solution of track optimisation in transport.

At searching for optimal routes is very important to consider that the track must be as reliable, short as possible and consequently the cheapest and most economical. At creating new routes, it is considering the maximal track capacity too. The optimal path searching is possible in two main methods:

– graph theory methods;
– CPM method.

The next example describes the optimal flight route (one way track) searching based on graph theory.

The vertices represent airports or waypoints, and the edges show flight routes. For a clearer calculation, the edges (flight routes) have recalculated nautical miles to simple values, which represent the track distance from point 1 (AD 1) to point 2 (AD 2).

From the theoretical point of view, the graph $G$ is an oriented, direct and edge evaluated graph (Fig. 5).

With the help of graph theory, it is possible to determine the shortest way and describe in the following Table 1:

In the table, the shortest routes from the point $U_0$ to other points are marked in red. It means that from $U_0$ (start point) to $U_8$ (destination or final point) the shortest route has a value of 10. Table 2, in summary, describes the final shortest routes from point to point.

The shortest path can be calculated and graphically illustrated by the CPM method. The CPM method calculates the shortest distances from the start point (vertex) $U_0$ to the final point (vertex) $U_8$. $U_8$ in this example is the alternate or adjacent airport, point or vertex and $U_8$ is the final or destination point.

Unlike the CPM method used in the project management, where the longest path is calculated from the $U_l$ vertex to the $U_l$ vertex, in this case, it is the opposite - the shortest route.
Table 1

<table>
<thead>
<tr>
<th>u₀</th>
<th>u₁</th>
<th>u₂</th>
<th>u₃</th>
<th>u₄</th>
<th>u₅</th>
<th>u₆</th>
<th>u₇</th>
<th>u₈</th>
<th>u₉</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0+1</td>
<td>0+4</td>
<td>0+2</td>
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<td>4+5</td>
<td>4+5</td>
<td>1+10</td>
<td>1+10</td>
<td>4+5+3</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>9</td>
<td>3</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>13</td>
<td>12</td>
<td>9</td>
<td>9</td>
<td>13</td>
<td>14</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>14</td>
<td>16</td>
<td>12</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* the shortest paths from the point U₀

Table 2

<table>
<thead>
<tr>
<th>u₀</th>
<th>u₁</th>
<th>u₂</th>
<th>u₃</th>
<th>u₄</th>
<th>u₅</th>
<th>u₆</th>
<th>u₇</th>
<th>u₈</th>
<th>u₉</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>11</td>
<td>9</td>
<td>9</td>
<td>13</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>U₀</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>13</td>
<td>-</td>
<td>13</td>
</tr>
<tr>
<td>U₁</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>U₂</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>9</td>
<td>7</td>
<td>11</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U₃</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U₄</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U₅</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U₆</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U₇</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U₈</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 6 Graph G - the shortest path by the CPM method [own source]

Fig. 6 illustrates the shortest track from the starting (U₀) to the final (U₉) vertex (point) in the graph G by a CPM method. The shortest routes are marked in red.

It is known from the above-mentioned graph that the flight path would extend:
- by 1 value through vertex U₃ and U₄;
- by 3 value through U₄ and U₇;
- by 4 value through U₅, U₆ and U₇.

In air transport, new air routes are being constructed, or optimal routes (shortest, most economical and ecological) for passenger, cargo, and goods transport flight. In pre-flight briefing documentation, the pilots have available the favourable routes, generated by the scheduling system. The system works on the bases of graph theory, programming and algorithms. Determining the optimal route is a key factor in minimizing flight time, fuel consumption, emission, track length and delays. It ensures an organised and efficient air traffic flow management.
4. Conclusions

The safe, economical, ecological and fast air traffic flow is the key factor in aviation transport management. The main goal of the airline companies is to choose the optimal flight routes in terms of safety, distance, economy and length. Most of the air companies have a system for generating the optimal flight routes, which works on the bases of graph theory, system analysis and algorithms.

The methodology of transport system theory works with a set of concepts, methods and knowledge about transport, abstracting from the specific characteristics of individual modes of transport. As well as aviation, also a rail, road and ship transport department use the graph theory segment. The essence of the problem that transport systems theory solves in different transport departments is the same, and their mathematical model is similar. Therefore, it is important to choose the right method and then to correctly apply this method in the issue.

References

Analysis of the Intra-Day Irregularity of Intaken Empty Wagon-Flows During the Day Periods

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Abstract

The article deals with the formulation and solution of the problem of intra-day distribution of wagon-flows entering the section of the transportation directorate. As a research method for estimating the intake of empty wagons, with the account for their daily and intra-day irregularity, the method of dynamic programming has been used. The process of empty wagons’ intake on the railroads’ junction points is described by time series, representing a plurality of observations, fixed in the timeline. The mathematical modelling of daily wagon-flows, as stochastic time series, made it possible to forecast their future values at the required predefined time with a given confidence probability.

KEY WORDS: irregularity of traffic, wagon-flows, time series, technological process, relative frequency of wagons’ intake, dynamic programming method

1. Introduction

One of the most urgent tasks at the present stage of development of railway transport is the task of increasing freight turnover. At the same time, there is increasing competition from other modes of transport, especially the road and water ones. First of all, this is due to higher efficiency and relatively lower tariffs for services of modes of transport competing with the railway. In this regard, the problem of increasing freight turnover should be solved by attracting new customers and increasing the competitiveness of rail transport by improving the quality of freight services, which is directly related to the stability of providing customers with rail wagons. The set problem can be solved by continuous monitoring and evaluating the quality of the provided services, taking into account the specific characteristics of all stages of the freight transportation process [1-3].

In the field of transport services, it is important to take into account that customer needs are constantly changing, which requires a rapid response from the railway [4-8]. Therefore, this article is focused on new solutions regarding the evaluation of the regularity of empty wagons’ intake, using various types of appropriate software.

The stability of technological cycles in many manufacturers of the metallurgical, mining, chemical and other industries depends on the rhythm of providing these industries with wagons. Unfortunately, in practice, there is an irregularity of freight traffic, which affects both the quality of customer serving and all aspects of the operational activities of railways.

The problem of studying the irregularity and forecasting fluctuations of wagon-flows occupies a special place in scientific publications of many authors [9-14], which also confirms its relevance. Researchers emphasize the need to study the irregularity of empty wagons’ intake, as one of the important steps in improving the use of rolling stock and increasing the quality of servicing industrial enterprises. Thus, to take into account the inevitable fluctuations and forecast future work volumes, it is necessary to study seasonal, daily, as well as intra-day irregularities [15].

Intra-day irregularity manifests itself in various types of operational activities, including the thickening of the intake of trains to the railroads’ junction points from a railroad to a railroad before the reporting time, especially due to the intake of trains composed of empty wagons [16].

There are several theoretical approaches to solving the problem of operational and short-term forecasting of intra-day irregularities in the intake of empty wagons.

The first of these is based on direct modelling involving the average lead-time of operations [17, 18] and is used in multi-day forecasting. The second approach involves the use of traditional statistical forecasting methods [19]. This approach is applicable only to the processing of continuous statistical data in automated control systems, where a priori it is necessary to know the deterministic basis of the forecast. The third method is based on the use of analogies combined with statistical methods. It has found a fairly complete expression in the situational-heuristic method of forecasting [20].

The objective nature of the fluctuations of the wagon-flows, including within 24 hours, is determined by the
peculiarities of the work of railway transport. To ensure the technological cycles of manufacturers, the forecast of the fluctuations of the wagons’ intake is important. To optimize the shift-daily handling of the wagon-flows, it is necessary to develop a mathematical model that allows forecasting the wagons’ intake by day periods.

2. Defining the Problem

The article deals with the formulation and the solution of the problem of intra-day distribution of wagon-flows on the basis of the method of dynamic programming. The process of empty wagons intake on the railroads’ junction points is described by time series, representing a plurality of observations, fixed in the timeline. In practice, monitoring of the empty wagons’ intake is carried out at discrete time points, which allows, for statistical analysis, to consider these processes as discrete time series.

For the analysis, fluctuations in wagon-flows were taken at the railroads’ junction points between the railroads (Odessa and Prydniprovska), where they are taken into account most precisely – the railroads’ junction points Tymkovo and Piatykhatky.

Conventionally, the day was divided into eight periods with a starting point equal to the beginning of the railway day – 5 pm. Thus, discrete time series are observed at a fixed interval \( A \), which is equal to three hours. If there are \( N \) consecutive values of such a series available for analysis, then we can write \( x_1, x_2, ..., x_N \) denoting observations made at equal time points \( t_0 + h, t_0 + 2h, ..., t_0 + Nh \).

A special feature of the study of time series is their stochastic nature since future values can only be described using the statistical laws of distribution. Therefore, in the future, it is natural to consider the time series to be analyzed as a particular implementation of the stochastic process being studied for empty wagons intake at the railroads’ junction points.

The statistical law of the distribution of the relative number of entering wagons at the observed time points during the day indicates the intra-day irregularity of the wagon-flows. Table 1 presents data for November 2018 for the Tymkovo and Piatykhatky stations.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Time points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8 pm</td>
</tr>
<tr>
<td>Tymkovo</td>
<td>0,07</td>
</tr>
<tr>
<td>Piatykhatky</td>
<td>0,09</td>
</tr>
</tbody>
</table>

The data of Table 1 show that a significant proportion (about 0.4) of entering wagons is observed at 05 p.m., thus emphasizing the irregularity of their intake. Fig. 1 shows the line graph of the distributions presented in Table 1, which underlines the irregularity of the wagons’ intake at the observed time points.

![Fig. 1 Line graph of distributions of the number of entering wagons at Tymkovo and Piatykhatky stations](image)

3. Methodology

Accumulated statistical data are used to develop a mathematical model necessary for forecasting-determining for the future probabilistic characteristics on the irregularity of the wagons’ intake by periods of the day.

Tables 2 and 3 present the results of calculating the relative frequency of the number of entering wagons at the observed time points for November 2018 at the stations Tymkovo and Piatykhatky respectively.

In the first row of Tables 2 and 3, there are marked time points, denoting the three-hour intervals, in which the intake of trains of empty wagons was observed. The first column of Tables 2 and 3 shows the number of wagons; proportional to the number of trains, taking into account the variation in the number of wagons in these trains. Tables 2
and 3 show the relative frequencies of the intake of the number of wagons observed at the marked time points as well.

<table>
<thead>
<tr>
<th>$X_{i+x}$</th>
<th>$t_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>05-08 pm</td>
</tr>
<tr>
<td>0</td>
<td>0.54</td>
</tr>
<tr>
<td>60±9</td>
<td>0.13</td>
</tr>
<tr>
<td>100±15</td>
<td>0.33</td>
</tr>
<tr>
<td>150±15</td>
<td>0.14</td>
</tr>
<tr>
<td>200±20</td>
<td></td>
</tr>
<tr>
<td>250±20</td>
<td></td>
</tr>
<tr>
<td>300±24</td>
<td></td>
</tr>
<tr>
<td>350±24</td>
<td></td>
</tr>
<tr>
<td>400±24</td>
<td></td>
</tr>
<tr>
<td>450±25</td>
<td></td>
</tr>
<tr>
<td>500±24</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$X_{i+x}$</th>
<th>$t_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>05-08 pm</td>
</tr>
<tr>
<td>0</td>
<td>0.67</td>
</tr>
<tr>
<td>60±9</td>
<td>0.17</td>
</tr>
<tr>
<td>100±15</td>
<td>0.13</td>
</tr>
<tr>
<td>150±15</td>
<td>0.03</td>
</tr>
<tr>
<td>200±20</td>
<td></td>
</tr>
<tr>
<td>250±20</td>
<td></td>
</tr>
<tr>
<td>300±24</td>
<td></td>
</tr>
</tbody>
</table>

Mathematical modelling of the wagon-flow during the day is to distribute the daily wagon-flow over three-hour intervals so that the probability of the calculated number of wagons is maximum. For this purpose, we used bar charts that characterize the distribution of the number of wagons every three hours.

According to Table 2, in the period of days from 5 pm to 8 pm, it can be seen that the relative frequency of observations when the wagons were not received is 0.54. The relative frequency of intake of one train of empty wagons in the period from 5 pm to 8 pm is 0.13, of two trains – 0.33.

Mathematically, this problem can be formulated as extreme:

$$F = \prod_{i=1}^{8} W_i \rightarrow \max \left(x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8 \right);$$

$$\sum_{i=1}^{8} x_i = u,$$

where $W_i$ – relative frequency in the $i$-th time point; $x_i$ – the number of wagons in the $i$-th time point; $u$ – the number of wagons per day.

The number of wagons per day $u$ – is the set number of wagons, whose intake is forecasted by periods of the day.

Obviously, the maximum $W_i$ depends on both the value $u$ and the method of selection $x_i$.

The above described problem relates to dynamic programming tasks. The solution to this problem is implemented consistently with the maximization of the objective function at each step. The optimization step corresponds to the period of the day. Since the day is conventionally divided into 8 periods, the optimization, in this case, has 8 steps.

At each step, we select the maximum value of the function: the product of the relative frequency of wagons’ intake and the conditionally optimal frequency obtained at the previous step.

In order to find the maximum, functional equations are compiled:

$$\phi_i(u) = \max \left\{ w_i \left(x_i \right) \right\} = w_2 \left(x_i \right);$$
For the $j$-th time interval:

$$
\varphi_j (\Delta) = \max \left\{ w_j (x_j), \varphi_{j-1} (\Delta - x_j) \right\}, \quad 0 \leq x_j \leq \Delta, \quad j = 2,3,...,8.
$$

At the first optimization step, we take the relative frequencies of the intake of the number of wagons as the conditionally optimal probability:

$$
\varphi_1 (0) = 0.54; \\
\varphi_1 (50) = 0.13; \\
\varphi_1 (100) = 0.33.
$$

At the second step with $x_2 = 0$, the value of the probability of wagons’ intake depends on the intake in the previous period.

$$
\varphi_2 (\Delta) = \max \left\{ w_2 (x_2), \varphi_1 (\Delta - x_2) \right\},
$$

where $\Delta$ – the chosen difference between the wagons’ intakes, $\Delta = 50, \Delta = 100, \Delta = 150$, etc.

$$
0 \leq \Delta \leq u.
$$

When $\Delta = 0$, $x_2 = 0$, $\varphi_2 (0) = \max \left\{ w_2 (0), \varphi_1 (0) \right\}$, substituting values, we get:

$$
\varphi_2 (0) = 0.77 \cdot 0.54 = 0.4157; \\
x_2 (0) = 0.
$$

When $\Delta = 0$, $x_2$ can take two values 0 and 50.

$$
x_2 = 0; \\
\varphi_2 (50) = \begin{cases} 
    w_2 (0) \cdot \varphi (50) = 0.77 \cdot 0.13 = 0.1001 \\
    w_2 (50) \cdot \varphi (0) = 0.13 \cdot 0.54 = 0.0702
\end{cases}.
$$

The maximum value $\varphi_2 (50) = 0.1001$ at $x_2 = 0$.

This means that at the second optimization step, taking into account the conditionally optimal frequency at the first step, with the possible intake of 0 or 50 wagons, the relative conditionally optimal intake frequency $x_2 = 0$ is maximum.

It is important that the setting of the objective function $F$ can be done both analytically and in the form of tables or graphs.

4. Investigation Results

In Table 4 the solution to the problem of intra-day distribution of wagon-flows with $u = 350$ at Tymkovo station for November 2018 is presented according to the data of Table 3.

The data in this table forecast the intake of empty wagons at the Tymkovo junction during the day:

- from 08 am to 11 am an intake of 100 wagons is expected;
- from 02 pm to 05 pm an intake of 250 wagons is expected.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>05-08 pm</td>
<td>08-11 pm</td>
<td>11 pm-02 am</td>
<td>02-05 am</td>
<td>05-08 am</td>
<td>08-11 am</td>
<td>11 am-02 pm</td>
<td>02-05 pm</td>
</tr>
<tr>
<td>$x_i$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>250</td>
</tr>
</tbody>
</table>

Table 4: The distribution of the number of wagons during the day.
In practice, the daily intake of wagons on November 25, 2018 is presented in Table 5.

<table>
<thead>
<tr>
<th>Period</th>
<th>05-08 pm</th>
<th>08-11 pm</th>
<th>11 pm-02 am</th>
<th>02-05 am</th>
<th>05-08 am</th>
<th>08-11 am</th>
<th>11 am-02 pm</th>
<th>02-05 pm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x_i$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>58</td>
<td>0</td>
<td>256</td>
</tr>
</tbody>
</table>

The solution to the problem makes it possible to forecast the expected intake of wagons at the railroads’ junction points between the railroads by periods of the day. In practice, it is possible to use such a forecast when planning work on providing large-scale loading stations with empty wagons. The solution to this problem is relevant for employees of enterprises responsible for operations in accordance with technological cycles.

The block-diagram of the solution of the problem of intra-day distribution of wagon-flows is shown in Fig. 2.

5. Conclusions

The article analyzes the wagon-flows with regard to their daily and intra-day irregularity. At the same time, a new, extreme, formulation of the problem of intra-day distribution of the wagon-flow on the basis of the dynamic programming method has been developed and implemented.

Mathematical modelling of daily wagon-flows as stochastic time series made it possible to make a forecast of their future value for the required predefined time with a given confidence probability. A practical solution to the problem of intra-day distribution is advisable to implement in the existing automated control system of the railway.
References

Taking into Account the Cold Start Engine Conditions in National Emission Inventory of NOX and NMVOCs

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Abstract

The paper presents results of NOX and NMVOCs emission inventory obtained using the COPERT 5 software. Applied Tier 3 method lets to estimate emissions taking into account specific engine conditions connected with the engines’ operational states.

In case of both pollutants the cold emissions are decreasing along with increase of the trip length (ltrip parameter), and are driven by passenger cars. However, in case of CS emissions the increase of vapours’ pressure is significant, it can substantially increase the emissions from gasoline evaporation.

KEY WORDS: road transport, air pollution, emission inventory, COPERT

1. Introduction

NMVOC and NOX emissions affect air quality and human health. Road transport sector is an important source of these pollutants in Polish emission inventory. In 2017 road transport in Poland was responsible for almost 40% of total Polish NOX, and 12% of NMVOC emissions [1]. The sources of those emissions in vehicles are in majority exhaust systems.

In this article, the authors apply the COPERT 5 software [2, 3] which uses the ‘Tier 3’ methodology approved for compilation of air emission inventories in European countries [4, 5]. In the ‘Tier 3’ methodology the estimated total exhaust emissions are split between the ‘cold start emissions’, released into the air during transient thermal engine operation, and ‘hot emissions’, when the engine achieves its normal operating temperature (e.g. engine coolant ≥ 75-90°C, three-way catalyst (TWC) ≥ 250°C). The general equation for the ‘Tier 3’ methodology is presented below:

\[ E_{Total} = E_{Hot} + E_{Cold} \]  (1)

where \( E_{Total} \) – total emissions [g] of any pollutant for the spatial and temporal resolution of the application; \( E_{Hot} \) – emissions [g] during stabilized (hot) engine operation; \( E_{Cold} \) – emissions [g] during transient thermal engine operation (cold start).

Cold start (CS) emissions make a large contribution to total emissions from motor vehicles due to fuel-rich combustion in the engine, increased friction, and reduced emission control efficiency. CS emissions are defined as the excess emissions at the initial startup when the engine is cold (is in ambient temperature), and expressed as grams of pollutant per the vehicle start [4, 6, 7]. The CS emissions can be compared with the stabilized, hot emissions released when the engine is at its normal running temperature. Then the travel time can be transformed into the travelled distance (Fig. 1). The distance needed to reach stabilized emissions is called \( l_{trip} \).

CS (excess) emissions can be measured in laboratory using the chassis dynamometer, if the applied driving cycle is long enough to reach the stabilization distance, and running conditions of the engine. The driving cycle should imitate desired actual state of the vehicle’s engine. Assessing the relationship between the CS emissions and the chosen parameter (e.g. the vehicle’s velocity) through the applied driving cycle the driving behaviour must be the same during the cold and hot phases. The distinction is made between urban, rural and highway driving (1). Cold-start emissions are attributed mainly to urban driving (and secondarily to rural driving), as it is expected that limited number of trips start at highway conditions [4], then:

\[ E_{Total} = E_{Urban} + E_{Rural} + E_{Highway} \]  (2)

where \( E_{Urban}, E_{Rural}, \) and \( E_{Highway} \) are the total emissions [g] of any pollutant for the respective driving situations.
2. Emission Modelling

The monthly averaged temperature (Table 1) is used for the modelling of pollutants emissions.

Table 1

The average monthly temperatures in Poland in 2017 [9*,10]

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mar</td>
<td>Apr</td>
<td>May</td>
<td>Jun</td>
</tr>
<tr>
<td>$T_{\text{min}}$ [°C]</td>
<td>-2.1</td>
<td>-2.2</td>
<td>5.0</td>
<td>8.9</td>
</tr>
<tr>
<td>$T_{\text{max}}$ [°C]</td>
<td>7.6</td>
<td>8.6</td>
<td>15.0</td>
<td>19.3</td>
</tr>
</tbody>
</table>

However, the cold ambient temperatures can substantially increase the air pollutants’ emissions from spark ignition and diesel vehicles, there is a number of publications mentioning about the dependence between the ambient temperature and cold start emission [7, 8]. Only the carbon monoxide, hydrocarbons, NOX, and particulate matter emissions are currently regulated at cold temperature. Therefore, it is of great importance to revise current EU winter vehicle emissions regulations [10, 11].

Total emissions are calculated by combining the activity data (fuel combusted) for each vehicle category with appropriate emission factors. The emission factors can vary according to the input data on driving and climatic conditions. CS emissions are estimated as a surplus emissions over the emissions that would be expected if all vehicles were only operated with hot engines and warmed-up catalysts. The CS emissions are estimated using the formula given below [3, 5, 12]:

$$E_{\text{Cold},i,k} = \beta_{i,k} \cdot N_k \cdot M_k \cdot \frac{e_{\text{cold},i,k}}{e_{\text{hot},i,k}} \left( \frac{e_{\text{cold}}}{e_{\text{hot},i,k}} - 1 \right),$$

where $E_{\text{Cold},i,k} =$ cold-start emissions of pollutant $i$ (for the reference year), produced by vehicles of the technology $k$; $\beta_{i,k} =$ fraction of the mileage driven with a cold engine (or the catalyst operated below the light-off temperature) for pollutant $i$ and vehicles of the technology $k$; $N_k =$ number of vehicles [veh] of the technology $k$ in circulation; $M_k =$ total mileage per vehicle [km/veh] in vehicles of the technology $k$; $e_{\text{hot},i,k} =$ hot emission factor for pollutant $i$ and vehicles of the technology $k$; $e_{\text{cold},i,k} =$ cold/hot emission quotient for pollutant $i$ and vehicles of the technology $k$.

The $\beta$ parameter depends on the ambient temperature, the conditions (pattern) of the vehicle use, and the average trip length needed to achieving stabilized emission conditions ($l_{\text{trip}}$). Official guidelines [3, 5, 12] suggests that the $l_{\text{trip}}$ is positively skewed. The $l_{\text{trip}}$ parameter can be obtained experimentally, however there is no available $l_{\text{trip}}$ for average Polish conditions of driving. Due to the fact, the emissions are simulated for the $l_{\text{trip}}$ varying from the 8 to 15 km.

Another parameter which can affect the level of the NMVOCs emissions is the fuel vapor’s pressure (kPa). In Poland, over the last years, the demand for motor gasoline has been gradually decreasing, which is a common trend in the European Union. At the same time, the use of bioethanol is increasing which is a direct effect of the existing European regulations [13] which obliges European Union Member States to achieve at the end of 2020 the share of energy from renewable sources in transport at the level of least 10%. In accordance with the [14], this objective will be pursued in Poland primarily based on the use of biocomponents in fuels and liquid biofuels (8.5%). The directives [15, 16] obliges countries to set limits for NOX and NMVOCs, and ensure the suitable treshold of the emission reduction.
Mixing of the two types of the motor gasoline (containing and not containing bioethanol) is inherently associated with the processes of storage, transport and storage in the tanks of petrol stations and related conditions. The result of this is an increase in the pressure of motor gasoline vapours, which will not overwhelm before mixing. Change of the gasoline vapours’ pressure affects the value of the emission factor. Estimations of NMVOCs emissions are given for two possible values of vapours’ pressure: 60 kPa and 68 kPa, respectively [3, 17].

NMVOCs emissions from evaporated gasoline is calculated using the COPERT 5 software [3, 5, 12]. It is split into the three components:
1. Daily emission caused by the changes in ambient temperature (applies to vehicles parked);
2. Emission from the hot, but not working engine;
3. Losses while driving – during high ambient temperatures.

The input data for the COPERT 5 software are elaborated on the basis of available real data, expert assumptions and default values proposed in the software. The vapour pressure is introduced as RVP (Reid Vapour Pressure) parameter.

3. Results

The estimations are carried out for the basic assumptions on: the number of vehicles (Table 2), mileage and share per road class (Table 3), and the average speed per road class (Table 4), given below.

### Table 2

<table>
<thead>
<tr>
<th>Category</th>
<th>N [×10³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars (PCs)</td>
<td>22,510</td>
</tr>
<tr>
<td>Light Duty Vehicles (LDVs)</td>
<td>2,752</td>
</tr>
<tr>
<td>Heavy Duty Vehicles (HDVs) + Buses</td>
<td>1,120</td>
</tr>
<tr>
<td>L-Category</td>
<td>2,818</td>
</tr>
<tr>
<td>Total</td>
<td>29,201</td>
</tr>
</tbody>
</table>

The number of vehicles is based on data derived from [18, 19].

### Table 3

<table>
<thead>
<tr>
<th>Category</th>
<th>U [%]</th>
<th>R [%]</th>
<th>H [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCs</td>
<td>39</td>
<td>48</td>
<td>13</td>
</tr>
<tr>
<td>LDVs</td>
<td>37</td>
<td>50</td>
<td>13</td>
</tr>
<tr>
<td>HDVs</td>
<td>29</td>
<td>56</td>
<td>15</td>
</tr>
<tr>
<td>Urban buses</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coaches</td>
<td>29</td>
<td>56</td>
<td>15</td>
</tr>
<tr>
<td>Mopeds</td>
<td>80</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>55</td>
<td>32</td>
<td>13</td>
</tr>
</tbody>
</table>

*U* – Urban; *R* – Rural; *H* – Highways

### Table 4

<table>
<thead>
<tr>
<th>Category</th>
<th>U [km/h]</th>
<th>R [km/h]</th>
<th>H [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCs</td>
<td>31.5</td>
<td>70</td>
<td>120</td>
</tr>
<tr>
<td>LDVs</td>
<td>29.5</td>
<td>65</td>
<td>105</td>
</tr>
<tr>
<td>HDVs</td>
<td>26</td>
<td>55</td>
<td>80</td>
</tr>
<tr>
<td>Urban buses</td>
<td>22</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Coaches</td>
<td>26</td>
<td>55</td>
<td>80</td>
</tr>
<tr>
<td>Mopeds</td>
<td>30</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>45</td>
<td>75</td>
<td>120</td>
</tr>
</tbody>
</table>

In the article, the authors present two scenarios concerning the influence of the parameters that were input to the model for a cold start. In the first scenario the simulation is carried out using the COPERT 5 software (see Eqs. (1) and (2)), assuming different values for the \( l_{wp} \) parameter in order to determine the parameter’s impact on the cold start emission. Simulations are performed assuming the maximum and minimum ambient temperatures (Table 1) occurring in Poland in 2017 [9, 20].

NOX annual CS emissions [kt] for rural and urban driving are presented respectively in the Figs. 2-3.
NMVOCs annual CS emissions [kt] for rural and urban driving are presented respectively in the Figs. 4-5.

Table 5
The NMVOCs CS and evaporation emissions [kt] from urban driving depending on the vapours’ pressure

<table>
<thead>
<tr>
<th>Category</th>
<th>60 kPa</th>
<th>68 kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold start (CS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCs</td>
<td>29,782</td>
<td>29,511</td>
</tr>
<tr>
<td>LDVs</td>
<td>2,958</td>
<td>2,926</td>
</tr>
<tr>
<td>Gasoline evaporation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCs</td>
<td>13,695</td>
<td>14,551</td>
</tr>
<tr>
<td>LDVs</td>
<td>1,072</td>
<td>1,152</td>
</tr>
</tbody>
</table>
4. Summary

For both pollutants (NO\textsubscript{X} and NMVOCs) the cold emissions decrease along with the increase of the trip length ($l_{trip}$). In case of Rural driving conditions the increase of trip length above 10 km causes that the emissions of NO\textsubscript{X} and NMVOCs become insignificant. The cold emissions are driven by PCs.

However in case of CS emissions the increase of vapours’ pressure is insignificant, it can substantially increase the emissions from gasoline evaporation.

References

   Available from: https://www.ceip.at/ms/ceip_home1/ceip_home/status_reporting/2019_submissions/
16. Directive 2016/2284 sets emission levels based on the quantity of fuels sold using a linear reduction path, set between their emission levels for 2020 and the emission levels set in emission reduction commitments for 2030.
Railway in the Logistics Service of Urban Inhabitants – a Case Study of Agglomeration in Poland

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Abstract

The dynamic development of modern cities entails economic, social, cultural and ecological problems. Typical negative phenomena are pollution emission, noise, traffic accidents and congestion. Efficient logistic service of the residents is a remedy for these problems. It is a system of transport organization that limits negative phenomena and at the same time increases users' satisfaction with the mobility offered to them. A fundamental element of this system is rail transport. Railway lines are the backbone of the agglomeration transport system, and railway means of transport generate low external costs.

The aim of the article is to present solutions for logistic service of city dwellers in the field of rail transport in Poland. The article discusses the basic conditions of the functioning of agglomeration railways, including strengths and weaknesses, the place of agglomeration railways in the rail passenger transport market and the functioning of rail systems in selected agglomerations.

KEY WORDS: railway in Poland, agglomeration railway, city logistics

1. Introduction

One of the problems of modern cities is their overcrowding. High intensity of traffic generates difficulties in movement of people and goods, pollution of the environment, increase in the number of accidents and collisions, disturbances in traffic flow, economic and social dysfunctions of the agglomeration. Efficient logistic service of city residents is a remedy to these problems.

The most important task of logistic service for residents is to organize the system and the flows taking place in it in such a way that they do not constitute a barrier limiting the current functioning and development of the city. The introduction of various types of improvements in the transport structure of the city favours its effective functioning and optimisation of passenger and freight transport. Theoreticians of urban logistics indicate that this system should [1]:

- improve the process of travelling, including shortening its time;
- reduce the travel costs associated with congestion;
- protect the environment;
- increase user’s satisfaction with mobility needs.

Since the late 1990s, various concepts have been developed and implemented to improve mobility flows, including a multimodal urban journey, referred to in the literature as "broken". (public and private transport in one journey). The main aim of these solutions is to change the transport structure, i.e. to reduce the share of individual transport in favour of collective forms of transport. EU transport policy also aims to increase the competitiveness of environmentally friendly modes of transport and to create integrated transport chains using two or more modes of transport. Only collective public transport modes are socially efficient and consistent with the efficient functioning and development of the city [2]. Rail is the backbone of the agglomeration transport system, and the other modes of transport (bus, tram, trolleybus, metro) support its functioning by serving as a feeder to interchanges.

The aim of the article is to present solutions for logistic service of city dwellers in the field of rail transport in Poland and to identify the problems of its development. These issues will be presented against the background of the analysis of the entire rail passenger transport market. The subject and purpose of the research implies the analysis of the subject literature, statistical data, evaluation reports, as well as legal acts. The method of comparative analysis and analysis of cause and effect relationships was applied, which increase the accuracy of the obtained results and conclusions formulated on this basis.

2. Transport Policy for Agglomeration Railways

The rail passenger transport system is traditionally divided into four subsystems: inter-agglomeration, inter-regional, regional and agglomeration. Regional and agglomeration transport systems are used to service metropolitan areas. However, metropolitan railways have a greater potential, providing a convenient and fast connection between
suburbs and satellite cities and agglomeration centres. They enable significant flows of travellers to be moved efficiently and safely. They satisfy the transport needs within agglomerations, serving as a fast and reliable means of transport, independent of road traffic congestion and, above all, faster than a car or a bus.

The position and role of railways in the transport system of Polish cities was determined by the SWOT analysis in the document "Master plan for rail transport in Poland until 2030" [3]. It is presented in Table 1.

Table 1

<table>
<thead>
<tr>
<th>SWOT analysis for agglomeration railways in Poland [3]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strengths</strong></td>
</tr>
<tr>
<td>- low external costs</td>
</tr>
<tr>
<td>- a high level of safety</td>
</tr>
<tr>
<td>- large capacity</td>
</tr>
<tr>
<td>- no exposure to congestion</td>
</tr>
<tr>
<td>- high commercial speed in comparison with individual motorisation and other means of urban transport</td>
</tr>
<tr>
<td>- technical, organisational and tariff-ticketing integration with urban and individual transport systems</td>
</tr>
<tr>
<td>- the process of passenger transport self-regulation</td>
</tr>
<tr>
<td>- the possibility of the emergence of new carriers as a result of market liberalisation</td>
</tr>
<tr>
<td>- operation of regional airports</td>
</tr>
<tr>
<td>- an increase in the number of routes ordered under public service obligations</td>
</tr>
<tr>
<td>- the use of existing but so far poorly used railway infrastructure in agglomerations for this category of services</td>
</tr>
<tr>
<td>- purchase and modernisation of rolling stock</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunities</th>
<th>Hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>- the progressive transport congestion in cities</td>
<td>- lack of sufficient resources to purchase modern rolling stock</td>
</tr>
<tr>
<td>- technical, organisational and tariff-ticketing integration with urban and individual transport systems</td>
<td>- further deterioration of the technical condition of the line and point infrastructure</td>
</tr>
<tr>
<td>- the process of passenger transport self-regulation</td>
<td>- the lack of appropriate legal solutions to facilitate long-term public service contracts</td>
</tr>
<tr>
<td>- the possibility of the emergence of new carriers as a result of market liberalisation</td>
<td>- lack of legislative separation of agglomeration transport from regional transport</td>
</tr>
<tr>
<td>- operation of regional airports</td>
<td></td>
</tr>
<tr>
<td>- an increase in the number of routes ordered under public service obligations</td>
<td></td>
</tr>
<tr>
<td>- the use of existing but so far poorly used railway infrastructure in agglomerations for this category of services</td>
<td></td>
</tr>
<tr>
<td>- purchase and modernisation of rolling stock</td>
<td></td>
</tr>
</tbody>
</table>

The agglomeration railway has strong technical, organisational and operational links with other urban transport systems and is the most important part of the so-called "intermodal partnership". The aim of this concept is to optimise the use of different modes of transport and to create links between different modes of public transport (train, tram, metro, bus, taxi) and different modes of individual transport (car, motorcycle, bicycle). The practical implementation of this concept requires efficient connections within cities (with airports and railway stations), connections between the urban and suburban networks, and connections to the Trans-European Transport Network (TEN-T).

3. The Place of Agglomeration Railways on the Rail Passenger Transport Market

Transport needs of people in Poland, like in other EU countries, are satisfied mainly by private individual transport - passenger cars, and then by bus and rail transport, as well as by means of public transport - metro and trams. The largest market share is held by individual transport - 77% on average, followed by bus transport - 14% and rail transport - 7% (passenger-km) [4]. However, if we consider only the public transport market (without passenger cars), it is served by bus and rail transport in various forms of transport.

The rail passenger transport market in Poland can be divided into several segments:

- regional transport;
- interregional and inter-agglomeration transport;
- international and cross-border transport.

Regional transport is carried out mainly by passenger and express trains, in the territory of one province. They include traditional regional and agglomeration services. Transport services are provided by public companies: Regional Transport, Mazovian Railways, PKP Szybka Kolej Miejska (PKP SKM) in Tri-City, Szybka Kolej Miejska (SKM) in
Warsaw, Koleje Śląskie (Silesian Railways) and smaller local government companies operating in urban agglomerations.

Another category of transport - interregional and inter-agglomeration - is serviced primarily by the state company PKP Intercity (PKP IC). The company offers connections between large cities by express trains under the trademarks Express InterCity (EIC) and Express InterCity Premium (EIP) operated by Pendolino trains. PKP IC’s share in this market segment amounts to 97%. Moreover, express and passenger train transport services are provided, inter alia, by companies: Regional Transport and Mazovian Railways.

International transport is also the domain of PKP IC, which offers long-distance, express and express train services - IC, EIC, EN. PKP IC trains run to: Berlin, Prague and Ostrava, Vienna, Bratislava, Budapest, Lviv, Kiev, Rivne, Brest, Grodno, Minsk and Moscow.

The volume of passenger transport in particular segments of the market in comparison to all rail transport is presented in Fig. 1.

In general, rail transport is characterized by an annual increase in the number of passengers, which in the studied period amounted to 18%. This trend occurs in the regional and international transport segment. In this first category of transport, the increase was the largest and reached the level of 25%. However, fluctuations in the number of transported passengers in the segment of interregional and inter-agglomeration transport were caused by the modernization of railway lines, which meant numerous track works or traffic restrictions on certain sections. At the same time, the lines launched after the modernization attract passengers, which has been visible since 2015. Thanks to the modernisation, travel time is shortened, railway companies invest in the purchase and modernisation of rolling stock, which improves the quality of the offer and the return of passengers.

The largest share in the rail transport market is held by the segment of regional connections, which has also increased its share from 80% in 2010 to 85% in 2017. The development of regional and agglomeration railways is connected with the establishment of local government companies: Mazowieckie Railways (2004), SKM in Warsaw (2004), Śląskie Railways (2010), Łódzka Kolej Aglomeracyjna (2010), Małopolskie Railways (2013). In 2004, as a result of new legal regulations, voivodship self-governments became responsible for the organisation of railway transport in their areas, including the financing of transport and the preparation of transport offers. At the same time, there was an increase in the financing of railways, including EU funds. Local authorities, especially in the case of large urban agglomerations, encountered at the same time a serious problem of congestion. The individual motorisation rate exceeded 500 passenger cars/1000 inhabitants, e.g. in Warsaw, Gdańsk, Katowice, Kraków, Poznań, Wrocław. These factors caused that local governments began to restore the role of the railway as the "backbone" of the transport system.

While studying the rail passenger transport market, it is also worthwhile to analyse the share of individual carriers. The detailed division of transport tasks is presented in Fig. 2.
These figures show that the overall increase in the number of passengers is due to the dynamic growth of metropolitan rail transport. Local government railway companies take over passengers previously served by Przewozy Regionalne (a 15% decrease in shareholding) and acquire new customers. The development of the agglomeration transport market is very visible in the case of Warsaw, where SKM Warszawa and Warszawska Kolej Dojazdowa (WKD) operate, as well as Śląska (Koleje Śląskie), Wrocław (Koleje Dolnośląskie), or Poznań (Koleje Wielkopolskie).

4. Rail in the Transport Service of Selected Agglomerations

The position of agglomeration railways in the logistics service of the inhabitants can be traced by using the example of agglomerations in which railway companies transport the largest number of passengers. This is the Tri-City, Warsaw and Silesian agglomeration (Fig. 3).

The Tri-City Metropolitan Area (OMT) is made up of three connected cities: Gdańsk, Sopot, Gdynia and neighbouring districts. It covers an area of 414 km² and is inhabited by 1.5 million people. Railway transports is carried out there by SKM and Przewozy Regionalne. SKM provides services on the section of the 44 km long railway line between Gdańsk and Wejherowo and on the Pomeranian Metropolitan Railway (PKM). It is a new investment of the voivodeship self-government, commissioned in 2015. It is one 19 km long diesel traction line with eight stops. The line connects Gdańsk with Gdynia, at the same time serving the Gdańsk airport. The total length of the tracks operated by SKM is about 500 km, and 117 thousand passengers use them daily. The highest transport intensity is on the main section of the railway line - between Gdańsk and Wejherowo, with a length of 44 km. Every day over 100,000 passengers travel on this section. In the remaining routes, passenger flows are relatively smaller. The frequency of train runs between Gdańsk Śródmieście and Gdynia Cisowa is 7.5 minutes in the transport peak and 15 minutes outside the peak [6]. Besides, rail transport is also provided by Przewozy Regionalne. These are mainly regional relations, including connections to and from the core of the metropolis.

The transport system of the Warsaw agglomeration covers the city of Warsaw and 33 neighbouring communes. It serves a total of about 2.5 million inhabitants. Railway transport is provided by three local government companies: Railways Mazowieckie, SKM Warszawa and WKD (Fig. 4). Mazovian Railways operate mainly regional connections to the larger urban centres of the province. At the same time, some of these connections are used by passengers who regularly arrive at work in Warsaw. SKM Warszawa offers connections on four routes with a total length of almost 150 km. It connects the centre of Warsaw with its suburbs and some satellite towns and operates the Warsaw-Okęcie airport. It carries about 65 thousand passengers a day, its commercial speed is 40 km/h and it is the fastest means of transport in...
the agglomeration [8]. The WKD, in turn, is the first standard track electric railway launched in Poland. It has been operating since 1927, and its network is located in the south-western part of the agglomeration, and it runs through two districts of the city (Ochota and Wlochy) and six communes. It consists of three railway lines with a total length of 40 km. It is used daily by about 22 thousand people [9].

The Warsaw agglomeration railway network is very well integrated with other means of public transport. And one of the important elements of integration is a common ticket for Mazovian Railways, WKD and the Municipal Transport Authority Katowice (responsible for the organization of public transport) and SKM (on specific sections). One ticket does not require any extra charges or a priori choice by the passenger, whether he wants to use public transport or public and railway transport. Railway companies - SKM and Mazovian Railways - have been cooperating in timetabling for many years. Thanks to this, an offer for travellers which is created meets the needs of the residents of the agglomeration and areas outside it. Moreover, railway carriers offer the possibility of leaving the car at the starting station of the journey in the Park&Ride system. Parking there is often free of charge for those with valid travel tickets.

The Silesian Railways serve the largest metropolitan area in Poland, called Silesia, located in the central part of the Silesian Voivodeship. The metropolis comprises 41 communes with a total area of 2553 km² and a population of 2.2 million. The metropolis consists of 13 larger cities, of which Katowice, Gliwice and Sosnowiec are the most important. It is a highly urbanised area, with many industrial centres, with a high saturation of road and railway infrastructure. The spatial range of the metropolis, significant distances between cities and social and economic ties between them cause that the Silesian Railways provide regional transport services. The carrier operates 13 railway lines in the Silesian Voivodeship with a total length of about 980 km (Fig. 5). It uses 56 electric traction units which carry over 47 thousand passengers daily [10].

![Fig. 3: Rail transport scheme in Tri-City][7]
The problem for the functioning and development of the Silesian Railways is the poor condition of the infrastructure: on many sections of the line there are restrictions of 40 or even 20 km/h. Such low speed means that rail cannot compete with road transport, which uses a very well-developed network of expressways. Therefore, modernization of the main, most heavily loaded section of the serviced railway line Katowice-Gliwice was planned. After the modernization, the travel time will be shortened and the frequency of train runs will be 15 minutes during rush hours. Another problem is incomplete tariff integration with other means of transport. The so-called Silesian monthly ticket is available for passengers, entitling them to travel on Silesian Railways and all bus, tram and trolley bus lines organized by the Metropolitan Transport Authority (ZTM) in Katowice (responsible for the organization of public transport). However, there are no statutory discounts in this ticket. For several years, there has also been a so-called EcoTicket - a common time ticket (6-hour, 12-hour, 24-hour). These activities are an important element of the integration process of the local public transport [11].
5. Conclusions

Rail transport is „the backbone” of the transport system of most agglomerations, it is a fast and reliable means of transport, independent of the congestion in road traffic. Therefore, cities looking for a solution to traffic jams, air pollution and excessive noise are rediscovering the potential of railway lines running through the middle of urban areas. It is the municipal and provincial authorities that have contributed to the revitalisation of the agglomeration railways in Poland. Demand for agglomeration transport has been growing for several years, and the agglomeration transport segment has the highest growth dynamics in the rail transport market. However, as the research shows, the potential of railways is not fully exploited at present. The fundamental problems of practical integration of railways with urban transport are insufficient tariff and ticket offer and the number of integration places - change centres. A common fare system - one ticket, one timetable, valid for all modes of transport in the entire agglomeration - is the basic prerequisite for the success of urban transport systems in agglomerations in Germany. However, as far as transport infrastructure is concerned, a dense network of railway stops, extensive interchanges integrated with transport and car parks (Park&Ride system) or separation of agglomeration traffic by building new tracks on the most overloaded sections of the network is important. The implementation of these postulates requires close cooperation between local authorities at all levels (cities, communes, districts, voivodeships) of the agglomeration in the field of transport policy. Further actions
undertaken by them may make the agglomeration railway system the basic element of improving the competitiveness of public transport in metropolitan areas.

The conducted research is a diagnosis of current conditions and the level of development of agglomeration railways and their place on the passenger transport market. Conclusions formulated on this basis may be helpful for decision-makers at various levels in the context of identifying problems and shaping the directions of the agglomeration transport policy. Further research may focus on the monitoring of this market segment and the analysis of "good practices".

References

Evaluation the Efficiency of Urban Transport Modes Using Multi-Criteria Analysis

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Abstract

The aim of this study is to evaluate different urban transport modes by applying different quantitative and qualitative criteria. The methodology of research includes four steps. The criteria for the assessment of urban transport modes have been determined in the first step. Three main groups of criteria for evaluating the transport modes have been defined named Costs, Benefits and Risk. The total fourteen sub-criteria have been defined. The alternatives have been determined in the second step of methodology. In this research is investigated transportation by metro, buses and cars. The third step includes determination the weights of criteria. The Best Worst Method (BWM) which is based on linear programming method has been applied. The fourth step includes ranking of the variants of transportation by applying Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE II) - Geometrical Analysis for Interactive Aid (GAIA) methods and verification the results. The practicability of the methodology is demonstrated through the case study of parallel routes from Sofia's transport network. It was found that the carriage by metro is the best transport technology for investigated route. The methodology could be applied to evaluate different transport alternatives for different routes in urban transport network.

KEY WORDS: Best worst method (BWM), PROMEHEE-GAIA, urban transport, metro, bus, cars

1. Introduction

The urbanization of the cities implies the development of various types of urban transport to meet the needs of passengers for traveling. Some of transport modes as buses and cars are main source of air pollution; others as electrified rail transport are environmental friendly. Much of the environmental pollution is due to the exhaust gases from transport activities. Therefore, it is necessary to use efficient transport technologies that are environmentally friendly and improve the quality of life in cities. In addition, the choice of efficient transport depends on economic, technological, social and other factors. Therefore, the assessment of the efficiency of urban transport mode should be investigated depending on factors of different nature.

In [1] authors studied the choice of different alternatives for urban transport according the criteria capital cost, capacity, environmental benefit and socio-economic benefit. The ANP method and AHP method were applied to rank the alternatives. In [2] the following criteria for selecting the best mode of transportation were used: transportation cost, environmental effect, capacity, safety, comfort, reliability, number of interchanges required and journey time. The criteria weights and ranking the alternative were determined using AHP method. The criteria as time, fare, comfort, reliability and accessibility, etc. has been used in [3] to assess the importance of various parameters affecting the mode choice made by urban transport. The values of criteria have been determined by AHP method. A set of six criteria was proposed in [4]: waiting time; riding time; accessibility to the stop; comfort of travel; cost of rolling stock purchase; cost of building, maintenance and renewal of route. The ELECTRE III/IV and AHP methods have been used for decision making. In [5] the authors defined the main groups as social, economic, technological, and transportation to investigate alternative-fuel buses for public transportation using multi-criteria analysis. Sub-criteria for each main group have been defined. In [6] authors the proposed the following criteria for evaluation of public transportation system: travel cost, travel time, waiting time, suitability, accessibility and safety. An integrated multi-criteria approach based on Delphi method, group AHP method and ROMETHEE method have been proposed. The research conducted in [7] proposes two types of factors to investigate the passenger flows by rail and buses: price and quality of service (travel time, frequency, comfort, etc.).

It can be summarized that the developed researches use as main criteria for assessment of different alternative modes of transportation the transport costs, travel speed, frequency, prices of the tickets, safety and comfort. The different multi-criteria methods have been used to determine the weights of defined criteria and rank the alternatives. The Best-Worst Method (BWM) is a new method of multi-criteria decision-making developed by Jafar Rezaei in 2015, [8, 9]. The method is used to determine the weights of predefined criteria and to evaluate of alternatives with respect to these criteria. The BWM uses the most important criterion called best, and the criterion with opposite role, called worst identified by decision maker to make a pairwise comparison of the decision criteria. The method is based also on linear programming to define the criteria weights. BWM is used in various decision-making areas such as logistics [10-12], economics [13], transport and engineering [14, 15] due to its easy applicability and reliable results. Some authors applied the BWM together with others methods of multi-criteria analysis as VIKOR, ELECTRE, MABAC, [13-15].
The PROMETHEE II Method is one of mostly used multi-criteria methods to make decision which rang the alternatives, [16, 17]. This method is outranking and has simple mathematical properties. The PROMETHEE II method can be used along with Geometric Interactive Decision Aid (GAIA) analysis. The GAIA analysis is based on principal component analysis and gives a graphical representation of results obtained by the PROMETHEE II method. This paper presents a new hybrid model for evaluation the efficiency of urban transport modes. The model considers 3 main criteria and 14 sub-criteria. The Best-Worst method is implemented to determine criteria weights. The weight coefficients of the criteria are used to ranking the different urban transport modes by PROMETHEE-GAIA method. The verification of results is made according the utility of alternatives.

2. Methodology

The methodology of research includes four steps. In the first step includes determination the criteria to assess different transport mode. The alternatives of urban transportation are determined in the second step. The third step includes determination the weights of criteria by applying BWM method. The ranking the alternative is made in the fourth step by using PROMETHEE II-GAIA methods. This step includes also verification of results.

2.1. Determination the Criteria to Assess Urban Transport Modes

The following main groups of criteria have been determined in the study:
- Costs - This group presents the costs for transport operator and for passengers.
- Benefits - This group includes the advantages for passengers of modes of transport.
- Risk - This group includes the ecological risks of modes of transport.

The main group Costs includes the following sub-criteria:
- Fuel costs - This sub-criterion presents the transport costs for fuel (electric energy), BGN/pass.
- Ticket Price - This sub-criterion presents the price for ticket for urban carriage, BGN/pass.
- Direct operating costs, BGN/pass. This sub-criterion includes the costs for transportation and the wage costs of drivers, BGN/pass.

The main group Benefits includes following sub-criteria:
- Time - This is a time needed to travel with the appropriate mode of transport, min.
- Frequency - This is the number of transport means per hour, means/h.
- Comfort - This means the possibility of a seating place during a trip, and a comfortable trip of the standing.
- Security - This means safety with regard to road accidents.
- Reliability- This means the accuracy performance of the timetable.
- Stability - This mean independence from meteorological conditions.

The criteria Comfort, Security, Reliability and Stability are qualitative. Their values are set wit "1" if the answer for performance of criteria is "yes", and "0" if the answer for performance of criteria is "no".

The main group Risk includes following sub-criteria:
- CO2 - Carbon dioxide, g/pass.km.
- CO - Carbon monoxide (CO), g/pass.km.
- NOx - Nitrogen oxides (NOx), g/pass.km.
- NC - Non-methane hydrocarbons (NC), g/pass.km.
- PM - Particulate matter (PM), g/pass.km.

2.2. Determination the Alternatives

The alternatives differ according the mode of transportation. In the study have been investigated different modes of transportation along parallel routes.

2.3. Determination the Weights of Criteria

This study proposes the BWM method to calculate the weights of criteria. The methodology of BWM consist the following steps, [8, 9]:
- Step 1: Determination the criteria for decision making.
- Step 2: Determination of best and worst criteria. In this step the expert identifies from his point of view, based on his competence most important, i.e. best criterion, and least important, i.e. worst criterion.
- Step 3: Determination the preference of the best criterion over all the other criteria. Table 1 presents the linguistic scale for pairwise comparison for BWM.
Table 1

<table>
<thead>
<tr>
<th>Scale</th>
<th>Score</th>
<th>Scale</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equally important</td>
<td>1</td>
<td>Strongly more important</td>
<td>5</td>
</tr>
<tr>
<td>Equal to moderately more important</td>
<td>2</td>
<td>Strongly to very strongly important</td>
<td>6</td>
</tr>
<tr>
<td>Moderately more important</td>
<td>3</td>
<td>Very strongly more important</td>
<td>7</td>
</tr>
<tr>
<td>Moderately to strongly important</td>
<td>4</td>
<td>Very strongly to extremely more important</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extremely more important</td>
<td>9</td>
</tr>
</tbody>
</table>

The scale of pairwise comparison includes numbers between 1 and 9. The score 1 shows that the compared criteria have the same importance. The value 9 presents the extreme importance.

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

$$A_B = \left( a_{B1}, a_{B2}, \ldots, a_{Bn} \right)$$,

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

- Step 4: Determination the preference of each of the other criteria over the worst criterion. For this purpose the scale of pairwise comparison 1-9 is used again. The results Others-to-Worst vector is as follow:

$$A_W = \left( a_{W1}, a_{W2}, \ldots, a_{Wn} \right)^T$$,

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

- Step 5: Determination the optimal weights.

For this purpose the following minimax model is formulated:

$$\min \max \{ w_B = a_{Bj} \cdot w_j, w_j = a_{jW} \cdot w_W \};$$

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

$$w_j \geq 0, \text{ for all } j = 1, \ldots, n,$$

where \( w_j \) – weights of criteria, \( j = 1, \ldots, n \).

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

$$\min \xi^*;$$

$$w_B = a_{Bj} \cdot w_j \leq \xi^*, \text{ for all } j;$$

$$w_j = a_{jW} \cdot w_W \leq \xi^*, \text{ for all } j;$$

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

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

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

The received results of the weights can be used to determine the score of alternatives on the different criteria.

2.4. Ranking the Alternatives by Using PROMETHEE II – GAIA Methods

The weights of the criteria determined by BWM are used in the PROMETHEE II method to estimate the alternatives. This method applies a comparison of pair per pair of possible decisions along each criterion. The type of optimization of criteria has to be set as minimum or maximum. The PROMETHEE II method uses also a preference function \(P_j(a, b)\) which depends on a pairwise difference between the evaluations \(f_j(a)\) and \(f_j(b)\) of alternatives \(a\) and \(b\).
Six basic preference functions have been applied - usual criterion; quasi criterion; criterion with linear preference; level criterion; criterion with linear preference and indifference area; Gaussian criterion. The main steps of the PROMETHEE II method are summarised below [17]:

- Step 1: Determination for each pair of possible decisions and for each criterion, the value of the preference degree.
- Step 2: Determination for each pair of possible decisions, a global preference index \( \pi(a,b) \):
  \[
  \pi(a,b) = \frac{\sum_{j=1}^{n} w_j \cdot P_j(a,b)}{\sum_{j=1}^{n} w_j} ,
  \]
  where \( j = 1, \ldots, n \) – number of criteria.
- Step 3: Determination the outranking flows for each of the alternatives. In this step the positive outranking flow \( \phi^+(a) \) and the negative outranking flow \( \phi^-(a) \) are computed. The positive outranking flow expresses how much each alternative is outranking all the others. The negative outranking flow expresses how much each alternative is outranked by all the others.
  \[
  \phi^+(a) = \frac{\pi(a,b)}{m-1} ;
  \]
  \[
  \phi^-(a) = \frac{\pi(b,a)}{m-1} .
  \]
- Step 4: Determination the ranking of the criteria for each of the alternatives. The alternatives are ranked according the values of the net outranking flows. The net outranking flow \( \phi(a_i) \) of \( a_i \) in the alternatives set \( m \) of a possible decision is computed as a difference between \( \phi^+(a_i) \) and \( \phi^-(a_i) \).
  \[
  \phi(a_i) = \phi^+(a_i) - \phi^-(a_i) ,
  \]
  where \( i = 1, \ldots, m \) – number of alternatives.

For net outranking flow, the following conditions are valid:
  \[
  \phi(a_i) \in [-1,1] ;
  \]
  \[
  \sum_{i=1}^{m} \phi(a_i) = 0 .
  \]

The highest value of the net outranking flow (formula 14) shows the best decision.

The GAIA method is a geometrical presentation of the results, which help to verify the results of PROMETHEE II method. The GAIA method uses a matrix compiled of the single criterion net flows of all the alternatives. The set of \( m \) alternatives can be represented as a cluster of \( m \) points in a \( n \)-dimensional space. The GAIA plane is developed by projecting these points on a plane. In this plane, the alternatives are represented by points and the criteria are denoted by axes.

### 2.5. Verification the Results

The verification of results is based on approach using the utility of the alternatives. The score of each alternative is determined as follow:

\[
V_i = \sum_{j=1}^{n} w_j \cdot x^\text{norm}_j ,
\]

\[
x^\text{norm}_j = \frac{x_j}{\max \{x_j\}} , \text{ if } x_j \text{ is positive};
\]
\[ x_{ij}^{\text{norm}} = 1 - \frac{x_{ij}}{\max \{x_{ij}\}}, \text{ if } x_{ij} \text{ is negative} \] (19)

where \( x_{ij}^{\text{norm}} \) – normalized values of criteria; \( V_i \) are the score of alternative \( i \).

3. Results and Discussion

3.1. Determination the Alternatives

The proposed methodology have been applied for study the alternative modes of transportation for parallel routes in Sofia’s transport scheme. The section Sofia University St. Kliment Ohridski metro station - G.M. Dimitrov metro station has been studied. This area is served by metro and on a parallel route runs bus 280. There are also cars that moved in this section. Fig.1 presents the scheme of metro line and the route of buses and cars.

In the research the following alternatives of transportation have been determined: Alternative 1 - metro; Alternative 2- bus; Alternative 3 - car.

Fig. 1 Scheme of the alternatives

The values of sub-criteria have been determined taken into account of following conditions:

- The morning peak period from 8.00 to 9.00 o'clock is examined. The number of metro trains and buses of line 280 for morning peak period is determined according the data given by Urban Mobility Centre. The cars' frequency is 10 minutes. The filling factor for metro trains and buses was adopted equal of 0.9. For carriage it is assumed that one or two passengers travel in one car.
- The number of cars with gasoline and diesel engines is equal; the Euro 5 standard of The European Environmental Protection Agency's is applied; the average fuel consumption for a car is 12 l/100 km; the average fuel consumption for a bus is 35 l/100 km; the cost for average fuel consumption is 3.06 BGN/km. The relative power consumption for metro trains series is 7.02 kWh/km. The electricity price is 282.46 BGN/MWh.
- The direct operating costs for metro trains include the costs of running trains (electricity) and wage costs of drivers. These costs are 4.80 BGN/train.km according data from Sofia metro. The running costs of a car included the cost of oil, tires, maintenance, insurance and taxes. These costs are 40% of the fuel costs. The operating costs are 0.34 BGN/km.
- The Carbon dioxide (CO2) emissions for electricity generation have been accounted for metro transport. The CO2 emissions are 0.460 t/MWh according data from National Statistical Institute of Bulgaria. The CO2 emissions are assumed to be 130 g/km for a car, and 170 g/km for a bus. When determining the pollutants emissions, a power of 180 kW for an urban bus was adopted with an average power of 80% of the bus power.
- The ticket price for the metro and bus transport is calculated according a discount for 10 trips and it is 1.20 BGN/ticket. When traveling by car, the ticket price is equal to the fuel consumption per passenger.
- The operating costs and the value of harmful emissions for different mode of transport are compared by passenger-kilometers.

Table 2 show the values of sub-criteria.

<table>
<thead>
<tr>
<th>Sub-criterion</th>
<th>Fuel costs</th>
<th>Ticket Price</th>
<th>Operating Costs</th>
<th>Time</th>
<th>Frequency</th>
<th>Comfort</th>
<th>Security</th>
<th>Reliability</th>
<th>Stability</th>
<th>CO2</th>
<th>CO</th>
<th>NOx</th>
<th>NC</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BGN/pass.</td>
<td>BGN/pass.</td>
<td>BGN/pass.</td>
<td>min</td>
<td>means/h</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>g/ pass.km</td>
<td>g/ pass.km</td>
<td>g/ pass.km</td>
<td>g/ pass.km</td>
<td>g/ pass.km</td>
</tr>
<tr>
<td>Metro</td>
<td>1.48</td>
<td>1.20</td>
<td>0.02</td>
<td>8</td>
<td>3.00</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10.5</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Bus</td>
<td>4.15</td>
<td>1.20</td>
<td>0.04</td>
<td>17</td>
<td>8.57</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.98</td>
<td>0.13</td>
<td>0.04</td>
<td>0.17</td>
<td>0.002</td>
</tr>
<tr>
<td>Car</td>
<td>1.32</td>
<td>0.66</td>
<td>0.17</td>
<td>14</td>
<td>10.00</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>65.00</td>
<td>0.38</td>
<td>0.06</td>
<td>0.06</td>
<td>0.003</td>
</tr>
</tbody>
</table>
3.2. Determination the Weights of Criteria

The BWM method has been applied to determine the weights of criteria and sub-criteria. In this study six experts (two are specialists from academia and four are specialists from Urban Mobility Centre of Sofia) have been evaluated the criteria. They made group assessment of criteria using scale 1-9, (Table 1)

First, the pairwise comparison is made for the main criteria. The criterion Costs have been selected by the experts as the best criterion and the criterion Risk respectively as the worst criterion. Table 3 and Table 4 present the pairwise comparison for the best and the worst criterion.

### Table 3

<table>
<thead>
<tr>
<th>Criteria: Best to Others</th>
<th>Costs</th>
<th>Benefits</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best criterion: Costs</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th>Criteria: Others to the Worst</th>
<th>Costs</th>
<th>Benefits</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worst criterion: Risk</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

The procedure of assessment of criteria is applied for sub-criteria of each main group. The criterion Ticket price has been determined as the best and the criterion Operating Costs as the worst for the sub-criteria of the main group Costs. Table 5 and Table 6 show the assessment of experts.

The criterion Time travel has defined as the best and Comfort as the worst for the sub-criteria of the main group Benefits. Table 7 and Table 8 present the assessment of experts for this main group.

The criterion Particulate matter (PM) has defined as the best and Non-methane hydrocarbons (NC) as the worst for the sub-criteria of the main group Risk. Table 9 and Table 10 present the results.

### Table 5

<table>
<thead>
<tr>
<th>Criteria: Best to Others</th>
<th>Fuel</th>
<th>Ticket Price</th>
<th>Operating Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best criterion: Ticket Price</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

### Table 6

<table>
<thead>
<tr>
<th>Criteria: Others to the Worst</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Costs</td>
<td>2</td>
</tr>
<tr>
<td>Ticket Price</td>
<td>3</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 7

<table>
<thead>
<tr>
<th>Best to Others</th>
<th>Time</th>
<th>Frequency</th>
<th>Comfort</th>
<th>Security</th>
<th>Reliability</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

### Table 8

<table>
<thead>
<tr>
<th>Others to the Worst</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>7</td>
</tr>
<tr>
<td>Frequency</td>
<td>5</td>
</tr>
<tr>
<td>Comfort</td>
<td>1</td>
</tr>
<tr>
<td>Security</td>
<td>5</td>
</tr>
<tr>
<td>Reliability</td>
<td>4</td>
</tr>
<tr>
<td>Stability</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 9

<table>
<thead>
<tr>
<th>Criteria: Best to Others</th>
<th>CO2</th>
<th>CO</th>
<th>NOx</th>
<th>NC</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best criterion: PM</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 10

<table>
<thead>
<tr>
<th>Criteria: Others to the Worst</th>
<th>NC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2</td>
<td>5</td>
</tr>
<tr>
<td>CO</td>
<td>2</td>
</tr>
<tr>
<td>NOx</td>
<td>3</td>
</tr>
<tr>
<td>NC</td>
<td>1</td>
</tr>
<tr>
<td>PM</td>
<td>7</td>
</tr>
</tbody>
</table>

For linear optimization according formulas from (3) to (10) is used SOLVER in EXCEL to determine the weights of main criteria and sub-criteria. Table 11 presents the results. It can be seen that the weights of main criteria Costs and Benefits are equal. The local weights for each group and the global weights of criteria have been determined. The local weights show the weight of each sub-criterion in the respective group of the main criterion. The global weights show the priority of all sub-criteria taking into account the weights of main criteria.

Fig. 2 presents the global weights of criteria. It can be seen that the criteria ticket price, fuel, time and security have the main importance.

The ticket price is the main sub-criterion for main group Costs. The time travel is the main sub-criterion for the main group Benefits. The PM is the main sub-criterion for the main group Risk.

Table 11

<table>
<thead>
<tr>
<th>Main Criteria</th>
<th>Weight</th>
<th>Sub-criteria</th>
<th>Local weight</th>
<th>Global weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td>0.416</td>
<td>Fuel Costs</td>
<td>0.385</td>
<td>0.160</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ticket Price</td>
<td>0.462</td>
<td>0.192</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operating Costs</td>
<td>0.154</td>
<td>0.064</td>
</tr>
<tr>
<td>Benefits</td>
<td>0.416</td>
<td>Time</td>
<td>0.281</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency</td>
<td>0.164</td>
<td>0.068</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Comfort</td>
<td>0.039</td>
<td>0.016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Security</td>
<td>0.242</td>
<td>0.101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reliability</td>
<td>0.109</td>
<td>0.046</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stability</td>
<td>0.164</td>
<td>0.068</td>
</tr>
<tr>
<td>Risk</td>
<td>0.168</td>
<td>CO2</td>
<td>0.270</td>
<td>0.045</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CO</td>
<td>0.090</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NOx</td>
<td>0.108</td>
<td>0.018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NC</td>
<td>0.058</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PM</td>
<td>0.474</td>
<td>0.079</td>
</tr>
</tbody>
</table>
The values of Consistency $\xi^*$ for main criteria and sub-criteria are shown in Table 12. It can be seen that these values are closer to zero, which shows a high degree of consistency.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Main criteria</th>
<th>Sub-criteria of Costs</th>
<th>Sub-criteria of Benefits</th>
<th>Sub-criteria of Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\xi^*$</td>
<td>0.083</td>
<td>0.076</td>
<td>0.047</td>
<td>0.066</td>
</tr>
</tbody>
</table>

### 3.3. Ranking the Alternatives Using PROMETHEE II-GAIA Methods

The received results of the weights have been used to determine the score of alternatives on the different criteria. The PROMETHEE II method has been used for ranking the alternative. Table 13 presents the type of optimization of criteria and the type of a preference function for each of criteria. The linear preference function is usually chosen for quantitative criteria; the usual preference function corresponds to the optimization when the larger value is better.

<table>
<thead>
<tr>
<th>Sub-Criteria</th>
<th>Type of optimization</th>
<th>Preference function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Costs</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>Ticket Price</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>Time</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>Frequency</td>
<td>max</td>
<td>linear</td>
</tr>
<tr>
<td>Comfort</td>
<td>max</td>
<td>usual</td>
</tr>
<tr>
<td>Security</td>
<td>max</td>
<td>usual</td>
</tr>
<tr>
<td>Reliability</td>
<td>max</td>
<td>usual</td>
</tr>
<tr>
<td>Stability</td>
<td>max</td>
<td>usual</td>
</tr>
<tr>
<td>CO2</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>CO</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>NOx</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>NC</td>
<td>min</td>
<td>linear</td>
</tr>
<tr>
<td>PM</td>
<td>min</td>
<td>linear</td>
</tr>
</tbody>
</table>

The Visual PROMETHEE software has been used to make research, [18]. Table 14 show the net outranking flows, positive and negative outranking flows for alternatives. The last column of the table presents the rank of alternatives. Fig. 3 presents the results and consists two parts. The first part show the ranking according net outranking flows, the second part presents the values of sub-criteria.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>$\varphi(a_j)$</th>
<th>$\varphi^+(a_j)$</th>
<th>$\varphi^-(a_j)$</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metro</td>
<td>0.333</td>
<td>0.436</td>
<td>0.103</td>
<td>1</td>
</tr>
<tr>
<td>Car</td>
<td>-0.009</td>
<td>0.206</td>
<td>0.216</td>
<td>2</td>
</tr>
<tr>
<td>Bus</td>
<td>-0.324</td>
<td>0.084</td>
<td>0.407</td>
<td>3</td>
</tr>
</tbody>
</table>

The profile of an alternative consists of the set of all the single criterion net outranking flows. Table 15 presents the net outranking flows according the alternatives.
Fig. 4 presents the net outranking flows of the criteria according the alternatives. The alternative transportation with metro transport has the most positively influencing criteria with positive values of net outranking flows. The criteria time, security, reliability and stability have a big positive impact of alternative whit metro transport. The criterion fuel has also positive impact on this alternative. The criteria frequency and comfort have negative impact. The car transport is the alternative with three positive impacts of the criteria – comfort, frequency and fuel. The negative impact for this alternative has the criteria CO2, security, reliability and stability. The bus transport has only two criteria that influenced positive.

Fig. 4 Alternative profile according criteria

Fig. 5 presents the PROMETHEE II Rainbow of the impact of the criteria on outranking flows of alternatives. The criteria in the upper part of the figure have positive outranking flows. The positive (upward) flows correspond to good features while negative (downward) flows correspond to weaknesses. The criteria in the lower part of the figure have negative outranking flows. The balance between positive and negative flows is equal to the net outranking flows of the alternatives. The alternatives are ranked from left to right according to the PROMETHEE II Complete Ranking.

Fig. 5 PROMETHEE Rainbow of the impact of criteria on alternatives
The GAIA method is a visual interactive tool which helps to make a sensitivity analysis. The GAIA plane is the plane for which as much information as possible is preserved after projection. GAIA uses a dimension-reduction technique that is borrowed from statistical data analysis. The GAIA method computes and displays two first principal components (named U and V) in the GAIA plane, Fig. 6.

The GAIA plane is the best two-dimensional representation of the multi-criteria problem. The alternatives and criteria are presented in the GAIA plane. The GAIA decision stick and the GAIA decision axis help to decision maker to provide a sensitivity analysis. The Gaia stick is presented in the lower left part of the Fig.6 and shows the direction of the compromise solution. It is show the vector of the weights. It can be represented in the GAIA plane by the projection of the unit vector of the weights. As the projection is long, the GAIA decision axis has a strong decision power and the assessments of the decision makers are good. The GAIA decision stick and the GAIA decision axis provide a sensitivity analysis tool. It can be seen in Fig. 6 that the projection of the GAIA decision stick is long which indicates that the results are adequate. The alternatives are represented by sing square. The criteria are represented by axes drawn from the center of the plane. The length of the line indicates the importance of the criterion. The alternatives that are similar to each other appear close to each other in the GAIA plane. The alternatives that are very different from each other appear far away from each other in the GAIA plane. It can be seen that the three alternatives studied are located in different quadrants of the graph. The criteria expressing similar preferences are represented by axes oriented in similar directions. This is valid for example for the criteria frequency and comfort which are situated in North-East direction. Criteria expressing conflicting (opposite) preferences are represented by axes oriented in opposite directions. That is the case for example for criteria comfort and CO2. The length of a criterion axis is representative of its relative discriminating power: the longer the axis the more discriminating the criterion. Such a criterion is CO2 emissions.

The sensitivity analysis have been made also according GAIA decision axis with respect to the criteria. Fig. 7 presents the decision axis for the criterion Time travel; Fig. 8 presents the decision axis for the criterion Frequency. Of the example of Fig. 7 the PROMETHEE II ranking according the criterion Time travel is: metro > bus > car. In this case the direction of decision axis of criterion is the same as the GAIA decision stick. The alternative metro is in direction on the GAIA decision stick; the alternative bus is in the opposite direction, the alternative car is in an opposite quadrant of the GAIA plane. The example given in Fig. 8 presents different ranking: car > bus > metro. The GAIA decision axis is an opposite direction with respect to the GAIA decision stick. In this case the alternative metro is in different direction with respect to the GAIA decision stick and is therefore ranked last in the ranking. The best alternative in this case is the car. Fig. 9 presents the decision axis for the criterion Fuel; Fig. 10 presents the decision axis for the criterion Comfort. The PROMETHEE II ranking for criterion Fuel is similar to that of criterion Time travel metro > car > bus. The PROMETHEE II ranking for criterion Comfort is car > metro > bus. The directions of GAIA decision axis in this case in an opposite direction with respect to the GAIA decision stick such as in the case of criterion Frequency.

The sensitivity analysis of the results have been made by Visual PROMETHEE software. Here we present the limits of changing the weights of the criteria while preserving the optimal solution. The stability intervals for which the ranking remains unchanged for the criteria CO2, Frequency and Comfort are as follow: from 0 to 0.42; Frequency from 0 to 0.22;
Comfort from 0 to 0.20. For the all other sub-criteria, the limits of the change of criteria while preserving the optimal solution are from 0 to 1.

3.4. Verification of the Results

The formulas (17) – (19) have been used to verify the results of hybrid model. The normalized values of criteria, presented in Table 1 are shown in Table 16. The values of criterion of prioritization and the rank of alternatives are indicated in the last two columns of the table. It can be seen that the alternative transportation by metro is the best alternative. The values of criterion for bus and car are close. There is a difference in the ranking for both alternatives bus and car by using PROMETHEE method and utility of alternatives. The both alternatives exchange their positions. This is due to the close values of the criterion of prioritization by formula (19) for bus and car. Fig. 11 presents the ranking of the alternatives according utility.
4. Conclusions

In this research has been developed a hybrid model based on Best-Worst Method and PROMETHEE-GAIA methods for evaluation the efficiency of urban transport modes. Three main groups of criteria have been defined named Costs, Benefits and Risk. It was found by using BWM that the criteria Cost and Benefits have equal weights (0.416). The total fourteen sub-criteria have been defined to assess the transport modes. The criteria Ticket price (0.19), Fuel consumption (0.16), Time travel (0.12), Security (0.10) and Particulate Matter (0.08) have a big importance.

Three alternatives – metro, bus and car have been compared for parallel routes of Sofia’s urban transport scheme. They have been ranked by using PROMETHEE-GAIA methods. It was found that the transportation by metro is the best alternative. The criteria time, security, reliability, stability and fuel have a big positive impact of the alternative metro transport according they net outranking flows. The transport with cars is the alternative with three positive impacts of the criteria – comfort, frequency and fuel. The bus transport has only two criteria that influenced positive –frequency and carbon dioxide polluting emissions. The verification of results by using the utility of alternatives confirms that the best alternative for transportation for given route is metro. The criteria frequency and comfort express similar preferences and are represented by axes oriented in similar directions in GAIA plane. The more discriminating criterion in regard to alternatives is the criterion CO2 emissions. The most of the criteria have wide ranges of variation where the ranking is retained. The criteria with small rang of variation are: CO2, frequency and comfort.

The elaborated hybrid model could be used to compare different alternatives of transport modes in urban area.

Acknowledgments

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References


The Comparative Analysis of Study Programmes in the Field of Transport Economics and Operation

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Abstract

The article is focused on the comparative analysis of individual study programmes the field of transport economics and operation of selected European technical universities and other institutions providing tertiary education in the field of transport.

The key impulse for writing current article is a generally known fact that in the sphere of transportation there occur profound changes in the knowledge and skill requirements of railway experts which are not sufficiently reflected by the system of education at different institutions of tertiary education. As a result of mentioned rapid changes, different study programmes need to be adapted to labour market demand. High quality of education in field of transport is crucial condition for sustainable transport solution.

The analysis used information from more than 900 European universities (included 300 technical universities) and more than 400 study fields and programmes (included 170 study fields focused on transport). Based on the results of comparative analysis of different study programmes in the field of transport, suggestions and eventual modifications can be applied on existing study programmes in the field of transport operation and transport economics at different European technical universities. As a tool for conducting a comparative analysis serves detailed description of every selected study programme. The chosen programmes are oriented towards both general and railway transport fields and the comparative analysis is mainly focused on the content of selected study programmes. Therefore, the article contains comparative analysis of 18 study programmes of which 6 are focused on the railway transport and 12 study programmes which are focused on general transport and logistics sphere.

KEY WORDS: European university, tertiary education, transport economics and operation

1. Introduction

Transport and services related to it are areas of economy which happen to develop most quickly. Thanks to this information, the everyday transport services and continuous flow of goods can be provided. Because of rapid development in transportation, it is necessary to come up with flexible study programmes for undergraduate students and specialists who not only will be capable of providing these services, but also will be capable of planning, organizing and managing them [2,4]. However, we face a problem as such study programmes are not universal for all European technical universities or other institutions offering such programmes which means that every university or institution can make its own study programme based on standards of the country where the institution of tertiary education is situated. Another problem is that requirements and skills necessary for future specialist change quickly. In addition, the universities are not capable of quickly and efficiently adapting to such quick changes. The importance of this phenomena is supported by the fact that various articles were written on it [3].

Taking into consideration the problems mentioned above, in the article we analyse current state of education in the area of transport economics and operation at various European technical universities as well as at institutions offering transport study programmes [6, 7]. We primarily focus on characteristics of study programmes of chosen technical universities and institutions. In addition, we characterise and carry out a comparative analysis of a structure and content of chosen study programmes of transport economics and operation. The article contains comparative analysis of 18 study programmes of which 6 are focused on the railway transport and 12 study programmes which are focused on general transport and logistics sphere [1].

2. Comparative Analysis of Study Programmes in the Field of Transport and Economics

The method, which we used to choose appropriate study programmes and based on which we later carry out comparative analysis itself, consists of three steps. Firstly, we did a research on the amount of universities and institutions of tertiary education where one can study transport. The tools used for searching the universities were Google and Academic Ranking of World Universities (known as Shanghai Ranking). In addition, we continuously searched for study programmes and syllabi of courses which we found on the websites of the universities. Secondly, we chose universities which met criteria we had previously set (the criteria will be explained later in the article) and which offered primarily study programmes in the field of transport economics and operation. Thirdly, we chose the courses and compared their content. When comparing, we mostly used amount and percentage of transport and economics oriented subjects or modules of the whole curriculum of a study programme.

Because of the wide-range of study programmes and their content, this article is mostly focused on the study
programmes in the field of transport economics and operation which not only does cover the transport part but also the economic part of transport operation [5, 8]. Study programmes focused on transport economics and operation that are characterized and analysed in the article are mainly chosen from the European universities and institutions of tertiary education based on the five key criteria. The first criterion is a choice of institutions of which more than a half of courses are technically focused, so they are primarily technical institutions of tertiary education. However, during data collecting we have found out that many study programmes and courses of transport economics and operation are taught at universities which are focused more generally, thus not technical universities. The second criterion is a choice of such universities which offer undergraduate and postgraduate study programmes. The third criterion results in the analysis of the particular study programmes because they can be divided into four groups according to their main focus of study. These programmes are production-technical study programmes (1); operation-economic study programmes (2); construction-engineering study programmes (3); and study programmes that do not fit any of above mentioned categories (4). According to this criterion we were able to identify such universities and institutions of tertiary education which offer study programmes belonging to at least one of above mentioned groups. Nevertheless, every study programme had to belong to operation-economic study programmes group at least. Another criterion is a choice of such study programmes of which syllabi and all the necessary information (content, course range, etc.) are published on the website of the particular universities. The last criterion is availability of all the necessary information in a world language, or in a language which can be translated and the translation can be understood. When applying the last criterion, we believe that it is important to absolutely understand the content of the syllabi in order to carry out the analysis.

To carry out the comparative analysis while applying the above mentioned criteria, we chose study programmes focused on transport economics and operation which are offered at University of Leeds (UK), Newcastle University (UK), Katholieke Universiteit Leuven (BE), RWTH Aachen (DE), Delft University of Technology (NL), Breda University of Applied Sciences (NL), University of Zagreb (HR), Technical University of Denmark (DK), and University of Žilina (SK).

The study programmes that have been selected for the comparative analysis in this article are Transport Economics MSc (University of Leeds), Railway Operations, Management and Policy MSc (University of Leeds), Transport Planning and Engineering MSc (Newcastle University), Master of Science in Engineering: Logistics and Traffic (KU Leuven), Mobility and Transport/Transport Engineering and Mobility (M.Sc.), specialization: Transportation Logistics (RWTH Aachen), Railway System Engineer (RWTH Aachen), Policy: Infrastructure, Planning and Environment (TU Delft), Design: Transport Systems & Networks (TU Delft), Operations: Traffic, Technology & Control (TU Delft), Engineering: Transport, Logistics & Supply Chains (TU Delft), Logistics Engineering (Breda University of Applied Sciences), Transport (University of Zagreb), Railway Transport (University of Zagreb), Railway Management and Engineering (Danmarks Tekniske Universitet), Railway Transport (BSc) (University of Žilina), Railway Transport (MSc) (University of Žilina), Forwarding and Logistics (BSc) (University of Žilina), and Forwarding and Logistics (MSc) (University of Žilina).

Table 1

<table>
<thead>
<tr>
<th>Study programme</th>
<th>Name of the study programme</th>
<th>Name of the institution of tertiary education providing the study programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>Transport Economics MSc</td>
<td>University of Leeds</td>
</tr>
<tr>
<td>P₂</td>
<td>Railway Operations, Management and Policy MSc</td>
<td>University of Leeds</td>
</tr>
<tr>
<td>P₃</td>
<td>Transport Planning and Engineering MSc</td>
<td>Newcastle University</td>
</tr>
<tr>
<td>P₄</td>
<td>Master of Science in Engineering: Logistics and Traffic</td>
<td>Katholieke Universiteit Leuven (KU Leuven)</td>
</tr>
<tr>
<td>P₅</td>
<td>Mobility and Transport/Transport Engineering and Mobility (M.Sc.), specialization: Transportation Logistics</td>
<td>Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)</td>
</tr>
<tr>
<td>P₆</td>
<td>Railway System Engineer (RSE)</td>
<td>Rheinisch-Westfälische Technische Hochschule Aachen (RWTH Aachen)</td>
</tr>
<tr>
<td>P₇</td>
<td>Policy: Infrastructure, Planning and Environment</td>
<td>Technische Universiteit Delft (TU Delft)</td>
</tr>
<tr>
<td>P₈</td>
<td>Design: Transport Systems &amp; Networks</td>
<td>Technische Universiteit Delft (TU Delft)</td>
</tr>
<tr>
<td>P₉</td>
<td>Operations: Traffic, Technology &amp; Control</td>
<td>Technische Universiteit Delft (TU Delft)</td>
</tr>
<tr>
<td>P₁₀</td>
<td>Engineering: Transport, Logistics &amp; Supply Chains</td>
<td>Technische Universiteit Delft (TU Delft)</td>
</tr>
<tr>
<td>P₁₁</td>
<td>Logistics Engineering</td>
<td>Breda University of Applied Sciences</td>
</tr>
<tr>
<td>P₁₂</td>
<td>Transport</td>
<td>University of Zagreb</td>
</tr>
<tr>
<td>P₁₃</td>
<td>Railway Transport</td>
<td>University of Zagreb</td>
</tr>
<tr>
<td>P₁₄</td>
<td>Railway Management and Engineering</td>
<td>Danmarks Tekniske Universitet (DTU)</td>
</tr>
<tr>
<td>P₁₅</td>
<td>Railway Transport (BSc)</td>
<td>University of Žilina</td>
</tr>
<tr>
<td>P₁₆</td>
<td>Railway Transport (MSc)</td>
<td>University of Žilina</td>
</tr>
<tr>
<td>P₁₇</td>
<td>Forwarding and Logistics (BSc)</td>
<td>University of Žilina</td>
</tr>
<tr>
<td>P₁₈</td>
<td>Forwarding and Logistics (MSc)</td>
<td>University of Žilina</td>
</tr>
</tbody>
</table>

Source: authors
A comparative analysis is a research method based on the mutual comparison of selected characteristics of several investigated elements. In the case of this article, the selected characteristics for comparative analysis are the structure and the content of the individual study programmes in the field of transport economics and operation.

In order to provide a clear structure and systematic approach to a comparative analysis of the structure and content of study programmes in the field of transport economics and operation, the individual study programmes are labelled and identified by a letter and a lower index in such a way that only their abbreviated labels can be used during the comparative analysis. The abbreviated forms of study programmes are shown in the following Table 1.

The comparative analysis of the structure of individual study programmes is based on the basic characteristics defining the organizational structure of the study programmes in the field of transport economics and operation. The monitored characteristics within the specification of the organizational structure of the individual study programmes are the degree of study within which the study programme is provided, the language of instruction of the study programme, the basic unit of the organizational form of the academic year, the duration of the full-time study (in months), the (non) existing option of external (part-time) study, the duration of the external (part-time) study (in months), the annual tuition fee for EU/EEA students at full-time study and the annual tuition for non-EU/EEA students at full-time study. The selected characteristics are compared in the following Table 2.

Table 2 depicts that 14 out of 18 described study programmes in the field of transport economics and operation are provided in the bachelor degree studies. Despite the fact that our choice of the study programmes is influenced by certain subjective criteria, their selection follows the general trend in terms of the organizational structure of study programmes in the field of transport economics and operation. The fact that most of the study programmes in the field of transport are provided only in the master’s degree is caused by the interdisciplinary character of transport in the countries of Western Europe – the transport studies are mainly linked to engineering, construction and science bachelor study programmes which usually include a study block dedicated to subjects oriented on the transport. However, in the countries of Central, South-Eastern and Eastern Europe, there are still several study programmes in the field of transport economics and operation which are provided in the bachelor degree studies.

Focusing on the division of the academic year into smaller organizational units, in 16 out of 18 study fields dominates the division of the academic year into semesters, i.e. divison into 2 main study blocks – these are divided either into autumn and spring, or winter and summer semester. If the academic year is divided into 3 basic parts, then these parts are considered to be trimesters.

Speaking about the duration of university studies in full time form, the study programmes in the degree are mostly made as 24 months-lasting (i.e. 2 academic years). However, there are many exceptions in which tertiary education lasts

### Table 2

<table>
<thead>
<tr>
<th>Study programme</th>
<th>Degree of study</th>
<th>Language of studies</th>
<th>Basic unit of the academic year</th>
<th>Duration of the full-time study (in months)</th>
<th>The (non) existing option of external study</th>
<th>Duration of the external study (in months)</th>
<th>Annual tuition fee for EU/EEA students at full-time study</th>
<th>Annual tuition for non-EU/EEA students at full-time study</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>12</td>
<td>√</td>
<td>24/36</td>
<td>6 900 £</td>
<td>22 750 £</td>
</tr>
<tr>
<td>P2</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>12</td>
<td>√</td>
<td>24/36/36</td>
<td>9 250 £</td>
<td>9 250 £</td>
</tr>
<tr>
<td>P3</td>
<td>2</td>
<td>English</td>
<td>trimester</td>
<td>12</td>
<td>√</td>
<td>24/36/48</td>
<td>2 083 £</td>
<td>18 750 £</td>
</tr>
<tr>
<td>P4</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>922,30 €</td>
<td>6 000 €</td>
<td>0 €</td>
</tr>
<tr>
<td>P5</td>
<td>2</td>
<td>German</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
</tr>
<tr>
<td>P6</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
</tr>
<tr>
<td>P7</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>2 083 £</td>
<td>18 750 £</td>
<td>0 €</td>
</tr>
<tr>
<td>P8</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>2 083 £</td>
<td>18 750 £</td>
<td>0 €</td>
</tr>
<tr>
<td>P9</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>2 083 £</td>
<td>18 750 £</td>
<td>0 €</td>
</tr>
<tr>
<td>P10</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>2 083 £</td>
<td>18 750 £</td>
<td>0 €</td>
</tr>
<tr>
<td>P11</td>
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<td>English</td>
<td>trimester</td>
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<td>∏</td>
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<td>2 078 £</td>
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<tr>
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<td>∏</td>
<td>8 400 kn</td>
<td>8 400 kn</td>
<td>0 €</td>
</tr>
<tr>
<td>P13</td>
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<td>Croatian</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>24</td>
<td>8 400 kn</td>
<td>8 400 kn</td>
</tr>
<tr>
<td>P14</td>
<td>2</td>
<td>English</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
</tr>
<tr>
<td>P15</td>
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<td>Slovak</td>
<td>semester</td>
<td>36</td>
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<td>0 €</td>
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<tr>
<td>P16</td>
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<td>semester</td>
<td>24</td>
<td>∏</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
</tr>
<tr>
<td>P17</td>
<td>1</td>
<td>Slovak</td>
<td>semester</td>
<td>36</td>
<td>∏</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
</tr>
<tr>
<td>P18</td>
<td>2</td>
<td>Slovak</td>
<td>semester</td>
<td>24</td>
<td>∏</td>
<td>0 €</td>
<td>0 €</td>
<td>0 €</td>
</tr>
</tbody>
</table>

Source: [available information from the websites of the universities; processing: authors](#)
only 1 academic year - most of such universities and study programmes can be found at universities and colleges in the
United Kingdom and other Western European countries. In the bachelor's degree, four study programmes in the field of
transport economics and operation were identified - these study programmes represent the general trend in education in
the field of transport in its territorial area - the study programme Logistics Engineering provided by the University of
Applied Sciences in Breda in the Netherlands is a 4-year, vocationally oriented bachelor study program that is
characteristic for the Western European countries; while Rail Transport and Forwarding and Logistics degree courses
offered at University of Žilina and study programme Transport provided by University of Zagreb represent the students’
thoretical teaching in the area of transport economics and operation, and at the same time, they represent the standard
length of bachelor's degree education in Central, Southeast and Eastern Europe. For the countries of Central, Southeast
and Eastern Europe, a bachelor's degree consisting of 3 academic years is characteristic.

Only four universities offer the possibility of taking part in an external (part-time) study within the identified study
programmes. External (part-time) study is available in the bachelor study programmes Transport (University of Zagreb)
and Rail Transport (University of Žilina) and in master's study programmes Transport Economics (University of Leeds),
Railway Operations, Management and Policy (University of Leeds), Transport Planning and Engineering (University of
Newcastle), Rail Transport (University of Zagreb) and Rail Transport (University of Žilina). The total length of study in
external form within University of Leeds and University of Newcastle is adaptable to the needs of students, but can last
from 36 to 48 months. University of Zagreb and University of Žilina have the length of external study fixed.

Paying attention to tuition fees, within the identified study programmes it is possible to observe that tuition fees are
paid by students mainly at universities and colleges within the area of Western Europe. However, the exception in the
Western Europe can be considered Germany and its RWTH Aachen – for students from the EU/EEA and also for students
coming from outside the EU, a free tuition fee is guaranteed at RWTH Aachen. Another university that provides free
tuition fees for all students is University of Žilina. Free tuition fees, but only for students from EU/EEA countries, are
also guaranteed for students at Danish Technical University. Of all the characterized and analysed study programmes, the
highest annual tuition fee (£ 22,750) is paid by students at the University of Leeds.

The comparative analysis of the content of individual study programmes is based on the characteristics defining
the content of the individual study programmes in the field of transport economics and operation. The monitored
characteristics within the content of individual study programmes are the types, respectively the focus of compulsory and
optional subjects or modules - according to the type of study field or program taught within individual study programs.

The following tables show the proportions of compulsory and optional modules (subjects) within the individual
study programmes, as well as the proportions of the different types of subject in thematic subject groups.

Table 3

<table>
<thead>
<tr>
<th>Study programme</th>
<th>The percentage share of compulsory modules/subjects (%)</th>
<th>The percentage share of optional modules/subjects (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁</td>
<td>57</td>
<td>43</td>
</tr>
<tr>
<td>P₂</td>
<td>54</td>
<td>46</td>
</tr>
<tr>
<td>P₃</td>
<td>100</td>
<td>0</td>
</tr>
<tr>
<td>P₄</td>
<td>29</td>
<td>71</td>
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<tr>
<td>P₅</td>
<td>14</td>
<td>86</td>
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<td>P₆</td>
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<td>73</td>
</tr>
<tr>
<td>P₇</td>
<td>21</td>
<td>79</td>
</tr>
<tr>
<td>P₈</td>
<td>19</td>
<td>81</td>
</tr>
<tr>
<td>P₉</td>
<td>19</td>
<td>81</td>
</tr>
<tr>
<td>P₁₀</td>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>P₁₁</td>
<td>61</td>
<td>39</td>
</tr>
<tr>
<td>P₁₂</td>
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<td>58</td>
</tr>
<tr>
<td>P₁₃</td>
<td>26</td>
<td>74</td>
</tr>
<tr>
<td>P₁₄</td>
<td>69</td>
<td>31</td>
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<tr>
<td>P₁₅</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>P₁₆</td>
<td>64</td>
<td>36</td>
</tr>
<tr>
<td>P₁₇</td>
<td>69</td>
<td>31</td>
</tr>
</tbody>
</table>

Source: available information from the websites of the universities; processing: authors

According to the information from Table 3 from the point of view of percentage of all taught subjects and thus
also in terms of the number of elective subjects within all taught subjects, the study programme Mobility and
Transport/Transport Engineering and Mobility (M.Sc.), specialization: Transportation Logistics (RWTH Aachen) is
considered the most customizable field of study. Its content is up to 86% made up of optional subjects.

Other study programmes which have 79 – 81% of the offered subjects optional are study programmes provided by
the Transport, Infrastructure and Logistics department at TU Delft. These are the programmes named Policy: Infrastructure, Planning and Environment; Design: Transport Systems & Networks; Operations: Traffic, Technology & Control; and Engineering: Transport, Logistics & Supply Chains.

Conversely, the least customizable study programmes, i.e. the study programmes in which compulsory subjects are most involved are study programmes Transport Planning and Engineering MSc (University of Newcastle) and the professionally oriented bachelor study programme Logistics Engineering provided by University of Applied Sciences in Breda. The proportion of compulsory subjects in the total content of the two study programmes mentioned is 90 – 100%.

Based on the division of subjects into individual thematic subgroups, it is possible to determine, by means of a summary of compulsory and optional subjects, which subjects are involved in what proportion of the overall content of the characterized study programmes in the field of transport economics and operation. The percentage of individual thematic subgroups of subjects in the total number of subjects taught within the study programmes is shown in the following Table 4:

<table>
<thead>
<tr>
<th>Study programme</th>
<th>Transport subjects (%)</th>
<th>Economic subjects (%)</th>
<th>Technical and general professional subjects (%)</th>
<th>General subjects (%)</th>
<th>Practice/Training (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>29</td>
<td>50</td>
<td>14</td>
<td>7</td>
<td>0</td>
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<tr>
<td>P2</td>
<td>39</td>
<td>38</td>
<td>15</td>
<td>8</td>
<td>0</td>
</tr>
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<td>69</td>
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<td>48</td>
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<td>13</td>
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<td>P5</td>
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<td>3</td>
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<td>P6</td>
<td>34</td>
<td>5</td>
<td>44</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>P7</td>
<td>36</td>
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<td>35</td>
<td>1</td>
<td>4</td>
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<tr>
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<td>1</td>
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<td>34</td>
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<td>4</td>
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<td>24</td>
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</tr>
<tr>
<td>P12</td>
<td>30</td>
<td>4</td>
<td>18</td>
<td>48</td>
<td>0</td>
</tr>
<tr>
<td>P13</td>
<td>69</td>
<td>12</td>
<td>15</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>P14</td>
<td>22</td>
<td>48</td>
<td>26</td>
<td>4</td>
<td>0</td>
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<td>P15</td>
<td>19</td>
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<tr>
<td>P17</td>
<td>21</td>
<td>17</td>
<td>9</td>
<td>47</td>
<td>6</td>
</tr>
<tr>
<td>P18</td>
<td>28</td>
<td>9</td>
<td>22</td>
<td>41</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: available information from the websites of the universities; processing: authors

In terms of the proportion of transport subjects (69%) in relation to the total content of the subjects of the given study programme, the leading study programmes are Transport Planning and Engineering MSc (University of Newcastle) and Railway Transport (University of Zagreb).

Conversely, the smallest share is made up of transport subjects within the bachelor study programmes Railway Transport (19%) and Forwarding and Logistics (21%) at University of Žilina.

From the point of view of the share of economic subjects in the total content of the study programme, the leading study programmes Transport Economics MSc (University of Leeds) with 50% of economic subjects and the study programme Railway Management and Engineering (Denmark Technical University) with 48% of economic subjects.

On the contrary, the smallest share is made up of economic subjects in the bachelor study programme Programme Transport (4%) at University of Zagreb and in the master study programme Railway System Engineer (5%) at RWTH Aachen.

3. Conclusions

The aim of the article was to characterize technical universities and institutions of tertiary education which offer study programmes in the field of transport economics and operation as well as to characterize chosen study programmes. In addition, we carried out comparative analysis of these programmes focused on their structure and content.

In order to write the article, we conducted a research amongst 910 European universities and institutions of tertiary education from which 319 institutions can be identified as technical universities offering any study programme related to any area of transport education – either in a form of directly related study programmes or study programmes which consist of special courses or of a set of courses related to the field. When it comes to transport field, we detected 400 study fields and programmes that included 170 study fields focused on transport economics and operation. In order to carry out comparative analysis, we chose 18 study programmes focused on railway transport, general transport or general transport
To conclude, not only should we sum up the results, but also we should raise awareness when it comes to training and educating future specialists in the field of transport who later would be able to face new challenges. In addition, the mobility of academic personnel and flexibility of study programmes in the field of transport economics and operation and their content should be taken into consideration as well.

References

1. Study materials and official websites of the universities: University of Leeds, Newcastle University, Katholieke Universiteit Leuven, Rheinisch-Westfälische Technische Hochschule Aachen, Technische Universiteit Delft, Breda University of Applied Sciences, University of Zagreb, Danmarks Tekniske Universitet and University of Žilina


Replacement of Public Passenger Transport from Cities: Fastening or Worsening of Accessibility

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Abstract

Rerouting of transit public transport lines to city bypasses or highways can make public transport faster as well as it can reduce public transport supply in bypassed cities. A part of transport services will not go to city centre more. It is an important issue of transport technology. The criterion which is commonly applied in the field of transport science is to reduce the sum of travel times of all passengers. It can cause an extension of travel time of passengers from or to less populated cities with an effort to make journey faster for transiting passengers (majority of passengers). This is a reason for this rerouting of lines. Individual aspects of this issue are solved in the paper. Possibility to replace one subsystem with a different subsystem of transport (of lower or higher category) – especially with urban public transport – is discussed as compensative measure. The research is based on a set of practical cases and on the methods designed for transport modelling.

KEY WORDS: bypass, public transport, detour, passengers, travel time accessibility

1. Introduction

The article is focused on possibilities and effects of public transport diversion to city bypasses. Several effects can be found in this consideration. There are two important effects assessed in the article. Does replacement of public transport services from cities cause fastening of transport or worsening of accessibility? This is the basic question for authors’ research in the article. There can be found examples of public transport lines operated in city bypasses as well as examples of lines detoured through city centres. The aim of the article is to find and describe the impacts of different ways of operation of public transport lines. Diversely situations will compared by support of modelling and mathematical methods.

This article takes a part of research for dissertation thesis, which is actually in process. The set of factors described in the article may not be final, but it may be extended in dissertation thesis. In spite of all attempts to maximize objectivity by the consideration of all factors and conditions, it must be stated that in some cases may be quite opposite effects (e.g. small municipality is able to negotiate a full range of long-distance public transport).

2. Literature Review

This chapter provides an overview about some of published methods and approaches. It is necessary to write that authors’ research topic has some specific aspects and published articles are concerned on bypassing in general point of view. Model for the analysis of traffic networks is provided by [1]. There is presented a domain level of optimal control for traffic networks applying Lyapunov function, and applying two level domain control on a realized network model of city Győr (Hungary). This model defines a unique structure of network elements and can be described map-graph independent by a special hyper matrix structure. Its main strength is the computing rapidity. The model can help by identification, where it will be effective to realize possible measures.

The paper [2] presents a simplified model of traffic assignment to the planned bypass road. The purpose of such model is to provide to the planners a tool for simple, fast and inexpensive way to estimate the expected traffic volume on the planned bypass road by using data that can be obtained relatively quickly. Inputs of the model of traffic assignment are annual average daily traffic on the planned bypass and on the existing routes. Feasibility traffic studies of eight cities in Bosnia and Herzegovina were utilized as source of data.

In the paper [3] is researched that planning of new high-capacity roads in small cities, whether they are collective-distributor routes or single variants, requires an effective traffic model which is able to provide insight into the mobility of the current city and simulate the future behaviour with the commissioning of the new route. Designing an adequate traffic model provides information about the behaviour of different potential alternatives in the construction of a new high-capacity route, and, in this way, facilitates selecting the one which captures more traffic and produces bigger savings in travel times, meaning the highest socioeconomic feasibility.

According to [4] there are 4 basic types of passengers flows in the city areas:
- passengers passing the city;
- passengers originating in the city and going to outlying areas (out of the city);
- passengers coming from outlying areas with destination in the city;
passengers moving within the city area only.

Understanding and modelling of decision-making process by passengers is crucial for this research topic as well. The paper [5] is focused on demand after transport and on passengers’ decision. Supplied transport network must fulfill the preconditions for successful operation.

Methodology for assessment of time schedule in network point of view is presented in the paper [6]. Application of the method for Slovak railway network is presented as well. Crucial fact for authors’ research is that accessibility and frequency of transport are crucial features for the passengers.

3. Structure of Passengers Flows within the City Area

Division of passengers’ transit flows can be modified in the frame of discussion to this:

- transit in the main direction,
- transit between the main direction and other directions,
- transit in other directions.

This structure of passengers’ traffic flows can be the base for decision of diverting of public transport lines from cities and for evaluation of effectiveness of this option in general point of view. This analysis consisted of main positive and negative impacts in each type of passengers’ transit flows is presented by following Table 1.

| Table 1 Analysis of positive and negative impacts of passengers’ transit flows |
|---------------------------------|------------------------------------------------------------------|
| **Transit in the main direction** | + bypass is usually built in this direction \ + the most of passengers flows could use diverted route (fastening of accessibility for transit passengers) | - limited offer of transport services when this transit is dominant (worsening of accessibility for potential passengers travelling from/to or changing in bypassed cities) |
| **Transit between the main direction and other direction** | + possibility to attract new (local) passengers \ + arise public transport services to new city parts (in the case of “new” approach to bypass) | - bypass could do diverting of public transport from the city centre (time and distance point of view) \ - passengers must use another transport services (usually with longer travel time) |
| **Transit in other directions and journeys within the city** | + possibility to attract new (local) passengers \ + bypass cannot be used in most cases (fastening of accessibility for local passengers) | - less operating transport services in the main direction (in the case of using bypass) \ - unsuitable to regular travel (limited offer of transport services) |
| **Journeys with origin or destination in the city, but going out or coming from out** | + primary using of the city mass transport \ + low demands on higher transport modes (fastening of accessibility for transit passengers) | - necessary to change to other transport services \ - using of frequented roads in the city (in the case of impossibility to use services in the main direction) |

Source: authors

The result is that using of the bypass is attractive for passengers traveling in the main transit direction. On the other hand, this solution causes worsening of accessibility for local passengers in some situations. Other transit journeys can be more attractive for local citizens because rerouting public transport lines through the city is demanded by these passengers’ flows. This can be a problem for transit passengers in main direction, using of city roads may cause worsening of accessibility for this passengers due to make travel time longer.

4. Possible Factors in the Field of Public Transport

According to authors’ research there are several factors affecting operation of public transport lines. First group contains possible factors related to transport demand:

- numbers of passengers travelling to/from the city;
- destination target of passengers is in one/multiple place;
- numbers of passengers transiting (continuing by the same bus);
- numbers of passengers interchanging to other public transport services in the city;
- time loss related to access of bus terminal in the city → possible to be modelled by using of system equilibrium (min. of average travel time).

Second group is composed by other effects:

- priority of line or of served relation (e.g. to connect important cities with no effort to serve bypassed ones);
5. Possibilities of Diverting of Public Transport from City Centres

There are several options for diverting public transport from cities depending on the mode of transport. The following is an overview of these options.

**Long-distance bus transport**

This transport mode is quite often diverted to city bypass. This option is the best for transiting passengers, but several questions are still opened:

- Which cities are not to be served by this transport mode?
- Is it suitable to detour the line to the city from bypass?
- Do diverting of lines signify reduce of count of transport connections (services) or replacement by new connections?

**Railway transport**

There is applied a different approach in the case of railway transport. Technology conditions can be quite different in railway transport due to dependence on infrastructure (details can be found e.g. in [7]). The result is that the issue of bypassing can be modified and divided into two parts:

- design of ‘express’ lines using current infrastructure, but passing in the city (with no stop);
- construction of a new infrastructure (e.g. construction of high speed lines).

The first case can be closer to the case mentioned situation in road transport. It is a local measure saving the time for transiting passengers.

The second case is related to construction of new lines in locations where adequate demand on transport is ensured. These new lines are bypassing some cities which are served by existing railway system. The difference is that these new lines are designed as infrastructure connecting different places as a whole, not as bypasses of individual cities. Some questions are open:

- Will be kept current number of trains (services) to remain on existing railway lines (infrastructure)?
- How will be interconnect bypassed cities with new railway lines?

**Urban public transport**

This transport mode operates mostly in the city area. Building of new connections is divided to two possibilities. First option is similar to railway transport and means design of new (or modified) lines to newly served city parts. Second possibility is replacing lower category of transport system (e.g. buses/trams) with higher category of transport system (e.g. trams/subway). Bypassed area is usually a part of city in this case. These questions are arisen in the case of urban public transport:

- Can be replaced or supplemented also higher category transport system by lower category transport system?
- Does lower category transport system remain in operation after its replacement by higher category transport system?

Third issue occurs in the frame of this research. Is it possible to apply lower category transport system for connection of bypassed city with fastened long-distance transport system. In practice, if it is possible to locate a stop of long distance transport system on the road bypass and connect it with the city by urban public transport. Similar situation can be in the case of high speed railway lines where the stations (with exception of main hubs) can be located on the backbone infrastructure of line bypassing the city.

**Suburban transport**

These lines cannot be replaced by other transport modes (in the point of view of city bypassing), but it is possible to short them to the border of city and to use urban public transport for transport inside the city. Some questions are also open in this transport mode:

- Does shortening of these lines cause fastening or worsening of accessibility for passengers?
- Is it possible to implement tangential transport lines in the suburban area?

The key for decision of these questions is based on quality, structure and punctuality of urban public transport system. For example, terminating of these lines in suburban areas is advantageous solution for the city of Prague (capital of the Czech Republic). Subway or railway can provide faster connection to the city centre than using of possibly direct suburban bus line passing number of city streets. On the other hand, some operational problems of trams (impossibility to bypass possible place of traffic accident) were mentioned as argument for termination of bus suburban lines in the city centre of Ostrava (ca. 320,000 inhabitants).
6. Practical Examples of Transport Operating in Selected Cities

Several cities have been selected as examples covering as many options as are possible. Different operational situation is in any selected city, but conditions may be similar. This chapter contains practical examples of possibilities of line routing in some of Czech and Slovak cities.

**Long-distance bus transport**

In general, servicing of cities by long-distance bus transport is depended on demand, possibilities of substitution public transport (train, regional bus transport) and ability to negotiate. Significant factor is also quality of road network, because there can be a difference between bypassed and non-bypassed cities. This factor is connected with roads category, primarily with highway or first category roads. Detour from highways is usually longer than from bypasses located on first category roads, because highways are built farther from cities. Summary of city examples is in Table 2.

<table>
<thead>
<tr>
<th>City</th>
<th>Population</th>
<th>Substitution public transport</th>
<th>Number of connections</th>
<th>Connections using bypass</th>
<th>Connections passing city</th>
<th>Time difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olomouc (CZ)</td>
<td>100,523</td>
<td>Regional bus, railway</td>
<td>20</td>
<td>2</td>
<td>18</td>
<td>11 min</td>
</tr>
<tr>
<td>Nitra (SK)</td>
<td>76,655</td>
<td>Partly regional bus</td>
<td>46</td>
<td>–</td>
<td>46</td>
<td>14 min</td>
</tr>
<tr>
<td>Poprad (SK)</td>
<td>51,304</td>
<td>Regional bus and railway</td>
<td>8</td>
<td>–</td>
<td>8</td>
<td>12 min</td>
</tr>
<tr>
<td>Trenčín (SK)</td>
<td>55,333</td>
<td>Railway</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>16 min</td>
</tr>
<tr>
<td>Jihlava (CZ)</td>
<td>50,845</td>
<td>Partly regional bus and railway</td>
<td>66</td>
<td>56</td>
<td>10</td>
<td>20 min</td>
</tr>
<tr>
<td>Martin/Vrútky (SK)</td>
<td>62,380</td>
<td>Partly railway</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>12 min</td>
</tr>
<tr>
<td>Levoča/Spišská Nová Ves (SK)</td>
<td>51,951</td>
<td>Partly regional bus and railway</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>24 min</td>
</tr>
<tr>
<td>Vyškov (CZ)</td>
<td>20,883</td>
<td>Regional bus, railway</td>
<td>22</td>
<td>4</td>
<td>18</td>
<td>9 min</td>
</tr>
<tr>
<td>Beroun (CZ)</td>
<td>19,510</td>
<td>Regional bus, partly railway</td>
<td>40</td>
<td>40</td>
<td>–</td>
<td>11 min</td>
</tr>
<tr>
<td>Jičín (CZ)</td>
<td>16,577</td>
<td>Regional bus, partly railway</td>
<td>48</td>
<td>–</td>
<td>48</td>
<td>7 min</td>
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<td>–</td>
<td>14</td>
<td>12 min</td>
</tr>
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<td>5 min</td>
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</table>

Source: authors on the base of [8, 9]

This article is focused on medium-sized cities (in context of central Europe). For application and appraisal of the factors is necessary to divide cities into two categories. Cities are divided from the point of view of regional importance. The first category is composed of cities with transregional significance. These cities generate much origin (availability) and destination (attractiveness) routes as well as many routes have transit character. These cities have built bypass, but absolute majority of long-distance bus connections pass these cities and serve them.

Second category includes cities with regional or municipal importance. These cities are mostly attractive for citizens from nearby and satellite city areas. Some of these cities have built bypass but some have not. Cities without bypass are mostly served by long-distance bus transport. Second category bypassed cities are served in dependence on specific case. Detailed aspects of lines operating and practical examples are stated in following text.

Absolutely clear situation arise in the examples of cities Olomouc and Nitra. These cities have built highway bypass but still are served by long-distance buses. In case of Olomouc are compared lines in direction Brno – Ostrava, in case of Nitra are focused on lines in direction Bratislava – Banská Bystrica. Difference between these cities is in accessibility of substitution public transport. Olomouc has quality connection to railway transport also in direction to Brno and Ostrava but direct trains in relation Brno – Ostrava are operated outside this city, buses are not. Nitra does not have quality railway transport with Bratislava and Banská Bystrica, into whose is access only with several changes.
and long travel time. In relation Bratislava – Banská Bystrica is also operated direct trains but them serve other places and have longer travel time than direct buses. City of Poprad has lower regional importance than Olomouc or Nitra, but situation in this city is similar to Olomouc, but in this case is the focus on direction Košice – Bratislava/Prague.

Next examples are cities of Trenčín and Jihlava. These cities are resembled in regional point of view and they have similar population. Both cities have built highway bypass but difference is in connection to public transport in focused direction, which is Brno – Prague in case of Jihlava and Bratislava – Žilina in case of Trenčín. Jihlava does not have quality train connection with Prague, better situation is in connection with Brno. Buses connecting Brno and Prague are operated directly, only minimum of them serve the city. Time delay caused by detour to the city is approximately 20 min, which is relative enough (travel time between Praha and Brno is usually between 2.5 and 3 hours). In the case of Trenčín there is different situation due to accessibility of substitution railway transport in focused direction between Bratislava and Žilina. It is probable that higher number of bus connections would use bypass without detour to the city. In cities Martin/Vrútky and Levoča/Spišská Nová Ves happens similar situation. Focused direction is the same in this case like in Poprad, it means relation Košice – Bratislava/Prague, highway bypass is at disposal.

Next cities in the Table 2 show differences between cities bypassed by highway and road. City of Beroun has in direction Prague – Plzeň – Germany bypass alike as city of Vyškov in direction Brno – Zlín. Detour of buses in these cities is almost the same in both situations in spite of short detour time loss. On the other hand situation in bypassed cities by road is different from previous examples. In direction Prague – Jičín – Vrchlabí/Trutnov are served cities of Poděbrady and Jičín in all cases, what is interesting, because time saved by using bypass is similar like in case of Beroun and Vyškov. There are more examples located on the end of the Table 2. These cases are suchlike previews examples. More interesting are two nearby cities in Czechia (Mirotice and Čimelice). City of Mirotice has bypass and many long-distance bus services (36 from 38 between) are diverted outside the city. By contrast smaller city of Čimelice does not have bypass and it is served by all long-distance buses. This suggests that the bus service of the city is dependent on more factors, not only on regional impact and bypass.

The question of substitution of long-distance public bus transport

There can be found different forms, how possibly missing long-distance bus transport can be replaced:
- interconnection of a stop located on bypassing road with city centre by urban public transport (or suburban bus line with similar function), in the case of small distance walk connection can be considered as well;
- existence of parallel bus line(s) in the same direction as long-distance line allowing travelling in both (all) directions with longer travel times, but with more stops (it can be advantage for covering of local transport relations as well);
- connection of bypassed city with the system of higher category by line terminated at some of other hubs;
- connection with the main destination by local suburban line(s) not ‘copying’ whole the replaced long-distance bus line in both directions.

Summary of long-distance public transport

There can be different operational situation in each city as it can be seen from the Tab. 2, but following aspects can be generalized:
- Time savings reach for transiting passengers by using of a bypass can be relative serious, minimal recorded value is 5 min (Čimelice), maximal is 24 min (Levoča/Spišská Nová Ves). Issue can be more important if more cities will be served by the line.
- Dependence of the value of savings on city population is not strict. It can be said that it is less than 15 min for the cities with less than 30,000 inhabitants (see Fig. 1). On the other hand, the situation for cities with the population of 40,000 – 60,000 inhabitants reflects the location of bus station in the city more than population.
- Important fact is that the ratio of services coming to the city is not strictly depended on the city population. There are cities will full extent of long-distance bus transport with relative small value of population (<30,000 inhabitants), but also the cities of Jihlava (50,845 inhabitants) and Martin (62,380) are served only by 15% and 33% of services respectively. It means that the situation is depended also on character on passing buses.

![Fig. 1 Comparison of situation in selected cities based on city population](image)
Recommendation in case of long-distance public transport

Situation can be quite different in each individual situation as follows from chapters mentioned above. This can be crucial for mathematical modelling of this situation. It cannot be presupposed that one universal approach valid for all the cases can be found. Application of compromise criterion can be inadequate in some situations in spite of the fact that it can be determined as compromise.

Railway transport

There is different approach than in long-distance bus transport. In Czechia conditions are realized two ways in speeding up trains. First possibility is passing cities with no stop but this option brings limited time saving between metropolitan cities. The city of Benešov is an example for this situation. Trains of express line Prague – České Budějovice are passing without stop and long-distance transport for this city is ensured by lower category of fast trains only.

Second way is building of new railway lines, what will be a great issue in future years. Up to present there are made several studies in whose building of new high-speed lines in Czechia is solved. For example there are high speed lines between Prague and Dresden or between Brno/Bratislava/Vienna. These new lines are usually designed outside the cities and servicing cities by high-speed trains will be limited.

On the other hand new railway lines can clear conventional lines from express trains, what is benefit for suburban and regional railway transport. Rerouting of high category trains to new high-speed lines will improve accessibility between metropolitan cities as well as accessibility in suburban areas due to saved capacity of suburban railways allowing shorter interval between connections. Good example for this solution is railway Westbahn in Austria, which is built between Vienna and Salzburg. This railway line represents good solution of division of railway lines for suburban and long-distance railway transport.

Urban public transport

Substitution of public transport subsystems by other subsystems is researched in this case. In building of new public transport lines is similar approach like in railway transport. In general there are building new lines in places where is adequate demand for passengers transport. In Czech conditions there are two different examples in city of Prague. The first occurred in 70’s years, when tram line between Pražského povstání and Pankrác was cancelled and replaced by new subway line C. Subsystem of lower category (trams) was replaced by higher category subsystem (subway). Another situation occurred after extension of subway line A (2015) from station of Dejvická to station of Nemocnice Motol. Parallel tram line is remaining in operation.

Other cities in Czechia do not have subway but also in these cities has been arisen to replacement of transport subsystems. In most cases came to replace trolleybuses by trams, which have bigger capacity and could be built independent of road network. For example in Plzen is three tram lines in 4 min interval, which make backbone of public transport in this city.

Interesting situation with tram (and tramtrain) lines is gradually arising in Paris, specifically in region Ile de France. There are lines which can be very similar to public transport lines because they ensure transport in fixed area. In fact, they are lines T1–T10, which have arisen in last 20 years. These lines serve only suburban places (no city centre), but replace buses and attach some city parts with subway system. Additional information about these lines are available in [10].

Suburban transport

In general, bypasses do not have significant impact to suburban bus lines operation. But there are some situations when is possible to introduce transit bus lines which would use bypass. The other way is shortening bus lines to city border or to create tangential lines while passengers are using urban public transport to traveling between city centre and city border (suburban transport lines). This can be simulated like line journey leading via bypass because bus stop in city border is similar to stop in city bypass.

Star-shaped lines can be used for this case. Definition of these lines is that a set of lines (routes) is interconnected in one point. This point might be in city centre but in mentioned case that can be in bus terminal located in city center. In progressive thinking this meeting-point will be located in public transport terminal near high-speed railway line and city border which represents interconnection between all important transport subsystems. Practical examples of this solution are not applied in current Czech conditions, but planned construction of new high-speed lines gives conditions to apply that in future.

7. Mathematical Model in Field of Public Transport

Simple mathematical model has been developed for assessment of situation of long-distance lines in bypassed cities. The model is also based on principle of system equilibrium, but the function is a little bit modified. There are modelled basic transport relations in the model only, but with an effort to incorporate most of typical situations. On the other hand, this simplification can allow serious decrease of computing demands.

The model is compiled with two basic variants of routing of long-distance lines. City bypass is used in the first variant, route passing city centre or central business district is used in the second variant.

Transport network connects five places where to start or finish the trip – 2 final stops of long-distance bus line, stop located on the city bypass, one stop for the city centre and one for suburban area of city. There is necessary to travel by long-distance line to one final stop. Second final stop of long-distance line is connected with the city centre by parallel
regional bus line able to be used as an alternative connection. Suburban area, city centre and stop at city bypass (and surrounding areas) are interconnected by line of urban public transport.

Changeable inputs are: travel times on individual network segments and interchange and dwell times at all the stops (Fig. 2). Minimal travel times needed for transport between each pair of stops are calculated by Floyd algorithm. Systematic evaluation of accessibility is provided by the model. Attractiveness of public transport can be assessed for all these relations individually.

Both variants of routing of long-distance bus line (using city bypass and detoured route passing city centre) can be simply compared by the model. This comparison is based on searching for route with minimal travel times. The model is implemented in Microsoft Excel application by using of macros programmed in the Visual Basic for Applications. Extended and more important aim of the model is determination of ideal operating features of urban public transport lines within the system using a stop of long-distance line located at the city bypass. This assessment can be made in the point of view of passengers travelling from/to the city centre or in the point of view of all passengers. The accuracy of solution (if or how travel times can be extended) can be selected. Assessment is provided by an exhaustive-search algorithm stepwise changing values of travel times on urban, suburban and regional lines as well as changing interchange times. Ratio of input values can be modified for possibility to reduce computing demands by omitting of unrealistic variants or for possibility to examine some specific variants (e.g. to use longer travel times than now).

Assessed ideal features of urban public transport can be compared with current situation in practice and this can be used for decision about route of long-distance line as well as a guideline for possible improvement of urban public transport with an effort to compensate possible discomfort caused by bypassing. Design of model in more complex way is also possible in the case of need.

Fig. 2 Demonstration of the created mathematic model – the case of Jihlava

8. Illustrative Case Studies

The model was applied within two illustrative case studies prepared for this paper. The first is focused on the city of Jihlava and on issue of design of a new railway station located on the high-speed line (in fact bypassing the city along the highway D1). The Fig. 2 represents screen shot of a part of model with inserted values for this case. Planned high-speed line is expressed by red and marked as long-distance line. Detoured lines south and north model possible branching of high speed trains to conventional infrastructure for serving the station in the city.

It can be seen that travel time from Prague to Brno (by using of these study values) can be 80 min in the case of using of bypassing route. Possible detouring to the railway station in the city centre represents time loss of 13 min for these passengers travelling in main direction from Prague to Brno. Detoured line can be advantageous for passengers from/to Jihlava and also to all localities connected to the city (represented by ‘SUB’ stop). Bypassing can cause time loss of 4 min for the passengers travelling from/to Prague. Travel time on the line UPT connecting new and state-of-art railway station should be shorten from 7 to 3 min for fully compensation. It is unrealistic due to passed distance.

Model shows that modified solution can be: shortening of interchange time from trunk high-speed line to municipal’ UPT line about 2 minutes (from 5 to 3 min), e.g. by allocation of both trains to the same platform shortening of travel time at UPT line about 1 min and extension of this UPT line to suburban areas in a direct way (shortening of interchange time in the city centre about 1 min). This can cause that the time loss of passengers travelling to Jihlava can be reduced by 3 min to 1 minute in total. Passengers travelling to suburban areas will not have any time loss by this solution.
Model was applied also on the field of bus transport for the case of Mladá Boleslav (important city in the Central Bohemian Region bypassed by the highway D10). Interpretation of results is similar, but the time loss for passengers from/to the city is more serious (8 min) due to the fact the bus urban public transport line with longer travel time is applied. May be, time values in future practice can be changed, because more specific projects for high speed railway lines can bring some modifications, but the way, how the model can be applied is illustrated.

9. Following Research – Discussion

In frame of discussion about railway transport is necessary to write that high-speed lines in Czechia are designed currently in study level of design. Developed mathematic model provides an option to decide interconnection of future high-speed lines with city centres and with other subsystems of public passenger transport.

Several examples exist on conventional railway lines. Historical process of building of conventional railway lines shows, that in the past were main focus put on the connection of the city to the railway network, shortening of travel times were accented minimally. This situation often caused high distance between railway stations (stops) and city centres and followed-up migration of housing development near railway. It would be good to learn from these situations for future research in field of high-speed lines. Focus must be put also on ensuring of quality of transport services. This can prepare followed-up migration of housing development near railway. It would be good to learn from these situations for future planning process in the Czech Republic now. Idea-design of mathematical model for complex assessment of interconnection of cities with bypassing urban public transport lines is presented as well as first case studies applying this model. The illustrative case study for the city of Jihava is opening the question how can be similar cities connected to high speed railway network.

Acknowledgement

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Exhaust Emission Measurement Methodology from a Motor Coach in Real Operating Conditions

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Abstract

The article presents the specifics of exhaust emission measurement methods in real operating conditions for a passenger rail vehicle. The selected modern motor coach was equipped with PEMS type device designed for measuring exhaust emissions from vehicles in motion. Tests were carried out on a specialized test track designed for testing rail vehicles operability, reliability and safety. Due to lack of a legal framework defining the methods and requirements required to ensure reliability and repeatability of the obtained results the authors designed and implemented a custom set of drive cycles and specified the expected drive parameters for the tested vehicle in each test cycle. The advantages and limitations of the selected measurement method were discussed based on the experimental emission results obtained in the tests.

KEY WORDS: rail vehicles, exhaust emissions, RDE, motor coach, test methods

1. Introduction

There are numerous aspects that must be tested in modern vehicles in order to permit their sale and operation. Among those are type approval tests which focus on several aspects of the vehicles, out of which the ecological indicators have a significant impact on their environment and the whole world. Exhaust emission norms for various means of transport differ based on the vehicle type [1]. Similarly, the methods designed for each group of vehicles are specific for those types. Hence passenger cars and light commercial vehicles have their exhaust emissions measured relative to the distance covered, in terms of road emissions (g/km), while heavy-duty vehicles are tested based on their work output, in terms of specific emission (g/kWh). This variation is mostly the result of different operating characteristics of these vehicles, where using specific emission values allows comparing vehicles designed for hauling cargo with vehicles that perform stationary works, such as excavators and other non-road mobile machinery (NRMM). Introduction of real driving emissions (RDE) tests was the EU’s response to the “cycle beating” controversy, where certain manufacturers were caught introducing programming to new vehicles that allowed them to detect whether or not they were subjected to the specific conditions of exhaust emissions testing on a chassis dynamometer (WLTC tests) and specifically reduce the amount of emitted toxic compounds. A solution that did not help reduce exhaust emissions in real operation, thus contributing to the increasing problems of smog and air pollution [2]. While this issue was addressed for cars the type approval procedures for other types of vehicles were not subject to similar level of scrutiny and revision. As a result, exhaust emission tests in real operating conditions remain an optional addition for rail vehicles that, while very informative in terms of providing real emission data, does not serve any legal purpose. Thus the research conducted on a motor coach that was used as basis for this article was an innovative attempt at asserting the most proper and accurate method of exhaust emission measurement for this type of rail vehicles. This subject has been approached several times before [3] consistently revealing the discrepancies between emission results from type approval tests, typically done on water resistors, and RDE tests, but no proper method was proposed to replace the existing one.

2. RDE Testing Method for a Motor Coach

The main aspect regarding the RDE testing procedure is setting the limits for conditions for which the emission data can be considered valid. For road vehicles the test requires the drive cycle to have about a third of its total distance covered in each of the three different road conditions, urban, rural, and motorway [4]. These are characterized by different speed ranges the vehicle is to travel at, thus determining whether the test drive exhaust emission data can be used or not. The operating conditions of rail vehicles are somewhat different, but also differ more widely between rail vehicles depending on the type of work they perform. Shunting locomotives, for example, have been shown to have a completely different operating characteristics than freight locomotives [5]. This, in turn, means that testing those vehicles in the same set operating points (same engine load and same weights assigned to them) does not provide reliable emission results that could be extrapolated onto wider operation of these vehicles to estimate their total exhaust emissions. Additionally, to avoid confusion the limit values set for stationary tests were also used for RDE emission test results but with limit values given more flexibility in the form of a defined “conformity factors” [6]. In the case of rail vehicles such an adjustment would also be necessary, but there are no standardized vehicle exhaust emission tests in real operation to base them on, and all regular emission tests are performed for just the engines themselves. This, however, fails to consider the very different conditions and operating points at which these engines can be used depending on the role assigned to the vehicle in which they are mounted. Hence the specific exhaust emission values obtained in real driving conditions mimicking the
real operation of a given vehicle would be preferred. The same setup as for road vehicles in RDE tests was used, based on a PEMS device and a flowmeter (Fig. 1). This was later simplified and narrowed down to two different types of tests:
  - Exhaust emission relative to speed on a test track;
  - Exhaust emission relative to acceleration on a test track.

Both of which were performed for two different test drive parameter values in order to allow a full comparison. The remaining requirements regarding the ambient weather conditions: relative humidity, ambient temperature, can use the same value ranges as the ones listed for RDE tests of road vehicles. Such an approach was tested and tried previously by Merkisz et. al. [7] in an effort to develop an RDE testing methodology for agricultural tractors, which legally fall under the same non-road mobile machinery category as rail vehicles.

The standard testing procedure relies on the Non-road Steady Cycle (NRSC) as defined in the ISO 8178 standard. This is the steady state test that is used for testing compliance of engines at all Stage norms. For Stage IV an additional test called the Non-Road Transient Cycle (NRTC) was introduced, which is run twice, once for cold and once for hot start. Then the weighted average is taken with only 10% weight given to the cold start results (or 5% in the USA). This additional test applies to Stage IIIB/IV exhaust emission testing, and has a total duration of 1238 seconds. The ISO 8178 test cycles have weighting factors assigned to each of the 11 torque-speed settings that determine the importance of each type of operating conditions (Table 1). Rail vehicles are placed in category F of the test type, which means they are only tested for three operating points.

Table 1

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The NRTC test itself is performed in accordance with the legally defined parameters of engine speed and engine load (Fig. 2), and are applicable to all engines tested in line with the Stage IIIB/IV norms.

![Fig. 1 The measurement setup: a - flowmeter attached to the exhaust pipe; b - PEMS device for measuring emissions](image-url)
For these tests the engine speed and torque must be normalized, due to the differences in the operating parameters of various engine types used in such a wide array of vehicles. This once again stems from the fact that all rail vehicles are placed in one category, irrespective of the type of work they perform, or their operating parameters and characteristics. The engine rotational speed is defined in the standard based on (1):

\[
n = \frac{\%n_{\text{nor}} \left( n_{\text{ref}} - n_{\text{idl}} \right)}{100} + n_{\text{idl}},
\]

where \( n_{\text{nor}} \) – normalized engine rotational speed; \( n_{\text{idl}} \) – idling speed; \( n_{\text{ref}} \) – the reference engine speed calculated using formula (2):

\[
n_{\text{ref}} = n_{50} + 0.95 \left( n_{70} - n_{50} \right),
\]

where \( n_{50} \) – minimum engine speed for which the engine reaches 50% of its rated power; \( n_{70} \) – maximum engine speed for which the engine reaches 70% of its rated power.

Engine torque for the NRTC test is defined as:

\[
M_0 = \frac{\%M_{\text{nor}} \times M_{\text{max}}}{100},
\]

where \( M_{\text{nor}} \) – normalized engine torque, \( M_{\text{max}} \) – maximum engine torque.

The exhaust emission limit values that these tests are expected to meet are once again split into two categories. For the current Stage IV these are categories: Q, for engines with net power in the range 130-560 kW and R for engines with net power in the range 56-130 kW, and each has their own set of limit values defined (Table 2). Additionally, the new Stage V norm still being implemented also divides the emission limit values for individual exhaust components. However instead of dividing it by engine power it splits the engines into categories based on the technical designation of the rail vehicle they are used in (Table 2).

<table>
<thead>
<tr>
<th>Category</th>
<th>Net power [kw]</th>
<th>CO [g/kWh]</th>
<th>HC [g/kWh]</th>
<th>NOx [g/kWh]</th>
<th>PM [g/kWh]</th>
<th>PN [1/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage IV</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>130 ≤ P ≤ 560</td>
<td>3.5</td>
<td>0.19</td>
<td>0.4</td>
<td>0.025</td>
<td>-</td>
</tr>
<tr>
<td>R</td>
<td>56 ≤ P &lt; 130</td>
<td>5.0</td>
<td>0.19</td>
<td>0.4</td>
<td>0.025</td>
<td>-</td>
</tr>
<tr>
<td><strong>Stage V</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RLL</td>
<td>P &gt; 0</td>
<td>3.5</td>
<td>4.0</td>
<td>0.025</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>RLR</td>
<td>P &gt; 0</td>
<td>3.5</td>
<td>0.19</td>
<td>2.0</td>
<td>0.015</td>
<td>(1 \times 10^{12})</td>
</tr>
</tbody>
</table>
3. Test Apparatus and Data Analysis

All the RDE test procedures rely on special type of exhaust emission measuring equipment, designed to work in mobile conditions, referred to as PEMS (Portable Emission Measurement System). Their proper use and preparation before performing measurements has already been defined for road vehicles [9, 10], so no changes are really necessary for use in rail vehicles. The Analyzers in PEMS devices are capable of providing the toxic components concentration in the exhaust. This includes the measurement of all the exhaust components that must be tested as required by the legislation. Those substances are: carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM). In order to properly assess the emission values additional data is required regarding the engine operating conditions and the exhaust gas flow. For this the engine operating data needs to be recorded and the exhaust gas flow needs to be measured with a flowmeter. Then knowing the mass of exhaust gas released in time and the concentration of measured components at each point in time the mass of toxic components emitted in each second can be calculated. This can be used to determine the road emissions (given GPS measurements of travelled distance) or the specific emissions (when combined with the engine data regarding engine speed and load).

4. Test Drive Cycle Selection

The test drive was performed on a test rail track with a total distance of 7.7 km with four turns, each with a different radius, from 600 to 900 meters. The drive included an initial section with a steady acceleration and three stops towards the end of the drive before the final stop that ended the drive cycle. The stops were to simulate real operation od a motor coach where stops at several stations are a part of the standard operation of this type of a vehicle. Thus the obtained exhaust emission data could be referred to servicing stops for passengers as well as traveling on the track at a constant speed. This, in turn was measured for different vehicle drive parameters of maximum speed and acceleration. A total of four drives were performed, two sets of two. First, drives A and B were performed, which differed with the maximum travel speed of the vehicle. This was to show the impact of different rail travel speeds on the resulting exhaust emission values. Drive A was performed with a maximum speed of 70 km/h and drive B with a maximum speed of 100 km/h. This meant that drive A had a longer period of time where the vehicle was not accelerating, due to already reaching its maximum travel speed. The second pair of tests were drives C and D, which differed by the acceleration values as a representation of different drivers performing the tests. Drive C was characterized by lower accelerations and a more steady drive, while drive D was characterized by a more aggressive driver behavior where the driver tended to reach the maximum permitted vehicle speed in as short a time as possible. These two drive cycles provided data that can be used to normalize for the effects of the driving style during RDE testing. This is been known to be a contentious issue in road vehicles before, and multiple tests have shown that the driving style used when performing the test drive cycles has a significant impact on road emissions for cars [11, 12]. It can thus be asserted that the same holds true for rail vehicles, as the combustion engines used in either of those vehicles are based on the same technology and processes. The aspect of random driving style, highly dependent on the driver performing the given test and thus outside of legislative control, has been a hotly debated issue regarding RDE testing. Especially since the emission results can change significantly as a result of the driving style chosen. It was, therefore, decided to use the data from such outlier situations (most eco-friendly and most aggressive driving styles) to determine the margin of error for the obtained results.

5. Results Comparative Analysis

The overall results obtained for the performed mock tests on a motor coach in accordance with the procedure described in the previous chapters. The effect of increasing the vehicle maximum travel speed on the test track lead to changes in the engine operating parameters and the combustion process itself, thus having a direct effect on the exhaust emission values measured. The overall differences in exhaust emission values between the drives A and B for the same vehicle amounted to:

- less than 7% change in total CO2 emission;
- 27% change in total CO emission;
- 11% change in total HC emission;
- 10% change in total NOx emission.

Similarly the comparison between drives C and D, reflecting ecological and aggressive driving styles resulted in differences of exhaust emission values. Most of the exhaust components emitted were closer in overall value between those two drives than for drives A and B, with the exception of nitrogen oxides emission.

- less than 8% change in total CO2 emission;
- 15% change in total CO emission;
- 11% change in total HC emission;
- 36% change in total NOx emission.

6. Conclusions

Due to the variations in exhaust emissions of different compounds for the presented test drive variants it has been concluded that the use of RDE testing for rail vehicles, namely for a motor coach, would require assigning conformity
factors that are based on the expected operating parameters for the vehicle. The divergence of obtained values imply the need to adjust any proposed conformity factor values based on the two factors used in the research. Maximum vehicle speed represents the nature of operation for a given rail vehicle and could be based on the vehicle data sheet. It is important to note, however, that the travel speed is not only restricted by the vehicle maximum speed, but more often than not by the limit permitted on the rail lines on which the vehicle travels. This means that the overall data used to determine the exhaust emission limit values must be at least somewhat contextualized. The European Court of Auditors has found in its report [13] that the average travel speed of freight vehicle in EU is only around 18 km/h, with somewhat higher average speed in eastern and central European countries (in Poland the average travel speed of freight trains was over 22 km/h). This problem becomes more noticeable when comparing the exhaust emissions in real operating conditions of freight locomotives with shunting locomotives. Skoglund M. evaluated the test cycles for freight locomotives back in 2011 with similar conclusions about a need to better represent the transient states that locomotives operate in, as well as pointing out the obvious differences in the engine operating characteristics in vehicles performing such different work cycles [5].

While the range of exhaust emission values obtained for the same motor coach driving through the same test route with differing drive parameters (max. speed, acceleration) can be extensive, the final exhaust emission limit values and their respective conformity factors must remain reasonably universal. Based on the method used it can be concluded that an increase in maximum travel speed by 30 km/h (or approx. 40%) for a motor coach would result in a need to increase its exhaust emission conformity factors by 0.2 for CO limit value and 0.1 for HC and NOx emission values. Further testing of a more varied set of vehicles performing their assigned work could provide sufficient data to estimate the correction for any future conformity factor based on such comparisons. Exhaust emission differences due to driver’s driving style, however, cannot be easily or reliably controlled. Any data available will be contextual and useful only as a general reference. However, since the only significant differences in emissions were found for the emission of NOx, it can be concluded that CO and HC emissions should not provide a large discrepancy between different tests of the same vehicle types. Regardless of how difficult it is to predict, or measure the effects of independent factors related to driving patterns and driver behavior, it has not stopped researchers in attempting to estimate their effect for cars [14]. It would be expected that, as our need to increase control and accuracy over the exhaust emissions from rail vehicles they too will be subjected to such research.

References

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Use of Aircraft Engine Type and Quantity and their Impact on Air Transport Safety

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Abstract

Air transport is the safest way to transport people and goods in the world. Aviation has gone through many years of technological development to ensure that transport takes place not only quickly but also safely while maintaining the highest safety criteria. Over the past 50 years, jet engines have replaced older piston and turboprop engines in passenger and cargo air transport. At the same time mostly, aircraft starting began to be produced with two engines compared to previous older models that had three or more engines. This paper deals with the analysis and investigation of the influence of the use of the engine type and its number on aircraft in relation to air disasters (air safety).

KEY WORDS: air transport, engines, safety, air disaster

1. Introduction

Air transport is a very fast developing transport industry, which is also considered to be the safest. More and more passengers are transported every year, resulting in an increase in aircraft movements, which puts a heavy burden on maintaining a high level of aviation safety. However, there are air accidents or air incidents that will negatively affect all aviation safety statistics. If a large aircraft, such as a Boeing 737 or Airbus 320 part of air catastrophe is always very closely monitored by the media and there is a big pressure on investigators to explain the causes of the accident and incident.

In general, identifying the causes of air accidents and air incidents contributes to increased air safety. Based on the identified causes procedures and manuals are created (modified) and pilots, aircraft maintenance and air traffic control must use these safety measure.

2. Safety in Air Transport

Safety is an essential aspect for assessing air traffic [1]. Aviation has two concepts of safety and security [1]. Safety is „the state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level“ [2]. Security is the protection of air transport from unlawful acts (terrorist attacks) [3]. In this article, attention is focused on the safety section.

Government and non-governmental organizations address the issue of safety regulations and manuals and each of these organizations takes care of a certain component of safety. Below are the basic organizations operating in aviation.

- ICAO – The International Civil Aviation Organization.
- EASA – The European Aviation Safety Agency.
- IATA – The International Air Transport Association.

<table>
<thead>
<tr>
<th>Years</th>
<th>Number of Accidents</th>
<th>Number of Fatalities</th>
<th>Air Transport Passengers Transported (in trillion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>138</td>
<td>524</td>
<td>2,208</td>
</tr>
<tr>
<td>2009</td>
<td>113</td>
<td>670</td>
<td>2,250</td>
</tr>
<tr>
<td>2010</td>
<td>121</td>
<td>707</td>
<td>2,628</td>
</tr>
<tr>
<td>2011</td>
<td>126</td>
<td>414</td>
<td>2,787</td>
</tr>
<tr>
<td>2012</td>
<td>99</td>
<td>388</td>
<td>2,894</td>
</tr>
<tr>
<td>2013</td>
<td>90</td>
<td>173</td>
<td>3,048</td>
</tr>
<tr>
<td>2014</td>
<td>98</td>
<td>904</td>
<td>3,227</td>
</tr>
<tr>
<td>2015</td>
<td>92</td>
<td>474</td>
<td>3,464</td>
</tr>
<tr>
<td>2016</td>
<td>75</td>
<td>182</td>
<td>3,696</td>
</tr>
<tr>
<td>2017</td>
<td>88</td>
<td>50</td>
<td>4,100</td>
</tr>
</tbody>
</table>
Table 1 shows the number of air accidents and the number of fatalities over the last 10 years registered by ICAO. Table 1 shows that the number of accidents in the last 10 years has dropped almost to half, but in 2017 there were still 88 accidents that is a large number in aviation [4, 5]. What is positive is that the number of fatalities from these accidents has dropped significantly [4, 5]. At the same time, table 1 shows that the number of passengers carried has doubled over the last 10 years [6], and so there is increasing pressure for aviation safety.

Based on the statistics presented in Table 1, a correlation was made to show whether the number of air accidents and the number of fatalities affected the demand for air transport. The correlation coefficient is calculated based on the formula below [7]:

$$r_{12} = \frac{\sum x_1 x_2 - \sum x_1 \sum x_2}{\sqrt{\left[n \sum x_1^2 - (\sum x_1)^2\right] \times \left[n \sum x_2^2 - (\sum x_2)^2\right]}}$$  \hspace{1cm} (1)

where $n$ – number of pairs of data; $x_1$, $x_2$ – examined variables.

Correlation coefficient is used to measure the tightness of dependence between variables. Direct linear relationship exists between variables if the value of the coefficient equals to 1. Value minus 1 indicates the exact opposite, indirect linear relationship. Linear independence of variables exists if the correlation coefficient is zero [7]. The correlation coefficient between air accidents and the number of passengers carried is -0.827, this is probably indirect dependence. No dependence exists between the number of fatalities and the number of passengers carried, because the correlation coefficient is -0.568.

The test statistic that will finally confirm causal relationship between the variables is given by the following formula [7]:

$$t = \frac{r_{12}}{\sqrt{1-r_{12}^2}} \times \sqrt{n-2} \hspace{1cm} (2)$$

where $r_{12}$ – correlation coefficient; $n$ – number of pairs of data.

After calculating the $t$ value, it is necessary to know the critical field for dependency. Statistical tables state that the value of 2.306 is a value that indicates this critical field at 5% error tolerance [8]. The $t$ value is -4.166 between the number of transported passengers and the number of air accidents and is in the critical field. The result is -1.951 and this value is outside the critical field between the number of transported passengers and the number of fatalities. The test statistic thus proven the indirect dependence between the number of transported passengers and the number of fatalities.

3. Engines in Air Transport

In air transport, airplanes with piston, turboprop and jet engines are used. The oldest engines are piston engines, which are not used much at present. The use of piston engines was mainly in the first half of the 20th century, where these engines were used for military aircraft.

Turboprop engines are on airplanes that use airliners for the transportation of passengers and cargo, especially for short distances due to lower operating costs than jet engines. The most used aircraft with two turboprop engines is the ATR 72, which has a capacity of 78 passengers, to develop an average speed of 509 km/h with a range of up to 5,665 km [10].

The most commonly used in commercial aviation are jet engines, which are primarily produced by three leading manufacturers of Pratt & Whitney, General Electric and Rolls-Royce. Jet engines have higher operating costs compared to turboprop engines, but they can produce higher air speeds. They are used on larger aircraft with more passengers or cargo and for long distance. The most commonly used Boeing 737, which uses jet engines, transports up to 189 passengers at a travel speed of 842 km/h with a range of up to 5,665 km [10]. The largest airlines have a fleet of aircrafts primarily powered by jet engines, which are complemented by a few types of turboprop aircrafts, as already mentioned to ensure transportation primarily to short lines.

Aviation engines have a major impact on aviation safety and the highest safety requirements are placed on their manufacture and subsequent regular maintenance. It is imperative that engine maintenance is performed correctly and at predetermined operating intervals as specified by the manufacturer. Every airline seeks to minimize its costs, but this should not affect the quality and scope of maintenance work on aircraft engine maintenance [11]. To improve aviation safety, modern jet engines are designed so that, even if one engine fails during a flight, the aircraft can flight of no major changes, but must land at the nearest (suitable) airport for maintaining high level of safety in air transport. However, if all engines fail, it is imperative that pilots be able to land without thrust, all pilots are trained for these situations. The aircraft engine is the second most common cause of air disasters after the airframe [12].

Fig. 1 shows the number of air accidents over the last 50 years by engine type [13]. Aircrafts powered by turboprop engines accounted more air accidents until 90's of the 20th Century than jet-powered aircrafts. This fact is, of course, influenced by the fact that, since the 80's of the 20th Century, jet-powered aircraft have been increasingly being produced. These aircraft were immediately put into commercial operation and were used not only to carry passengers.
but also cargo. From 90’s of the 20th Century until now jet-powered aircrafts were included of air accidents more than turboprop engines aircrafts.

![Fig. 1 Trend in air accidents by type of engines for last 50 years](image)

After following Fig. 1, it is necessary to analysis a more in-depth of these air disasters and focus on the number of aircraft engine. Then the impact of the type used and the number of engines on the aircraft on safety in the air transport can certainly be seen in this analysis.

![Fig. 2 Number of air accidents by engine types and quantity for last 50 years](image)

Fig. 2 shows the analysis of air accidents over the last 50 years [13]. The authors chose two criteria, according to the type of engine and at the same time as the second criterion used the number of engines used on the aircraft. Most airlines use twin-engine aircraft because two jet engines can power big commercial aircrafts (such as the Boeing 777) and for airlines represent lower operating costs than four-engine aircrafts such as Airbus 340, Airbus 380 or older Boeing 747.

It follows from Fig. 2 that aircraft powered by two jet engines are most often involved in an air disaster. The second group consists of aircraft with two or one turboprop engine, but it is almost half of air disasters than in the first group. The four-engine turboprop and jet aircrafts have less impact on aviation safety than two engines aircrafts. Four-engine included in only 30 of the 199 air disasters.

4. Conclusions

Within analysis of the air accidents over the last 50 years, the authors have focused especially on the number of engines and their kind used on a given aircraft that was part of a given flight disaster. The investigation revealed that
over the last 50 years, aircrafts powered by twin jet or twin turboprop engines were in 169 of the 199 air disasters. While the proportion of four-engine, turboprop and jet engines, does not record higher occurrences in these air disasters. It is thus clear that, based on statistical data, four-engine aircraft are more safe than twin-engine aircraft, but the maintenance and operation of four-engine aircraft represents a higher cost for airlines.

Depending on the correlation calculation, which shows that demand for air transport is indirectly dependent on the number of fatalities in air disasters, it is indispensable to constantly increase aviation safety and avoid air disasters completely, especially on jet-powered aircrafts because they can transport more passengers than turboprop aircrafts.

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References

Assessment of Current State of Education in the Field of Risk Management in the Transport Sector in Visegrad Four Countries

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Abstract

The training of managers is becoming an inevitable need in the business management process nowadays. Owners and managers of SMEs should be prepared for various dynamic influences of the business environment. Based on the current global trends managers and owners of the SMEs in the transport sector are looking for education and training activities, which are oriented on risk management. In 2017 – 2018 the authors of this article realized empiric research aimed at the area of implementing the risk management in the SMEs. Part of this research was focused on assessing the contemporary state of managers’ education in risk management. The main goal of this article is to analyze and assess the current state of owners and managers education in the field of risk management in the transport sector in Slovakia. Results were gain based on mathematical and statistical methods and compare with results of V4 countries (the Czech Republic, Poland, and Hungary), too. Results of this article show, that companies in the transport sector do not provide sufficient education, which is focused on risk management. Enterprises are not interested very much in this type of training and education, too. Therefore it is necessary to persuade the owners and managers that investments into the education of the risk management will help increase the company performance and achieve stability in the conditions of the current changes of the environment or strengthen the company competitiveness.

KEY WORDS: risk, risk management, assessment, education, small and medium-sized enterprises (SMEs), transport

1. Introduction

The dynamic development of the small and medium sized business is one of the basic assumptions for a healthy economic development of the country [1, 4]. The Slovak economy is possible to characterise as an open at present, which is oriented especially on export of cars and electronics – this represents more than 80% of the Slovakia’s GDP. Slovakia has been considered attractive mainly for foreign investments for several years. The investors are attracted by the cheap workforce and a positive geographical position in Europe. In spite of that, Slovakia faces serious problems which potentially threaten the attractiveness of the Slovak market. According to Central Intelligence Agency they are as follows [5, 12, 17]:

- shortage of qualified workforce;
- persisting problems with corruption;
- ineffective legal system;
- slow innovation performance of the Slovak economy.

The owners and managers of the SMEs also feel certain problems that affect their business. Based on the studies of several organizations and processed information we can identify the following current problems that the Slovak SMEs have to face [6, 8, 13-15, 18]:

- **Lack of cash.** The companies have not enough financial sources both in cash and on their bank accounts to cover their costs. They are unable to cover their expenses for material, raw materials or salaries of the employees.
- **Ineffective inventory management.** Not only the Slovak SMEs but companies worldwide can feel this problem. Due to unsuitably applied marketing tools ineffective sales operations take place and it leads to accumulation of products in the warehouse. The ineffectively applied purchasing tools as well as inventory management affect the company’s profitability.
- **Inability to pay the loan.** A lot of companies in Slovakia have problems with paying the loan. The reason can be that the banks offer the enterprises such conditions that are of a liquidation character and they are not able to ensure enough resources for their business.
- **Incorrect financial management.** The ineffective management of the cash flows can cause existential problems to the SME owners and managers. There are also problems with managing the obligations and receivables that are connected with the company’s indebtedness and lack of cash. In Slovakia the suppliers of the SMEs often require paying the so called in advance payments that are often a burden for the company because they have not sufficient cash for covering individual expenses.
- **Lack of experience with the company management** – the managers. These problems often occur during an incorrect implementation of the business plan. The insufficiently analysed expansion to the markets as well as a too
high product diversification cause big problems to the SMEs in Slovakia. Due to incorrect decisions in the company the managers feel more and more the necessity to deal with the company risk management.

The SMEs in Slovakia and the V4 countries face similar problems [7]. The Czech Republic is a prosperous market economy, however, also dependent on export. In 2017 it had one of the highest GDP growth amounting 4.5% and the lowest unemployment rate in the EU with 2.8%. These facts cause that the economic growth is exposed to a high contraction of the demand from abroad. The Czech export creates approximately 8% of GDP and is largely created by the automotive that is the largest industry in the country [2, 3]. The system economic problems in the Czech Republic are: ageing population, lack of qualified employees, problems with educational system, financing the retirement and healthcare system or diversification from production up to the technologically oriented knowledge economy based on advanced technologies [2, 3, 9].

Hungary transferred from the centrally planned economy of the country to the open economy with an average income of the inhabitants amounting approximately two thirds of the EU average (28). However, since 2010 the government has taken part in managing economy in a greater extent. The government introduced non-orthodox economic policies to maintain the fiscal balance as well as a six-year plan of increasing salaries to support the household consumption. The economic growth depends largely on export and this exposes Hungary to impacts from abroad [10]. The system economic problems of Hungary are: corruption, lack of qualified employees due to the demographic decline and migration, extended poverty in the rural areas, vulnerability against changes of demand for export and a strong dependence on the Russian deliveries of energy [10].

Poland has the sixth most developed economy in the EU and a macro-economic policy that is positive for the country. Poland is the biggest receiver of the EU development funds and their cyclic allocation can significantly affect the rate of its economic development [11]. The system economic problems in Poland are: problems of the road and railway infrastructure, in the entrepreneurial environment, a strict Labour Code, trade legal system, governmental bureaucracy and a burdensome tax system, especially for the entrepreneurs. Other long-term challenges include: enlarging the investments to innovations, research and development, effort to stop outflow of educated young Poles to other EU countries, etc. [11, 16].

The main goal of this article is to analyze and assess the current state of owners and managers education in the field of risk management in the transport sector in Slovakia. Results were gain based on mathematical and statistical methods and compare with results of V4 countries (the Czech Republic, Poland, and Hungary), too.

2. Results

In 2017 and 2018 the investigators of the project VEGA - Risk Management of Small and Medium Sized Enterprises in Slovakia as Prevention of Company Crises and KEGA - Research of Risk Management in Enterprises in Slovakia to create a new study program Risk Management for the FBl University of Zilina in the framework of the support of the Scientific Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic, realised an empirical research aimed at identifying the entrepreneurial risks of the SMEs in Slovakia. Its task was to detect the state of the risk management in the enterprises. Similar research was also carried out by partners in the Czech Republic, Poland and Hungary. Altogether 487 SMEs participated in this research in Slovakia. The structure from the point of view of their size: 64% - micro-companies, 24% - small enterprises, 12% - medium-sized enterprises. From the point of view of the lines of business the SMEs were working in the structure was as follows: industry 16%, trade 24%, agriculture 1%, building industry 12%, transport, information 6%, accommodation and boarding 9%, trade services 7%, other transport services 22%, other services 3%.

As the education in the area of the risk management is considerably underestimated in Slovakia, the goal of the authors was, based on selected mathematical and statistical methods, to analyse and assess the current state of training managers in the risk management area of SMEs in the sector of transport. Out of the whole number of enterprises we chose 28% of SMEs that realise their entrepreneurial activities in Slovakia in the sector of transport. The SMEs showed the biggest interest in the comprehensive risk management training – 28% and the lowest interest was in implementing the project, financial, safety ones.
In 2017 and 2018 the same empirical research aimed at identifying the key entrepreneurial risks as well as at the state of the risk management implementation process was carried out in SMEs in the Czech Republic, Poland, and Hungary.

In the Czech Republic, 409 SMEs participated in the research. The structure from the point of view of their size: 64% - micro-companies, 23% - small enterprises, 13% - medium-sized enterprises. From the point of view of the lines of business the SMEs were working in the structure was as follows: industry 22%, trade 23%, agriculture 4%, building industry 15%, transport, information 13%, accommodation and boarding 6%, other transport services 15%. Out of the whole number of enterprises we chose 28% of SMEs that realise their entrepreneurial activities in the Czech Republic in the sector of transport and information and services connected with this field. The empirical research brought the following results (Fig. 2):

- only 45% of the SMEs in the transport sector in the Czech Republic train their employees;
- more than 55% of the SMEs do not train their employees because they consider this education to be unnecessary or they have not enough time for searching for the trainings or they did not find any suitable content of the training.

From the point of view of company categorisation according to the number of employees we can say that:
- the medium-sized companies, 61%, train their employees in the greatest extent;
- and vice versa the micro-companies do not train their employees – 80%.

The results show that 42% of the total number of SMEs would welcome the risk management trainings. The SMEs showed the biggest interest in implementing the methods, techniques and tools of the risk management – 18% and the lowest interest was in trainings including managing special risks (project, financial, safety ones) – 10%. Only 16% of the SME owners and managers in the Czech Republic would welcome the comprehensive risk management training.

From the point of view of company categorisation according to the number of employees we can say that:
- the medium-sized companies, 61%, train their employees in the greatest extent;
- and vice versa the micro-companies do not train their employees – 80%.

The results show that 42% of the total number of SMEs would welcome the risk management trainings. The SMEs showed the biggest interest in implementing the methods, techniques and tools of the risk management – 18% and the lowest interest was in trainings including managing special risks (project, financial, safety ones) – 10%. Only 16% of the SME owners and managers in the Czech Republic would welcome the comprehensive risk management training.
of transport and information and services connected with this field. The empirical research brought the following results (Fig. 3):

- 39.87% of the SMEs in the transport sector in Hungary train their employees;
- more than 60.13% of the SMEs do not train their employees because they consider this education to be unnecessary or they have not enough time for searching for the trainings or they did not find any suitable content of the training.

From the point of view of company categorisation according to the number of employees we can say that:

- the medium-sized companies, 49%, train their employees in the greatest extent;
- and vice versa the micro-companies do not train they employees – 71%.

The results show that 41% of the total number of SMEs would welcome the risk management trainings. The SMEs showed the biggest interest in trainings including managing special risks (project, financial, safety ones) – 24% and the lowest interest was in implementing the methods, techniques and tools of the risk management – 8%. Only 9% of the SME owners and managers in Hungary would welcome the comprehensive risk management training.

In Poland 498 SMEs participated in the research. The structure from the point of view of their size: 50% - micro-companies, 21% - small enterprises, 29% - medium-sized enterprises. From the point of view of the lines of business the SMEs were working in the structure was as follows: industry 15%, trade 25%, agriculture 11%, building industry 7%, transport, information 29%, accommodation and boarding 6%, other transport services 7%. Out of the whole number of enterprises we chose 36% of SMEs that realise their entrepreneurial activities in Poland in the sector of transport and information and services connected with this field.

The empirical research brought the following results (Fig. 4):

- more than 68 % of the SMEs in the transport sector in Poland train their employees,
- 32% of the SMEs do not train their employees because they consider this education to be unnecessary or they have not enough time for searching for the trainings or they did not find any suitable content of the training.

From the point of view of company categorisation according to the number of employees we can say that:

- the medium-sized companies, 60%, train their employees in the greatest extent;
- and vice versa the micro-companies do not train they employees – 79%.

The results show that 57% of the total number of SMEs would welcome the risk management trainings. The
SMEs showed the biggest interest in the comprehensive risk management training – 29% and the lowest interest was in implementing the methods, techniques and tools of the risk management – 10%. Only 18% of the SME owners and managers in Poland would welcome trainings including managing special risks (project, financial, safety ones).

From the point of view of the overall assessment we can say that the results in Slovakia, the Czech Republic and Hungary develop on a similar way, there is lack of interest and aversion to implementing the risk management trainings in the future. Poland is an exception – here the SME managers in the transport sector show a larger interest in educating their employees in the risk management area.

From the point of view of Slovakia the overall research results show that the current state of implementing the risk management in the SMEs is not positive. The SME owners and managers are aware of the risks; however, they do not deal with them:
- they do not deal with the risk management in the company in a sufficient extent;
- they do not perceive the risk management as a strategic advantage for the company;
- they do not create a sufficiently large space for discussing about the key risks;
- they do not pay attention to the risk assessment, more or less to the particular suggestions for their reduction;
- they have no risk catalogue in their company;
- they usually look for the risk sources only for the most serious risks;
- they utilise especially the qualitative assessment from the point of view of possible consequences and probabilities for stating the risk value;
- they most frequently utilise the process of avoiding the risks for the risk reduction;
- the check of fulfilling the stated goals is only used for assessing the risks;
- they do not utilise particular methods and techniques of the risk management;
- they do not provide the education in the risk management area for their employees.

3. Conclusions

The research results show that the companies, SME owners and managers in the transport sector in individual countries do not provide sufficient education in the risk management area and do not show any big interest in this type of training. Poland is an exception – here is an opposite situation. The reason can be that the SME owners and managers in the transport sector in Slovakia, the Czech Republic and Hungary are not able to see the value added and return on investments of the education in the risk management area. Therefore, it is necessary to persuade the owners and managers that to invest to the risk management education will help increase the company performance and to achieve a higher stability in the conditions of the current changes of the environment or to strengthen the company competitiveness.

The detected results emphasise the importance of dealing with the applied risk management in the SMEs of individual countries. They underline the need of an active and systematic work with the risk and preparations for the traps of the current entrepreneurial environment. Therefore, we have to improve our knowledge about the possible causes and effects of the risk as well as implementing adequate measures for their reduction. The improvement of the risk management quality requires achieving knowledge about the risk management process, methods and tools usable in the risk management. The owners or the managers should be able to implement the risk management process in the companies with the goal to identify the changes in the case of an unfavourable development of the entrepreneurial environment at its beginning. It is important for the managers to be sure that an effective risk management ensures fewer negative surprises, a stronger financial stability and company performance.

Acknowledgment

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References


The Development of Collective Transport Modes Share in Total Inland Passenger Transport Performance of Selected European Countries from the Perspective of Sustainable City Logistics

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Abstract

Sustainable development of cities is based on three pillars – economic pillar, environmental pillar and social pillar. Emphasis is placed on the environmental pillar from the perspective of city logistics, because the transport is an important producer of emissions and associated negative environmental impacts. An important role in terms of negative environmental impacts is represented by passenger car transport, because passenger car transport produces more emissions per capita than collective transport. Collective transport modes represented by buses, coaches, trolley-buses and trains are more environmentally friendly than using individual passenger car transport. EUROSTAT defined seventeen sustainable development goals and groups of indicators. This article is focused on the indicator “Share of buses and trains in total passenger transport” which measures the share of collective transport modes in total inland passenger transport performance, expressed in passenger-kilometres. The aim of the article is to analyse the development of this indicator of selected European countries between 2007 and 2016 from the perspective of sustainable city logistics.

KEY WORDS: sustainable development, sustainable development indicators, collective transport modes, sustainable city logistics

1. Introduction

City logistics is a key catalyst in the urban economy, but in parallel, urban transport significantly affects the quality of life in the urban environment [1, 2]. Gatta et al. [3] stressed two fast-rising trends that make city logistics solutions even more challenging, there are: urbanization and e-commerce. Nathanail, Adams and Gogas [1] summarized the basic assumptions for dealing with the issue of use of collective transport modes from the perspective of sustainable city logistics, there are: over 50% of the world population is living in cities (see as well as [4]); more than 100 million people have migrated to cities globally since the beginning of this decade [5]; around 75% of the population lives in urban areas in Europe [6]; annually, approximately 1% of Gross Domestic Product is lost by the European economy due to congestion [7] and by 2050, at least 70% of world population will live in cities [5].

The concept of sustainable city logistics is closely related with the concept of sustainable development. Olawumi and Chan [8] stressed the importance of Brundtland Report for the World Commission on Environment and Development in 1992 where the term of “sustainable development” was introduced. Sustainable development is a development that meets the needs of the present generations without compromising the ability of future generations to meet their own needs [9]. The sustainable development is based on a three-pillar concept defined by Elkington [10]. This three-pillar concept is based on the integration the economic, the environmental and the social aspects and impacts into strategic and daily management and decision making processes [10]. Sustainable development is one of the main objectives of the global development strategy through 2030, adopted by the United Nations General Assembly in September 2015 [11].

Cheba and Saniuk [12] emphasize that one of the most important areas of sustainable development is the transport sector. The main trends in sustainable city logistics are according to Kauf [13] cooperation between suppliers, customers and the public administration, development and implementation of new business models enabling to generate benefits not only for operating entities, but also for the city. The transport system in a sustainable society is very important, because it has a direct impact on human health and safety [13].

The share of collective transport modes in terms of city logistics is quite significant. Increased use of collective transport modes, for example trains, motor coaches, buses and trolley buses, in comparison with individual passenger car transport has following advantages: lower emissions per capita; reduction of congestion, noise and vibration; lower energy intensity and greater accessibility to all population groups. The use of collective transport modes has a direct
impact on the quality of the city logistics system. The aim of the article is to analyse the development of the indicator “Share of busses and trains in total passenger transport” of selected European countries between 2007 and 2016 from the perspective of sustainable city logistics.

2. Materials and Methods

EUROSTAT [14, 15] defined seventeen groups of sustainable development indicators, there are: Group 1 – No poverty; Group 2 – Zero hunger; Group 3 – Good health and well-being; Group 4 – Quality education; Group 5 – Gender equality; Group 6 – Clean water and sanitation; Group 7 – Affordable and clean energy; Group 8 – Decent work and economic growth; Group 9 – Industry, innovation and infrastructure; Group 10 – Reduced inequalities; Group 11 – Sustainable cities and communities; Group 12 – Responsible consumption and production; Group 13 – Climate action; Group 14 – Life below water; Group 15 – Life on land; Group 16 – Peace, justice and strong institutions and Group 17 – Partnership for the goals. Each group of indicators consists of several sub indicators that are focused on a particular area of sustainable development.

Indicators linked to the sustainable city logistics are located in Group 11 entitled: “Sustainable cities and communities”. This group of indicators aims to renew and plan cities and other human settlements in a way that they offer opportunities for all, with access to basic services, energy, housing, transportation, green public spaces, while improving resource use and reducing environmental impacts and envisions cities as environmentally resilient human settlements, which drive sustainable development, stimulate innovation and foster community cohesion and personal safety [16]. This group is further subdivided into eleven sub indicators: Overcrowding rate by poverty status; Population living in households considering that they suffer from noise, by poverty status; Difficulty in accessing public transport by level of difficulty and degree of urbanisation; People killed in road accidents; Exposure to air pollution by particulate matter; Recycling rate of municipal waste; Population living in a dwelling with a leaking roof, damp walls, floors or foundation or rot in window frames of floor by poverty status; Population connected to at least secondary wastewater treatment; Share of busses and trains in total passenger transport; Artificial land cover and Population reporting occurrence of crime, violence or vandalism in their area by poverty status [16].

This article is focused on the sub indicator named “Share of busses and trains in total passenger transport” which measures the share of collective transport modes in total inland passenger transport performance, expressed in passenger-kilometres (pkm). Collective transport modes refer to buses, including coaches and trolley-buses, and trains. Total inland transport includes transport by passenger cars, buses and coaches, and trains. All data are based on movements within national territories, regardless of the nationality of the vehicle. The data collection methodology is voluntary and not fully harmonised at the EU level. Other collective transport modes, such as tram and metro systems, are also not included due to the lack of harmonised data. For countries, where rail transport statistical legislation does not apply, the totals contain only the share of coaches, buses and trolley buses [17].

The sub indicator “Share of busses and trains in total passenger transport” is composed of two values – \( x_i \) (“Share of motor coaches, buses and trolley buses in total inland passenger transport performance”) and \( x_j \) (“Share of trains in total inland passenger transport performance”). The standard deviation is used for the calculation of the amount of variation or dispersion of a set of data values. Standard deviation \( \sigma \) is usually defined as the square root of the variance \( D(X) \) of a random variable \( X \) – (Eq. (1)); standard deviation \( \sigma \) can be also calculated using the mean value \( E(X) \) or \( E(X^2) – (\text{Eqs. 2, 3}) \) [18]:

\[
\sigma = \sqrt{D(X)}; \quad \text{(1)}
\]
\[
\sigma = \sqrt{\left(E(X^2) – (E(X))^2\right)}; \quad \text{(2)}
\]
\[
\sigma = \sqrt{\left[1/n \cdot \sum (x_i – (1/n \cdot \sum x_i))^2\right]}; \quad \text{(3)}
\]

Average values (Eqs. 4, 5) of both analysed sub indicators (\( \bar{x}_i \) and \( \bar{x}_j \)) of selected European countries between 2007 and 2016 are compared with the average values of 28 countries of European Union, where \( \bar{x}_i \) is the average value of “Share of motor coaches, buses and trolley buses in total passenger transport”, \( \bar{x}_j \) is the average value of “Share of trains in total passenger transport”, \( n \) is the number of analysed values and \( x_{1n} \) and \( x_{jn} \) are specific values of both sub indicators:

\[
\bar{x}_i = \left[1/n \cdot (x_{11} + x_{12} + \ldots + x_{1n})\right]; \quad \text{(4)}
\]
\[
\bar{x}_j = \left[1/n \cdot (x_{j1} + x_{j2} + \ldots + x_{jn})\right]; \quad \text{(5)}
\]

In the following chapter there are summarized and discussed the results from presented research.

3. Results and Discussion

The first analysed sub indicator is “Share of motor coaches, buses and trolley buses in total passenger transport”. The results are presented in Table 1.

The value of the first sub indicator of 28 countries of European Union decreased by 0.4 percentage point in
79
comparison years 2016 and 2007. Turkey achieved the largest decline of sub indicator value between 2007 and 2016; it
was a decrease of 13.9 percentage points. A significant decrease in the sub indicator value between 2007 and 2016 was
also in these other countries: Bulgaria (- 7.7 percentage points), North Macedonia (- 7.0 percentage points), Poland
(- 6.6 percentage points) and Slovakia (- 6.2 percentage points). France achieved the greatest increase of sub indicator
value between 2016 and 2007; it was a growth of 3.3 percentage points. A significant increase in the sub indicator value
between 2007 and 2016 was also in these other countries: Ireland (+ 3.0 percentage points), Finland (+ 1.9 percentage
point), Romania (+ 1.7 percentage point) and Luxembourg (+ 1.2 percentage point).
Turkey has the highest standard deviation (4.367) between 2007 and 2016. This means that there were the
biggest fluctuations during the years 2007-2016 in the analysed sub indicator. On the other side, Iceland (0.000) has the
lowest standard deviation value of the analysed sub indicator. This means that Iceland has the most constant values.
Turkey reached the highest sub indicator values in all analysed years (2007-2016). Netherlands reached the lowest sub
indicator values between 2007 and 2016.
Table 1
Values of the indicator “Share of motor coaches, buses and trolley buses in total passenger transport”
(% of total inland passenger-km) [authors based on 17]
State
EU-28
Belgium
Bulgaria
CR
Denmark
Germany
Estonia
Ireland
Greece
Spain
France
Croatia
Italy
Cyprus
Latvia
Lithuania
Luxembourg
Hungary
Malta
Netherlands
Austria
Poland
Portugal
Romania
Slovenia
Slovakia
Finland
Sweden
UK
Iceland
Norway
Switzerland
N. Maced.
Turkey
Maximum
Minimum
Median
Explanatory
notes

9.8
9.8
9.2
9.4
9.4
9.5
9.8
9.6
9.5
9.4 0.196
14.1
13.0
13.0
12.7
12.8
12.9
11.9
11.4
10.9
10.5 1.056
21.8
20.8
16.8
16.4
15.9
14.8
14.0
15.1
14.6
14.1 2.597
17.0
16.9
16.9
19.5
18.0
17.7
17.9
18.5
17.3
17.1 0.793
10.7
10.5
10.4
10.5
10.1
9.8
9.8
9.7
9.8
9.8 0.359
6.5
6.3
6.1
6.0
5.8
5.6
5.7
5.8
6.0
5.8 0.265
20.7
18.5
16.4
16.6
16.3
16.8
17.4
16.5
20.0
17.9 1.489
14.2
14.4
15.0
14.5
19.4
14.4
14.1
17.3
16.7
17.2 1.721
18.5
17.9
16.9
17.3
17.6
17.7
17.8
17.7
17.5
17.1 0.424
14.0
14.3
13.3
12.3
13.5
13.7
13.2
10.6
11.9
11.8 1.107
5.5
5.7
5.2
5.3
5.4
5.4
8.1
8.1
8.0
8.8 1.408
12.1
12.5
10.7
10.7
10.5
10.7
11.5
11.9
11.0
12.3 0.722
12.4
12.4
11.7
12.8
13.2
14.7
14.1
13.7
12.3
12.0 0.923
19.7
18.8
17.6
18.1
18.3
18.7
18.5
18.2
18.7
18.6 0.521
15.7
16.1
15.1
17.1
18.9
18.3
18.0
17.0
15.8
15.1 1.290
8.4
8.2
7.1
7.6
8.3
7.3
7.8
10.8
9.9
9.1 1.115
11.1
11.4
11.4
12.1
12.5
12.4
12.4
12.2
12.4
12.3 0.489
21.5
22.1
20.7
21.5
21.5
22.3
22.3
22.6
22.3
21.7 0.543
19.4
19.2
18.1
18.5
17.6
17.5
17.0
16.9
17.7
17.4 0.817
2.9
3.0
2.9
2.9
3.0
2.7
2.7
2.7
3.0
3.0 0.125
11.1
10.6
10.0
10.6
10.4
10.4
10.3
10.3
10.2
10.2 0.288
20.8
19.9
17.9
16.8
15.7
16.0
15.3
15.5
14.7
14.2 2.089
6.5
6.4
6.2
6.5
6.3
6.4
6.6
6.1
6.2
6.7 0.181
14.0
20.7
17.3
16.3
16.2
17.2
16.8
16.9
15.5
15.7 1.637
11.4
10.9
10.7
10.8
11.0
11.1
11.4
11.6
11.8
11.8 0.385
22.0
20.6
15.8
15.3
15.7
15.6
15.1
15.2
14.8
15.8 2.396
10.0
10.1
10.0
9.9
9.8
9.8
9.8
9.8
9.7
11.9 0.618
7.2
7.1
7.1
7.3
7.4
7.3
7.5
7.3
7.3
7.2 0.119
5.5
5.9
6.0
6.2
5.9
5.8
5.6
5.4
5.4
4.6 0.427
11.4
11.4
11.4
11.4
11.4
11.4
11.4
11.4
11.4
11.4 0.000
6.7
6.7
6.7
6.9
7.0
5.6
5.5
5.4
5.7
5.9 0.609
5.5
5.2
5.1
5.1
5.7
5.7
5.7
5.8
5.9
5.9 0.301
20.1
22.1
21.6
22.9
23.1
21.2
17.8
15.0
14.8
13.1 3.522
42.4
41.3
40.6
38.3
38.4
36.6
34.9
33.5
30.7
28.5 4.367
42.4
41.3
40.6
38.3
38.4
36.6
34.9
33.5
30.7
28.5 4.367
2.9
3.0
2.9
2.9
3.0
2.7
2.7
2.7
3.0
3.0 0.000
12.4
12.5
11.7
12.3
12.8
12.9
12.4
11.9
11.9
12.0 0.722
σ (standard deviation), x̅ i (arithmetic mean), EU-28 (28 countries of European Union), CR
Republic), N. Maced. (North Macedonia), UK (United Kingdom)

̅xi
9.54
12.32
16.43
17.68
10.11
5.96
17.71
15.72
17.60
12.86
6.55
11.39
12.93
18.52
16.71
8.45
12.02
21.85
17.93
2.88
10.41
16.68
6.39
16.66
11.25
16.59
10.08
7.27
5.63
11.40
6.21
5.56
19.17
36.52
36.52
2.88
12.32
(Czech

The average value of the sub indicator (̅xi) of 28 European countries between 2007 and 2016 is 9.54% of total
inland passenger-km. These European countries have a lower sub indicator value than the EU-28 average value:
Lithuania (8.45%), Sweden (7.27%), France (6.55%), Portugal (6.39%), Norway (6.21%), Germany (5.96%), United
Kingdom (5.63%), Switzerland (5.56%) and Netherlands (2.88%). Other European countries have higher value than the


80
EU-28 average value.
The second analysed sub indicator is “Share of trains in total passenger transport”. The results are presented in
Table 2.
The value of the second sub indicator of 28 countries of European Union increased by 0.6 percentage point in
comparison years 2016 and 2007. Romania achieved the largest decline of sub indicator value between 2007 and 2016;
it was a decrease of 4.4 percentage points. A significant decrease in the sub indicator value between 2007 and 2016 was
also in these other countries: Croatia (- 2.3 percentage points), Bulgaria (- 2.2 percentage points), Hungary (- 1.7
percentage point) and Latvia (- 1.5 percentage point). Slovakia achieved the greatest increase of sub indicator value
between 2016 and 2007; it was a growth of 3.4 percentage points. A significant increase in the sub indicator value
between 2007 and 2016 was also in these other countries: Switzerland (+ 2.8 percentage points), United Kingdom
(+ 2.2 percentage points), Austria (+ 2.1 percentage points) and Czech Republic and Spain (+ 1.6 percentage point).
Romania has the highest standard deviation (1.352) between 2007 and 2016. This means that there were the
biggest fluctuations during the years 2007-2016 in the analysed sub indicator. On the other side, Estonia (0.145) has the
lowest standard deviation value of the analysed sub indicator. This means that Estonia has the most constant values.
Switzerland reached the highest sub indicator values in all analysed years (2007-2016). Lithuania reached the lowest
sub indicator values between 2007 and 2016, except 2014 when the lowest sub indicator value has Greece.
Table 2
Values of the indicator “Share of trains in total passenger transport”
(% of total inland passenger-km) [authors based on 17]
State
EU-28
Belgium
Bulgaria
CR
Denmark
Germany
Estonia
Ireland
Greece
Spain
France
Croatia
Italy
Cyprus
Latvia
Lithuania
Luxembourg
Hungary
Malta
Netherlands
Austria
Poland
Portugal
Romania
Slovenia
Slovakia
Finland
Sweden
UK
Iceland
Norway
Switzerland
N. Maced.
Turkey
Maximum
Minimum
Median
Explanatory
notes

̅xj
7.1
7.4
7.1
7.2
7.4
7.7
7.8
7.8
7.8
7.7 0.279
7.50
7.1
7.5
7.5
7.7
7.7
7.8
8.2
8.2
7.8
7.7 0.309
7.72
4.4
4.0
3.7
3.6
3.5
3.1
2.9
2.6
2.3
2.2 0.696
3.23
7.3
7.1
6.8
7.5
7.6
8.3
8.5
8.4
8.6
8.9 0.687
7.90
9.7
9.7
9.5
9.8
10.0
10.2
10.3
9.7
9.3
8.6 0.460
9.68
7.8
8.1
7.9
8.0
8.5
8.9
8.4
8.5
8.4
8.6 0.330
8.31
2.1
2.1
1.9
2.0
1.9
1.8
1.6
1.9
1.8
2.0 0.145
1.91
3.4
3.3
2.8
2.9
3.8
2.8
2.7
2.9
3.0
2.9 0.326
3.05
1.6
1.3
1.2
1.1
0.8
0.7
0.9
0.9
1.0
1.0 0.250
1.05
5.0
5.5
5.4
5.4
5.6
5.6
6.1
6.7
6.7
6.6 0.587
5.86
9.6
10.1
9.4
9.3
9.3
9.5
10.5
10.3
10.3
9.7 0.434
9.80
5.0
5.4
5.6
5.6
4.9
3.5
3.1
3.0
3.1
2.7 1.144
4.19
6.0
6.0
5.5
5.5
5.7
6.4
6.3
6.2
6.3
6.1 0.313
6.00
:
:
:
:
:
:
:
:
:
:
x
x
4.9
5.2
4.7
4.7
4.9
4.8
4.7
4.0
3.5
3.4 0.590
4.48
0.6
0.6
0.6
0.7
0.8
0.7
0.8
1.0
0.9
1.0 0.149
0.77
4.1
4.3
4.3
4.5
4.4
4.6
4.8
4.3
4.7
4.6 0.206
4.46
11.0
10.4
10.2
10.0
10.2
10.1
10.2
9.9
9.5
9.3 0.445 10.08
:
:
:
:
:
:
:
:
:
:
x
x
9.6
9.8
9.8
10.2
10.5
10.7
11.3
11.8
10.8
11.0 0.676 10.55
10.0
11.1
11.1
11.0
11.3
11.8
12.2
12.1
12.0
12.1 0.663 11.47
8.5
8.2
7.4
7.1
6.9
7.2
6.7
6.3
6.8
7.3 0.636
7.24
4.1
4.3
4.4
4.4
4.5
4.1
4.0
4.1
4.2
4.2 0.155
4.23
8.6
7.1
6.2
5.6
5.3
4.6
4.3
4.6
4.6
4.2 1.352
5.51
2.6
2.7
2.6
2.5
2.3
2.3
2.3
2.1
2.1
2.0 0.229
2.35
6.0
6.4
6.6
6.7
7.0
7.1
7.1
7.3
9.4
9.4 1.111
7.30
5.0
5.4
5.1
5.2
5.0
5.3
5.3
5.0
5.3
5.6 0.189
5.22
7.9
8.6
8.7
8.7
8.7
9.1
9.1
9.2
9.5
9.3 0.435
8.88
6.6
6.9
6.9
7.5
7.8
8.1
8.3
8.5
8.7
8.8 0.761
7.81
:
:
:
:
:
:
:
:
:
:
x
x
4.6
4.8
4.7
4.8
4.5
4.6
4.8
4.9
4.9
5.1 0.168
4.77
17.0
17.1
17.4
17.6
19.6
19.2
19.3
19.6
19.8
19.8 1.139 18.64
2.1
2.6
2.8
2.5
2.0
1.5
1.0
1.0
2.1
1.0 0.658
1.86
2.7
2.4
2.5
2.4
2.4
1.7
1.4
1.6
1.6
1.4 0.485
2.01
17.0
17.1
17.4
17.6
19.6
19.2
19.3
19.6
19.8
19.8 1.352 18.64
0.6
0.6
0.6
0.7
0.8
0.7
0.8
0.9
0.9
1.0 0.145
0.77
5.5
5.8
5.6
5.6
5.5
5.5
5.7
5.6
5.8
5.9 0.452
5.69
σ (standard deviation), x̅ j (arithmetic mean), EU-28 (28 countries of European Union), CR (Czech
Republic), N. Maced. (North Macedonia), UK (United Kingdom): (not available), x (not calculated)


The average value of the sub indicator ($\bar{x}_j$) of 28 European countries between 2007 and 2016 is 7.50% of total inland passenger-km. These European countries have a higher sub indicator value than the EU-28 average value: Belgium (7.72%), United Kingdom (7.81%), Czech Republic (7.90%), Germany (8.31%), Sweden (8.88%), Denmark (9.68%), France (9.80%), Hungary (10.08%), Netherlands (10.55%), Austria (11.47%) and Switzerland (18.64%). Other European countries have lower value than the EU-28 average value.

In the Figure 1 are presented average values (between 2007 and 2016) of analysed sub indicators only for countries with both available values. The Fig. 1 also indicates the average values of both sub indicators for 28 countries of European Union.

Five countries have higher values than the average values for 28 countries of European Union for both sub indicators: Hungary ($\bar{x}_i = 21.85$, $\bar{x}_j = 10.08$%), Austria ($\bar{x}_i = 10.41$, $\bar{x}_j = 11.47$%), Denmark ($\bar{x}_i = 10.11$, $\bar{x}_j = 9.68$%), Czech Republic ($\bar{x}_i = 17.68$, $\bar{x}_j = 7.90$%) and Belgium ($\bar{x}_i = 12.32$, $\bar{x}_j = 7.72$%). Only three countries have lower values than the average values for 28 countries of European Union for both sub indicators: Lithuania ($\bar{x}_i = 8.45$, $\bar{x}_j = 0.77$%), Croatia ($\bar{x}_i = 11.39$, $\bar{x}_j = 4.19$%) and Norway ($\bar{x}_i = 6.21$, $\bar{x}_j = 4.77$%). Lithuania, Croatia and Norway have a lower rail network length. Lithuania has a rail network length about 1 911 km, Croatia has 2 605 km and Norway has 4 134 km of rail network length [19]. For example, Czech Republic has the length of a railway network compared to these countries about 9 408 km and Hungary about 7 246 km [19].

In the Fig. 2 are presented average values of indicator “Share of busses and trains in total passenger transport” between 2007 and 2016 for countries with values less than 15% and higher than 20%; other countries have reached values close to the average value of the indicator.

Collective transport modes are widely used in Turkey, Hungary and the Czech Republic in comparison with individual passenger cars transport mode. The average value of analysed indicator is greater than 25% between 2007 and 2016 in Turkey (38.53%), Hungary (31.93%) and the Czech Republic (25.58%). On the other hand, there are many...
countries where the average value of the monitored indicator is less than 15%: Germany (14.27%), Slovenia (13.60%), United Kingdom (13.44%), Netherlands (13.43%), Iceland (11.40%), Norway (10.98%), Portugal (10.62%) and Lithuania (9.22%). Conversely, passenger cars transport is widely used in these countries.

4. Conclusions

The issue of the collective transport modes share in total inland passenger transport performance from the perspective of sustainable city logistics is very current, because individual passenger cars transport causes more negative environmental impacts per transported passenger compared with the collective transport modes. The aim of the article was to analyse the development of the indicator of selected European countries between 2007 and 2016 from the perspective of sustainable city logistics. This article was focused on the sub indicator named “Share of busses and trains in total passenger transport” which consists of two sub indicators – “Share of motor coaches, buses and trolley buses in total inland passenger transport performance” and “Share of trains in total inland passenger transport performance”.

The analysis showed that some countries use collective transport modes from 25% or more in the total inland passenger transport performance (Turkey, Hungary and the Czech Republic). On the other hand, Lithuania uses collective transport modes from less than 10% in the total inland passenger transport performance. However, this may be due to the quality and range of the rail and road transport network, the frequency of connections, fare prices, the quality of service provided and the quality of life in the country.

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References

Development of Rail Passenger Transport in the European Union

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Abstract

The aim of the article is to evaluate the development of rail passenger transport in the EU in the context of the plans put forward in the White Paper on European Transport Policy of 2011. The analysis of the statistical data leads to the conclusion that high speed rail and regional rail services, including agglomeration transport, are the only developing segments of the railway passenger market, while the interregional carriages on conventional routes suffer decline. Opportunities to reverse this trend and thus meet transport policy objectives lie in a significant improvement in the quality of rail transport services offered, mainly in terms of reducing overall door-to-door travel time and its reliability. The integration of rail passenger transport into the wider public transport systems is another necessary measure.

KEY WORDS: transport policy goals, rail passenger services, transport performance EU, high speed rail.

1. Introduction

An efficient transport system is one of the basic sectors of the well-functioning economy and an important component of life quality. Economic development entails an increase in transportation needs in the transport of goods and people, putting new requirements for ensuring the smooth flow of goods and mobility of people. At the same time, transport has a negative impact on the environment, contributing to climate change and global warming. Halting these changes has become a challenge for the present generation.

In the European Union, transport currently accounts for around a quarter of total greenhouse gas emissions [1]. Assuming a moderate economic growth over the long term, it is predicted that between 2010 and 2050 there will be an increase in demand for passenger transport of approximately 42% and for freight of 60% between 2010 and 2050 [2]. Reconciling the need for economic development and halting environmental degradation requires a shift in the EU transport system towards an environmentally friendly system. Rail transport, which has much lower external costs than road or air transport and a large and, in addition, underutilized transport potential, can play an important role in such a system. Increasing the share of rail in meeting the transport needs of the economy and society is one of the permanent priorities of the European Union's transport policy. Some measures in this direction were also indicated in the 2011 White Paper on Transport Policy [3]. The aim of the article is to assess the development of rail passenger transport in the EU in the context of the effectiveness of political and financial support provided to railways.

2. A Vision for Railways in the European Transport Policy Programs

A consistent policy to strengthen rail transport has been one of the priorities of European transport policy since the early 1990s. In the initial period, rail policy focused on three areas which created the conditions for the efficient and effective functioning of railway undertakings. They were:

– creation of a common railway market (through deregulation and liberalization);
– restructuring and revision of the functioning of state-owned railways;
– modernization of the railway infrastructure.

The measures taken led to the elimination of barriers to rail transport between EU Member States, to clear development of the supply side of the railway market and the emergence of new, also private carriers. These changes were accompanied by investments in railway infrastructure, also funded by large amounts of EU funds. These achievements are indisputable progress in the modernization of institutional structures and turn close this branch of the transport requirements of modern economies. However, in relation to the volume of freight, rail policy effects are rather moderate, although varied in different EU countries.

Key actions identified in the White Paper of 2011 is bringing structural changes to the end of the railway sector and the realization of investments to increase network bandwidth. In particular, these are the following:

– tripling the length of the existing high-speed rail network by 2030;
– maintaining a dense conventional rail network in all Member States of the European Union;
– increasing the capacity and improving the quality of railway network;
– integrating railways into the multimodal urban travel and transport network by better integrating all forms of public transport, including the transformation of transport points (airports, stations, stations, ports) into multimodal
connection platforms;
- development of multimodal internet information, electronic reservation and payment systems by 2020.

The 2011 White Paper program also sets specific transport objectives for rail transport, including the takeover by rail of the majority of passenger traffic over medium distances by 2050. An important action in relation to passenger transport is the integration of railways in public transport systems. This is not a new direction. The developed concept of integrating all forms of passenger transport in all possible areas was already presented by the European Commission in 1995 in the Green Paper on a Citizens’ Network [4]. In order to support these measures, the introduction of extended and more precise ex-ante evaluation criteria for projects was announced, which will guarantee selection for implementation only of projects bringing real economic and social benefits. This may mean opportunities for less capital-intensive projects, but yielding desirable effects, such as the integration of conventional rail into other public transport systems or behavioral changes, to stimulate demand for public transport.

3. Passenger Transport on High-Speed Railway Lines

In the overall volume of rail passenger transport, several segments are distinguished according to the needs served, coverage and technical solutions: urban and agglomeration transport, regional transport and interregional transport. In the inter-regional transport segment carriage is further provided on the conventional lines on lines newly built for this purpose with speeds exceeding 250 - 300 km/h (HSR - high speed rail). The first such lines in the EU were built in 1985 in France and Italy. By the year 2000, the construction of HSR lines in Germany, Spain and Belgium had been commenced. In 2000, the total length of high speed railway lines was 2707 km. The first decade of the 21st century saw a dynamic acceleration in the construction of new lines and the consequent doubling of their length. In 2010, high speed railway lines were in operation on the territory of the 7 EU Member States, and have a total length of 6348 km. Other countries which started operating the HSR lines are: Austria (2013) and Poland, and in Denmark the construction of such a line is underway [5]. The length of HSR lines in operation and under construction in the EU is presented in Table 1.

Table 1

<table>
<thead>
<tr>
<th>High-speed railway lines [km]</th>
<th>Lines in use [km]</th>
<th>Under construction [km]</th>
<th>Start of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1001</td>
<td>2707</td>
<td>6348</td>
</tr>
<tr>
<td>FR</td>
<td>717</td>
<td>1290</td>
<td>1912</td>
</tr>
<tr>
<td>IT</td>
<td>194</td>
<td>238</td>
<td>856</td>
</tr>
<tr>
<td>DE</td>
<td>90</td>
<td>636</td>
<td>1272</td>
</tr>
<tr>
<td>ES</td>
<td>-</td>
<td>471</td>
<td>1866</td>
</tr>
<tr>
<td>BE</td>
<td>-</td>
<td>72</td>
<td>209</td>
</tr>
<tr>
<td>UK</td>
<td>-</td>
<td>-</td>
<td>113</td>
</tr>
<tr>
<td>NL</td>
<td>-</td>
<td>-</td>
<td>120</td>
</tr>
<tr>
<td>AT</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PL</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DK</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The data in the table indicate that HSR lines are operated mainly in the countries of the "old" EU, while in the countries that acceded to the Community in 2004 and later is only one such line. In relation to the entire rail network, these lines represent less than 4% of the length. In the near future the situation will not fundamentally change, since the construction of new high-speed lines in the greatest extent is conducted only in Spain and to a lesser extent in other countries, continuing the expansion of existing networks. New, longer lines are being built only in Austria and Denmark. After completion of construction in 2029, the length of the HSR network in the EU will be 10,110 km.

Only two types of data on rail passenger transport are available in the statistics collected by Eurostat: high-speed and total. High-speed services include services performed by high-speed rolling stock, e.g. tilting trains, travelling at speeds of 200 km/h, not necessarily on infrastructure built for high speeds. Subject to this disclaimer, high speed transport is carried out in 13 EU countries, in addition to those mentioned above (without Austria) also in the Czech Republic, Portugal, Slovenia, Finland and Sweden. The HSR transport segment is developing dynamically. In 2010, the HSR transport segment accounted for 26.2% of the total rail passenger transport in the EU, and in 2016 it was already 35.2%.

The largest volume of HSR transport is carried out in France. The HSR performance in 2016 amounted to 50.54 billion pas.km, which constituted over 43% of the total rail performance. Apart from France, the leaders of high speed rail transport in the EU include Germany (27.21 billion pkm), Spain (15.1) and Italy (12.74). In total, high speed rail transport in these four countries accounted for 90% of the total HSR transport, accounting to 105.6 billion pkm (Table 2).
The development of rail passenger transport in selected EU countries [5]

<table>
<thead>
<tr>
<th></th>
<th>DE</th>
<th>Rail other</th>
<th>HSR</th>
<th>FR</th>
<th>Rail other</th>
<th>HSR</th>
<th>ES</th>
<th>Rail other</th>
<th>HSR</th>
<th>IT</th>
<th>Rail other</th>
<th>HSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td></td>
<td>61,5</td>
<td>13,9</td>
<td></td>
<td>35,1</td>
<td>34,6</td>
<td></td>
<td>18,2</td>
<td>1,9</td>
<td></td>
<td>44,5</td>
<td>5,1</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td>59,1</td>
<td>23,9</td>
<td></td>
<td>34,0</td>
<td>51,9</td>
<td></td>
<td>10,7</td>
<td>11,7</td>
<td></td>
<td>35,7</td>
<td>11,6</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td>68,6</td>
<td>27,2</td>
<td></td>
<td>37,3</td>
<td>50,5</td>
<td></td>
<td>11,6</td>
<td>15,1</td>
<td></td>
<td>39,4</td>
<td>12,8</td>
</tr>
<tr>
<td>% Change 2010-16</td>
<td></td>
<td>16,1</td>
<td>13,8</td>
<td></td>
<td>9,7</td>
<td>-2,7</td>
<td></td>
<td>8,4</td>
<td>29,1</td>
<td></td>
<td>10,4</td>
<td>10,3</td>
</tr>
</tbody>
</table>

The market success of high speed rail is undoubtedly connected with a huge quality leap in the railway offer, primarily with a significant reduction in travel time within the range of average distances of 300 - 500 km. High-speed rail travel has become an attractive alternative to air transport, so a significant part of HSR passengers are customers taken over from air transport. Some of the passengers have also been taken over from conventional railways, as shown by the decrease in traffic between 2000 and 2010 in all four countries that are leaders in HSR development. After 2010 this trend was reversed and transport on conventional lines grew even faster than on HSR lines.

![Graph](image)

Fig. 1 The development of rail passenger transport in the EU in the years 1995 - 2016 [5]

The superior quality of transport services provided on HSR lines is reflected in significantly higher dynamics of development of this segment (Fig. 1).

4. Passenger Rail Transport Except HSR

Railways operate in 26 EU countries, except Cyprus and Malta. In 2010-16 there was an increase in rail passenger transport in 16 countries. The data in Table 3 illustrate changes in countries with HSR network, but without HSR transport. Rail passenger transport in these countries accounts for 91% of total rail transport (except HSR) in the EU.

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2010</th>
<th>2016</th>
<th>% Change 2010-2016</th>
<th>% Under PSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>312,7</td>
<td>301,4</td>
<td>332,98</td>
<td>10,5</td>
<td>64,2</td>
</tr>
<tr>
<td>BE</td>
<td>6,8</td>
<td>9,5</td>
<td>8,5</td>
<td>-10,5</td>
<td>-</td>
</tr>
<tr>
<td>CZ</td>
<td>7,3</td>
<td>6,3</td>
<td>8,0</td>
<td>27,0</td>
<td>95,0</td>
</tr>
<tr>
<td>DE</td>
<td>61,5</td>
<td>60,0</td>
<td>68,6</td>
<td>14,3</td>
<td>58,5</td>
</tr>
<tr>
<td>ES</td>
<td>18,2</td>
<td>16,8</td>
<td>11,6</td>
<td>-30,1</td>
<td>43,0</td>
</tr>
<tr>
<td>FR</td>
<td>34,6</td>
<td>33,7</td>
<td>37,3</td>
<td>10,7</td>
<td>38,0</td>
</tr>
<tr>
<td>IT</td>
<td>44,5</td>
<td>35,6</td>
<td>39,4</td>
<td>10,7</td>
<td>56,6</td>
</tr>
<tr>
<td>NL</td>
<td>14,6</td>
<td>16,6</td>
<td>17,6</td>
<td>6,0</td>
<td>-</td>
</tr>
<tr>
<td>PL</td>
<td>24,1</td>
<td>17,9</td>
<td>17,8</td>
<td>-0,8</td>
<td>85,4</td>
</tr>
<tr>
<td>PT</td>
<td>4,0</td>
<td>3,6</td>
<td>3,7</td>
<td>2,7</td>
<td>-</td>
</tr>
<tr>
<td>FI</td>
<td>3,3</td>
<td>3,4</td>
<td>3,3</td>
<td>-3,0</td>
<td>97,0</td>
</tr>
<tr>
<td>SE</td>
<td>6,15</td>
<td>8,26</td>
<td>9,32</td>
<td>12,8</td>
<td>49,4</td>
</tr>
<tr>
<td>UK</td>
<td>38,4</td>
<td>54,79</td>
<td>65,2</td>
<td>19,0</td>
<td>97,0</td>
</tr>
<tr>
<td>AT</td>
<td>8,7</td>
<td>10,3</td>
<td>12,6</td>
<td>22,3</td>
<td>69,4</td>
</tr>
</tbody>
</table>
In the period under examination since 2000, rail passenger transport has shown a higher growth rate than total passenger transport by all means in the EU, which is an expected effect in the light of transport policy. In the period 2000-2010, when the HSR line length more than doubled, HSR rail transport developed and conventional lines decreased by 3.6% (Table 4).

### Table 4

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger transport [billion pkm]</td>
<td>5 763,5</td>
<td>6 208,3</td>
<td>6 650,1</td>
<td>7,7</td>
<td>7,1</td>
</tr>
<tr>
<td>Railways total [billion pkm]</td>
<td>371,5</td>
<td>407,3</td>
<td>450,1</td>
<td>9,6</td>
<td>10,5</td>
</tr>
<tr>
<td>Railways share [%]</td>
<td>6,4</td>
<td>6,6</td>
<td>6,8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EU HSR [billion pkm]</td>
<td>58,8</td>
<td>105,87</td>
<td>117,12</td>
<td>80,0</td>
<td>10,6</td>
</tr>
<tr>
<td>EU Rail other [billion pkm]</td>
<td>312,7</td>
<td>301,4</td>
<td>332,98</td>
<td>-3,6</td>
<td>10,5</td>
</tr>
<tr>
<td>HSR share [%]</td>
<td>15,8</td>
<td>26,0</td>
<td>35,2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger cars [billion pkm]</td>
<td>4 301</td>
<td>4 626</td>
<td>4 829</td>
<td>7,6</td>
<td>4,4</td>
</tr>
<tr>
<td>Passenger cars share [%]</td>
<td>74,6</td>
<td>74,5</td>
<td>72,6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air domestic [billion pkm]</td>
<td>460</td>
<td>535</td>
<td>713</td>
<td>16,3</td>
<td>33,3</td>
</tr>
<tr>
<td>Air share [%]</td>
<td>8,0</td>
<td>8,6</td>
<td>10,7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

However, between 2010 and 2016, these trends were reversed. The increase in transport performance on conventional railways was much higher at 31.6 billion pkm compared to 11.25 billion pkm on HSR lines. The volume of transport in both segments increased by approx. 10%, and as a result the share of rail in the total passenger transport market slightly increased from 6.6 to 6.8% (Table 4). Probably the reason for these changes may be an increase in demand in the segment of agglomeration rail transport related to urbanisation processes. In the conditions of growing road traffic, agglomeration railways are an attractive alternative to daily commuting. In conclusion, both segments of the rail passenger market included in the statistics show positive development dynamics in recent years. However, the available data do not allow for a precise assessment of the development of each segments of rail transport on conventional lines.

Short travel times, achieved through high speeds, are undoubtedly a great advantage of the HSR railways, which speaks in favour of their development, but this will depend on the availability of sufficient funds. As the European Commission points out, investment expenditures on the development of transport infrastructure amounting to 2.7% of GDP in 2016 are the lowest in 20 years [6]. This also has a negative impact on the maintenance of the existing railway network. Data analysis shows that the conventional rail network in the EU is shrinking. Since 2010, the length of the rail network has decreased in fourteen EU countries, remained unchanged in six, and increased in only six. The data in Table 5 illustrate the changes in the length of the rail network in selected EU countries.

### Table 5

<table>
<thead>
<tr>
<th>EU</th>
<th>Lines in use [km]</th>
<th>% Change</th>
<th>Decrease</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>UE-28</td>
<td>220 022</td>
<td>217 081</td>
<td>-1,3</td>
<td>0,7</td>
</tr>
<tr>
<td>BE</td>
<td>3 582</td>
<td>3 607</td>
<td>-0,7</td>
<td>0,7</td>
</tr>
<tr>
<td>DK</td>
<td>2 606</td>
<td>2 539</td>
<td>-2,6</td>
<td>3,5</td>
</tr>
<tr>
<td>DE</td>
<td>37 679</td>
<td>38 990</td>
<td>-3,5</td>
<td>0,5</td>
</tr>
<tr>
<td>ES</td>
<td>15 837</td>
<td>15 922</td>
<td>-0,7</td>
<td>0,5</td>
</tr>
<tr>
<td>FR</td>
<td>30 335</td>
<td>28 364</td>
<td>-6,5</td>
<td>0,4</td>
</tr>
<tr>
<td>IT</td>
<td>17 022</td>
<td>17 096</td>
<td>-0,4</td>
<td>0,5</td>
</tr>
<tr>
<td>NL</td>
<td>3 013</td>
<td>3 058</td>
<td>-0,5</td>
<td>0,5</td>
</tr>
<tr>
<td>AT</td>
<td>5 039</td>
<td>4 917</td>
<td>-2,4</td>
<td>0,5</td>
</tr>
<tr>
<td>PL</td>
<td>19 702</td>
<td>18 429</td>
<td>-6,5</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>16 175</td>
<td>16 253</td>
<td>-0,5</td>
<td></td>
</tr>
</tbody>
</table>

The largest decrease in the length of the rail network occurred in France and Poland, while the largest increase occurred in Germany, where the rail network is still the longest in the EU.

### 5. Conclusions

Despite political and financial support, the development of rail passenger transport in the European Union is showing weak dynamism. All segments of rail passenger transport require substantial public support. High-speed rail requires investment in new lines and rolling stock, regional and agglomeration railways need support for an attractive,
regular and relatively low-cost offer, and low-burden lines generate a deficit. This situation puts public budgets in a difficult position, especially in view of the need to develop infrastructure for alternative fuels and adapt new mobility patterns [6]. As a result, rail transport growth is mainly observed in countries with a high level of economic development, which are able to devote significant funds to the development of HSR system and to subsidising other segments of rail transport.

In order to strengthen the role of the railway, it is crucial to generate a high demand for its services. It is important that both high-speed and conventional lines are sufficiently exploited. Poor use of certain lines will lead to difficulties in maintaining and upgrading the whole network. It will therefore be difficult to maintain the current density of the conventional lines network, contrary to the vision of rail transport adopted in the European transport policy agenda. There are opportunities to attract passengers by increasing the utility of rail service, defined by three factors: speed, reliability and cost. Speed should be considered in terms of the entire door-to-door journey time and not only as the speed of travel.

The aim should be to increase the speed and comfort of travel, e.g. through access to dynamic information, better connected trains, improved transfer between sections of the journey, combining the rail offer with new mobility models, such as On-Demand-Transport, car- and bike-sharing, ride-hailing. These are measures aimed at integrating railways with other public transport systems, which is in line with the White Paper's proposals. A modern, integrated transport system, well serving societal needs, is not only an objective of EU transport policy, but should also be the subject of a broader discussion among scientists, practitioners and customers.

References

Psychographic Sources of Car Brands Pricing Strategies

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Abstract

Contemporary market reality indicates that traditional economic theories are failing and there is a need to replace them by a behavioural approach that includes both, sociological and psychological aspects of the examined economic phenomena. While for some areas of economic theory and practice is such an approach innovative, in other areas it is experiencing its renaissance. Such a renaissance also takes place within the brand management that stresses the behavioural approach across all its theoretical concepts. Therefore, there is a need to provide revision of traditional strategic concepts with emphasis on behavioural approach. Up to now, the theory has been limited mainly to state this and to avoid from the exact detection of specific brand value sources in conditions of particular nations and product categories. So, the aim of this paper is to identify relevant brand value sources which are significant for Slovak socio-cultural profile and to propose an effective innovative model of brand value building and management focusing on case study of car brands. The data used in the presented study were obtained by our own survey carried out on the sample of 2000 respondents (citizens of the Slovak Republic older than 15 years). We’ve statistically evaluated the given data by the so-called factor analysis supported by implementation of KMO Test, Barlett's test of sphericity and calculation of Cronbach's Alpha for relevant car brands value sources with significant impact on their pricing strategy. We have found out that specifics of the national socio-cultural profile affect the priority of the components of subjectively perceived brand value sources. The importance of brand value sources has been identified as following: 1) benefits; 2) imageries; 3) attitudes and 4) attributes. So, we can conclude that optimal pricing strategy of car brands should be set on the basis of the main competitive advantage of car brand – i.e. on subjectively perceived benefits and not on quality as a main car brand attribute from traditional point of view.

KEY WORDS: brand, brand value, car brand, pricing, pricing strategy, psychographic aspects.

1. Introduction

The schism between image and quality is present in day to day brand management theory and practice. Traditionally, this schism is considered as a consequence of bipolar construction of world economies during 20 century [1]. Thus, according to Pitra and Zauskova, image has been connected with brand value building in western brand schools while quality has been unified with brand schools from eastern (nowadays also so called transforming) economies [2]. This situation has caused that brand management is very challenging issue even for experienced managers who are operating on markets which are characterized by their post-soviet nature. Paradoxically, the need of revising contemporary managerial practice is bigger in big multinational corporations who manage and build world known brands. It is in contrast with traditional postulates of management where it is supposed that managers of small and medium enterprises are competitively handicapped due to the lack of experience. Here, on the contrary, the size of company can be mostly considered as competitive (dis)advantage. The reason is that the brand built by such a company usually operates on a smaller market where the managers are more oriented in business micro and macro environment [3]. Thus, also the practice of brand management is more focused on the regional specifics and that’s why also brand identity can be built homogenously [4, 5]. In case of large companies, operating on international market, this is rather impossible. The main reason are regional specifics which have to be accepted by brand managers in the process of brand value building and managing. We refer to the identification of negative correlation between size of the company and heterogeneity of brand identity provided recently by various authors [6, 7]. Majercak et al. stated that bigger the company is in scope of its cross border market operation, bigger is the risk of applying global branding activities [8]. It means that the respect towards regional specifics is an imperative of effective brand value building and management. On the one hand, this fact is well known but on the other hand its implementation into managerial practice is not a rule – mainly in such a managerial tasks which are demanding in scope of reflecting psychographic specifics of the selected market [9, 10]. Thus, the requirements for brand managers of large companies are not only of economic but also psychologic and sociologic nature. Only in this way, behavioral specifics of consumer's buying decision on selected market can be identified and appropriately implemented in practice of brand management to maximize brand value subjectively perceived by consumers [11].

In contrast with traditional schism between western image concept and eastern quality concept of brand value from the regional point of view, it has been highlighted the existence of such a schism even across markets from
product point of view [12, 13]. Akdeniz and Calantone focused on the examination of the impact of a quality perception gap on brand performance and its moderating role in the relationship between marketing-mix signals and performance in US automotive industry. They found out that the relationship between the quality perception gap and brand performance has an inverted U-shape and that except for advertising, the impact of marketing signals on performance is higher when the quality of a brand is perceived as higher than its actual quality. Basic assumption of their research has been that a quality perception gap, defined as the difference between perceived and objective quality, indicates either consumers' over appreciation or under appreciation of product or brand quality and can have critical effects on brand performance [14].

This study can be considered as detailed elaboration of Hanaysha who has stated that service quality has a significant positive effect on brand equity in Malaysian automotive market. Furthermore, this author has found that services quality has a significant positive effect on all dimensions of brand equity: brand awareness, brand loyalty, brand image and brand leadership [15]. Doing this, it has been created platform for future research of brand value sources across markets (not only in regional but also in product meaning), focusing on the Aaker's concept of brand value dimensions [16].

Trend of inclination to the consideration of regional psychographic specifics in brand management is visible also in researches provided by Adetunji at al. who have focused on implications of regional psychographic market specifics in communication activities of car brands on social media platforms [17]. Similarly, cross cultural aspects of car brand's communication policies have been analyzed by Strebinger et al. [18]. The importance of automotive industry as a pilot market for research of gap between image and quality regarding to the regional psychographic specifics has been stated also by Karlsson and Skold who identify areas and issues for management to consider in balancing specialization and communalization in large manufacturing corporations with multiple brands from a strategic research and development and manufacturing point of view [19].

2. Methods and Data

The data used in the presented study were obtained by our own survey carried out on the sample of 2000 respondents. The questionnaire survey was conducted using the method CAWI (Computer Assisted Web Interviewing) by an external agency in the first quarter of 2019 year. The main surveyed population was the population of the Slovak Republic aged over 15 years (acquiring legal personality according to valid Slovak legislation). The reason for such a limitation was the requirement to ensure the autonomy of purchasing decisions and the real mirroring of the value of the brand in the economic behavior of the Slovak population. The structure of the surveyed sample was socio-demographically representative.

In the light of the marketing implications of the questionnaire survey, we have compiled a questionnaire and filled the brand value sources (imageries, attitudes, attributes and benefits) with each relevant component [20]. These are summarized in Table 1.

<table>
<thead>
<tr>
<th>Brand value sources</th>
<th>Components of brand value sources / Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>imageries</td>
<td>prestige / 1</td>
</tr>
<tr>
<td></td>
<td>modernity / 2</td>
</tr>
<tr>
<td></td>
<td>certainty / 3</td>
</tr>
<tr>
<td></td>
<td>pleasure / 4</td>
</tr>
<tr>
<td>attitudes</td>
<td>I aim to buy branded products / 5</td>
</tr>
<tr>
<td></td>
<td>I am interested in branded products on a regular basis / 6</td>
</tr>
<tr>
<td></td>
<td>branded products attract my attention because I consider them better / 7</td>
</tr>
<tr>
<td></td>
<td>branded products attract my attention because I consider them more prestigious / 8</td>
</tr>
<tr>
<td>attributes</td>
<td>image / 9</td>
</tr>
<tr>
<td></td>
<td>quality / 10</td>
</tr>
<tr>
<td></td>
<td>popularity / 11</td>
</tr>
<tr>
<td></td>
<td>modernity / 12</td>
</tr>
<tr>
<td></td>
<td>creativity of ad / 13</td>
</tr>
<tr>
<td>benefits</td>
<td>it makes me happier / 14</td>
</tr>
<tr>
<td></td>
<td>it increases my social status / 15</td>
</tr>
<tr>
<td></td>
<td>it makes it easier for me to get friends / 16</td>
</tr>
<tr>
<td></td>
<td>it attracts the attention of others / 17</td>
</tr>
<tr>
<td></td>
<td>it belongs to my lifestyle / 18</td>
</tr>
</tbody>
</table>

Source: own processing

Brand value sources subjectively perceived by Slovak consumers in automotive industry (based on the Likert's
scale) were statistically evaluated using factor analysis. Factor analysis is a multidimensional statistical method aimed at creating new unobservable variables, the so-called factors, which reduce and simplify the original number of data while retaining a substantial portion of the information. The linear combination of factors approximates the original observation, capturing the hidden relationships between the original variables [21]. In the last decades, the use of this method has grown in the sphere of social sciences, mainly through the development of information technology and the reduction of subjective interventions [22]. The starting point for this analysis is the definition of the statistical model and the determination of rational assumptions. To determine the factors, it is necessary first to examine the dependencies between the original variables using the covariance or correlation matrix. The condition for performing the data reduction is the correlation of the original variables resulting from the matrix and the assumption that found correlation arises due to the existence of a smaller number of undetected hidden variables, the so-called factors. Consequently, it is possible on the basis of mutual relationships to diversify the original variables into subgroups where variables within one group correlate more than with the variables of the other groups [23, 24]. To determine the adequacy of the statistical sample, we’ve used the KMO (Kaiser – Meyer – Olkin) test where the adequacy of a statistical sample can be determined when the resulting test value is greater than 0.6. Barlett's test of sphericity has been used to determine the degree of dependence between variables. Its resulting value should be less than 0.05. The intrinsic consistency of the factors has been verified by the so-called Cronbach's Alpha.

Based on the results of factor analysis, we’ve been able to determine the order between the individual brand value sources in case of car brands and to formulate conclusions that can be used in the practice of brand value building and managing across products and markets.

3. Results and Discussion

KMO (Kaiser – Meyer – Olkin) test indicated the sampling adequacy (> 0.6) as it has reached a value of 0.934. Barlett's test of sphericity identified dependence between variables (< 0.05) by acquiring the resulting value at 0.00. We have demonstrated the relevance of four relevant factors.

The testimonial value of factor analysis has reached a value of 71,662 % (see Table 2).

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial Eigenvalues</th>
<th>Extraction Sums of Squared Loadings</th>
<th>Rotation Sums of Squared Loadings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% of Variance</td>
<td>Cumulative</td>
</tr>
<tr>
<td>3</td>
<td>1.270</td>
<td>7.054</td>
<td>66.628</td>
</tr>
<tr>
<td>4</td>
<td>.906</td>
<td>5.034</td>
<td>71.662</td>
</tr>
<tr>
<td>5</td>
<td>.748</td>
<td>4.157</td>
<td>75.819</td>
</tr>
<tr>
<td>6</td>
<td>.581</td>
<td>3.228</td>
<td>79.047</td>
</tr>
<tr>
<td>7</td>
<td>.468</td>
<td>2.599</td>
<td>81.646</td>
</tr>
<tr>
<td>8</td>
<td>.421</td>
<td>2.341</td>
<td>83.986</td>
</tr>
<tr>
<td>9</td>
<td>.368</td>
<td>2.046</td>
<td>86.032</td>
</tr>
<tr>
<td>10</td>
<td>.359</td>
<td>1.996</td>
<td>88.028</td>
</tr>
<tr>
<td>11</td>
<td>.340</td>
<td>1.887</td>
<td>89.915</td>
</tr>
<tr>
<td>12</td>
<td>.315</td>
<td>1.748</td>
<td>91.663</td>
</tr>
<tr>
<td>13</td>
<td>.303</td>
<td>1.685</td>
<td>93.348</td>
</tr>
<tr>
<td>14</td>
<td>.291</td>
<td>1.615</td>
<td>94.962</td>
</tr>
<tr>
<td>15</td>
<td>.267</td>
<td>1.483</td>
<td>96.445</td>
</tr>
<tr>
<td>16</td>
<td>.230</td>
<td>1.277</td>
<td>97.722</td>
</tr>
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<td>17</td>
<td>.217</td>
<td>1.207</td>
<td>98.929</td>
</tr>
<tr>
<td>18</td>
<td>.193</td>
<td>1.071</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Source: own processing

For individual components of brand value sources has been verified their grouping on factor analysis - i.e. imageries with Cronbach's Alpha value 0.854, attitudes with Cronbach's Alpha value 0.840, attributes with Cronbach's Alpha value 0.868 and benefits with Cronbach's Alpha value 0.873. It has been shown that the inclusion of these components is variant: 1) "prestige" into a group of factors "benefits" resp. "imageries"; 2) "image" into a group of factors "benefits" resp. "attributes"; 3) "modernity" into a group of factors "imageries" resp. "attributes"; 4) "creativity of ad" into a group of factors "benefits" resp. "attributes"; 5) "it makes me happier" into a group of factors "benefits" resp. "imageries". For more detailed information, see Table 3.
Rotated component matrix

<table>
<thead>
<tr>
<th>Code</th>
<th>Brand value source</th>
<th>Benefits</th>
<th>Imageries</th>
<th>Attitudes</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>.509</td>
<td>.499</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>.767</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>.871</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>.890</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
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<td>.823</td>
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<td>.724</td>
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<td>8</td>
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<td>.650</td>
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<td>9</td>
<td></td>
<td>.604</td>
<td>.507</td>
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<td>.524</td>
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<td>.681</td>
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<td>14</td>
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<td>.557</td>
<td>.427</td>
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<td></td>
</tr>
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<td>15</td>
<td></td>
<td>.814</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>.808</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>.752</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>.647</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: own processing

On the basis of rotated component matrix it is possible to create a ranking of brand value sources depending on their impact on consumers subjectively perceived brand value. This order is as follows: 1) benefits; 2) imageries; 3) attitudes; 4) attributes (see Table 4).

<table>
<thead>
<tr>
<th>Factors</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imageries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitudes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attributes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N of Items</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Cronbach's Alpha</td>
<td>0.873</td>
<td>0.854</td>
<td>0.840</td>
<td>0.868</td>
</tr>
<tr>
<td>% of Variance</td>
<td>46.947</td>
<td>12.626</td>
<td>7.054</td>
<td>5.034</td>
</tr>
</tbody>
</table>

Source: own processing

Provided factor analysis has shown that specifics of the national socio-cultural profile affect the priority of the components of subjectively perceived brand value sources. While traditionally, it has been discussed if the dominant source of car brand value is quality or image, it has been proven that in conditions of Slovak republic, both these attributes are clustered in one factor – attributes, and this factor has not significant impact on brand value subjectively perceived by consumers. On the contrary, this factor is the less important among all four factors, because the importance of brand value sources has been identified as following: 1) benefits; 2) imageries; 3) attitudes and 4) attributes. So, we can conclude that optimal pricing strategy of car brands should be set on the basis of the main competitive advantage of car brand – i.e. on subjectively perceived benefits (increase of social status, facilitation of making friends, attraction of attention of others, belonging to the lifestyle) and not on quality or image as a main car brand attributes from traditional point of view.

4. Conclusions

The need to provide revision of traditional strategic concepts with emphasis on behavioral approach has been the leading motive to provide analysis of consumer's perception of brand value sources. The data used in the presented study were obtained by our own survey carried out on the sample of 2000 respondents (citizens of the Slovak Republic older than 15 years). We’ve statistically evaluated the given data by the factor analysis supported by implementation of KMO Test, Barlett's test of sphericity and calculation of Cronbach's Alpha for relevant car brands value sources with significant impact on their pricing strategy. We have found out that specifics of the national socio-cultural profile affect the priority of the components of subjectively perceived brand value sources because the importance of brand value sources has been in specific conditions of Slovak republic identified as following: 1) benefits; 2) imageries; 3) attitudes and 4) attributes. So, we can conclude that optimal pricing strategy of car brands should be set on the basis of the main competitive advantage of car brand – i.e. on subjectively perceived benefits (increase of social status, facilitation of making friends, attraction of attention of others, belonging to the lifestyle) and not on quality or image as a main car brand attributes from traditional point of view.
competitive advantage of car brand – i.e. on subjectively perceived benefits like increase of social status, facilitation of making friends, attraction of attention of others, belonging to the lifestyle. Thus, in scope of traditional trigonal concept of pricing where consumers form one of its pillars, it is vital to take into account mainly perceived benefits as a way how to move reference prices higher on the basis of subjectively valuable brand’s existence.

Acknowledgement

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References

Optimization of Transport Service of Linear Railway Networks

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Abstract

This paper is mainly focused on the passenger rail public transport systems, which are really important in transport service of the regions. It concentrates on the definitions of the nodal regions. It is possible to observe typical transport relationships in those regions and also fit the public transport offer on main railway axis to these relationships. The paper presents optimization tool for operation of linear railway network. This tool is based on linear mathematic programming. Output of this tool is optimal line routing, which considers typical transport demand and general operational costs of the system.

KEY WORDS: areal transport services, linear programming, network, optimization, rail transportation, railway, region

1. Introduction

Satisfying transport needs of inhabitants (existential and social) in area depends on the transport system, which creates transport network for vehicles. Those needs can come out from the difference between the places where the needs emerge and where it can be satisfied. Mutual relationship is derived from sociodemographic attributes of the inhabitants and technical and operational attributes of transport system. This relationship leads to the balance between the transport demand and the offer. Research of this relationship is really complicated and almost always branches into partial solutions in segment of transport or certain area (region). The issue of this article is mainly about railway transport, which provides transport service of the area with simply defined linage between the centre and the region. There is a strong relationship between infrastructure and vehicle in railway transport. Railway operation is also highly organized, and it excels in safety. Really important for transport service of a region is the linear character of railway lines.

Railway transport could be a right solution of the problem of searching for effective and sustainable way of the area transport service. It is necessary to find out in which technical and operational areas is possible to develop its potential and provide auxiliary and decision-making tools. Main output of this article is a design of optimization model of linear railway network. The model is optimizing line routing on the railway linear network, where it considers basic technical and the operational architecture of the system (transport offer) and serviced transport relationships (transport demand). Basic criterion is the general operational cost of operation of such system.

2. Linear Railway Network and its Transportation Services

2.1. Transport Relationships in Regions and Suburbs

To understand the meaning of linear railway networks, it is important to define the term “region” first. That means to define certain transport relations, group of areas and its attributes – with focus on structure and type of the railway lines, which can provide their transport service. There are more definitions of the word region. In general, it is an area which is defined by the results of mutual relationships between natural and social elements [1]. According to the form can be distinguish:

1. homogenous regions;
2. heterogeneous regions (nodal, gradient);
3. planning regions.

Heterogeneous regions have certain kind of inside dependence that means that they are connected by intensive relationships. Important examples of heterogeneous regions are nodal regions. Their heterogeneity is expressed by different kinds of flows. Those are realised according to the move of people, goods, information or energy. The main assumption for defining a nodal region is the existence of the core (nodus, focus), that can be described as the communication centre of the whole region. It is an area, which is surrounded by region (suburb) and creates certain demand. Suburbs of the node are responding to this demand by its flows. Function and importance of the nodes are mainly influenced by its position in the region in relationship to the transport systems. To define the region in terms of transport we have to observe typical transport relationships and planning of transport offer.
Typical examples of nodal regions [2] are: commuting regions, migration regions, gradient regions of service facilities etc. Different parameters are used to define those regions considering availability and ability of indexes. Cores of nodal regions are mostly cities with strong concentration of socio-economical activities. Background of these cities is integrated according to the intensity of the flows. Transport relationships involve working (commuting to work) and servicing (commuting to services: school, business, leisure etc.) linkages. Those linkages can be used as great source of information about socio-economical relationships in a region. Definition of nodal region is connected with transport offer planning, because it should be planned to fit actual space and time requirements of the inhabitants of a region [3].

2.2. Factors Influencing Processes in Regional Transportation

The general aim in planning of transport offer is so that the largest possible flow goes by public transport. The defining factors [4] that are influencing planning and optimisation of public transport system from operational and technical point of view are:
1. speed factor;
2. frequency factor;
3. transfer linkage factor.

The most important of them is the speed factor, which is described by travel time. Passenger’s choice is affected by the largest permissible travel time, they have to travel. It is clear that travel time is dependent on technical and technological parameters of the transport system itself.

Frequency factor is strongly connected to the speed factor. Higher frequency of connections provides higher probability, that travel time will not be longer due to the waiting for a chosen or a random connection. Optimal solutions of these situations are timetables with periodical offer, whose can provide periodical offer of connections on particular lines or the whole system. In the terms of railway transport can be used the clock-face scheduling, which is called integrated regular timetable, when it is applied to the whole railway network.

There are two possible ways how the transfer linkage factor can be understood. On the one hand the transfer time is a part of a chain in the transport process, which usually increases the travel time. On the other hand, it is a disruption of movement continuity (comfortability) on certain connection. Optimal solution is that one with short transfer linkages with time coordinated connections. Connections should meet in certain places of the transport network – transfer nodes (terminals). In general, the maximal acceptable number of transfers is two and one for strong transport relationships. Best way to achieve those goals is the usage of periodical scheduling.

2.3. Transport Network in Transport Service of the Regions

Transport network and its infrastructure can be described as edge-rated graph. In case of railway transport are the edges represented by railway lines, whose rating is represented by their technical and operational parameters. Nodes of such graph are points, which are important for the infrastructure for the outside approach and inside structure and organisation.

There are several basic types of railway lines. These lines are distinguished by their routing, position in region and operational solution. There are only a few lines, which can be absolutely sorted, because most of the lines can be placed in more groups, thanks to the combination of technical and operational parameters. There are examples of such lines from the Czech Republic:

1. Direct centre feeder – radial line – a railway line is routed directly from the region to its centre. The example of this type is railway line Karlovy Vary – Potůčky in Carlsbad region. The chart of this railway line type is on Fig. 1.

2. Indirect centre feeder – radial railway line with connection to direct centre feeder – a railway line is routed from the region and it is connected to the other railway line, that is direct centre feeder. Indirect feeder is routed approximately in radial direction, so it should not cause delay to the passengers. The example of this type is railway line Nýřany – Heřmanova Huť in Pilsen region. The chart of this railway line type is on Fig. 2.

3. Indirect centre feeder – tangential railway line with connection to direct centre feeder – a railway line is routed from the region and it is connected to the other railway line, that is direct centre feeder. Indirect feeder is routed approximately in tangential direction, so it could cause delay to the passengers. The example of this type is railway line Bakov nad Jizerou – Dolní Bousov in Central Bohemian region. The chart of this railway line type is on Fig. 3.

4. Connection of more centres – a railway line is routed through more regions, so there are more commuting centres with their gradient regions on its route. This fact effects transport demand – it decreases in the direction from individual centres. The example of this type is railway line Nymburk hl. n. – Mladá Boleslav in Central Bohemian region. The chart of this railway line type is on Fig. 4.

5. Railway line without relationship to the centre – a railway line is routed through the area of the region, but it is not suitable for transport service of the centre due to its routing, parameters or other relations in the region. The example of this type is railway line Kojetin – Tovačov (line without regular passenger train operation) in Olomouc region. The chart of this railway line type is on Fig. 5.
2.4. Linear Railway Network

The leading transport system is defined by the basic knowledge of transport relationships in nodal region and general principles of their transport service. We consider simple railway network that connects centre of the region with its surroundings. Usually it is routed radially, and it does not branch – it is defined as a linear railway network. These principles can be modified for different types of networks, stated in chapter 2.3. Periodical scheduling is used for service of nodes (stations and stops) in these kinds of networks, that means that there is regular interval between connections on the network. Connections create one or more lines (each line has the same originating and terminating node).

This problem could be defined as optimization of transport offer on linear railway network, when transport demand in the nodal regions is known and certain optimization criterion is considered.

3. Model of Transport Service on the Linear Railway Network

The model suggests optimal line routing on the linear railway network. This line routing considers basic technical and operational architecture of the system (transport offer) and operated transport relations (transport demand). Basic optimization criterion is the general operational cost of operation of such system. The model is based on theoretical knowledge of designing a line routing. This knowledge uses basic method of operational research in the tasks of linear mathematical programming. The model is formed as a task of assigning optimal line routing on defined transportation network. Used method comes from the former formulation of PRIVOL method (přiřazení vozidel linkám = assigning.
vehicles to lines) [5] and it modifies an approach for designing line routing of public transport with heterogeneous rolling-stock [6].

3.1. Formulation of the Basic Task

There is a linear railway network that consists of an origin, terminal and intermediate nodes. Number of tracks, positions of railway stations and stops and the other parameters, which are important for final service conception (scheduling, crossing of trains etc.), are not crucial in the basic form of the problem. Lines could operate between every pair of nodes. Ratings of the edges – distances and the transport demand during operational day between all nodes – are known. Basically transport demand does not depend on the line connection frequency, whereas the more used direction is more important. This simplification is acceptable due to the defined time period and general transport relationships in nodal regions. We can assume (according to the nature of regular transport relations in nodal regions), that transport demand will aim mostly to the centre of these regions and that it will decrease in the opposite direction. The period of solution is characterised by the steady interval between connections of lines and transport demand. Lines could operate with different intervals, these intervals usually form the interval family, but there is the same interval on one certain line. Introduced lines are serving all the nodes and edges in their route. According to above-mentioned facts one hour from the rush hours is used researched period. It has one or more trains sets to operate linear network to use. Each trainset has its capacity – number of passengers, which can travel in trainset at one connection. We also know operational cost of each trainset. Each line operates by one type of trainset.

The task is to serve linear railway network with one or more lines. It has to satisfy the demand on individual segments, considering the line interval and the type of operated trainset. The operational cost of all lines should be minimal.

3.2. Input Definitions – Constants and Variables

Railway stations and stops are nodes of the linear railway network (quantity n) placed consecutively (lower indexes i, j) while i, j = 1, ..., n.

Transport demand \( p_{ij} \) (place/h) is the requested numbers of places on the section of linear railway network between nodes i and j, i.e. it is transport demand from the node \( i = 1, ..., n-1 \) to node \( j = i + 1, ..., n \). Only upper triangular matrix is defined, because only more frequent transport direction matters, i.e. (1), where \( P \) is the set of transport demand values.

\[
|P| = \frac{1}{2} n(n-1).
\]  

Acceptable intervals \( t_a \) [min], in which could be individual lines operate, create a.k.a. interval group with r members, i.e. \( a = 1, ..., r \). Considering periodical scheduling, it usually applies (2).

\[
t_{a+1} = 2t_a \quad \text{for} \quad a = 1, ..., r-1.
\]  

Usual interval groups are:

1. \( t_5 = 5 \text{ min} \); \( t_{5r} = 5, 10, 20, 40, 80, 160 \text{ min} \) – this interval group not suitable for creating periodical scheduling. It is more suitable for city public transport,
2. \( t_{7,5} = 7.5 \text{ min} \); \( t_{7,5r} = 7.5, 15, 30, 60, 120, 240 \text{ min} \) – intervals 15 min and higher could be successfully used in railway operation. They are also memorable thanks to recurring time values. However interval 240 minutes is, from the transports service point of view, beyond the border of acceptance.

The model assumes the same acceptable values of interval and their counts on all lines.

Operational length of the line (service) \( d_b \) (km) is the distance between nodes i, j, between which is the line routed, i.e. it is the line length from node \( i = 1, ..., n-1 \) to node \( j = i + 1, ..., n \).

Acceptable trainset \( b \), which can be operated on individual lines, creates a group with s members, each trainset could be described by its capacity \( k_b \) (seats), i.e. \( b = 1, ..., s \). Arbitrary trainset on each line and the same vehicle type on individual line is assumed. Each trainset \( b \) is described by its operational cost on the unit of transport performance \( c_b \) (CZK per train-km, alternatively another currency). This attitude benefits railway operator or manager of transport service. Passengers can be also benefited if their transport cost is involved in the model as well. Value of passenger’s time is usually related to the unit of time. Therefore it is necessary to modify the model in such situation by replacing operational length of the line constant \( d_b \) by constant, which takes path duration into account, i.e. travel times between nodes i a j.

There is negative or positive decision about operation of line (or lines) \( e_{ijab} \) in linear railway network in defined model. From this reason the variable has binary domain of definition, i.e. its value is 0 or 1.

Variables of the model are decisions of operating the line \( e_{ijab} \) from node \( i = 1, ..., n-1 \) to node \( j = i + 1, ..., n \) in the line interval \( t_a \) with the trainset type \( b \), while \( a = 1, ..., r \) and \( b = 1, ..., s \). If \( e_{ijab} = 1 \), then line from node \( i \) to node \( j \) in the line interval \( t_a \) with the trainset \( b \) will be operated. If \( e_{ijab} = 0 \), then line from node \( i \) to node \( j \) in line interval \( t_a \) with
the trainset type b will not be operated.

3.3. Definition of Purpose Function and Constraint

Mathematical function (purpose function) according to (3) optimizes line routing by minimizing optimization criterion, which is represented by total operational cost for one hour of linear network operation (rush hour assumed)\(^1\).

\[
\min f(e) = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \sum_{b=1}^{r} \frac{60d_{ij}c_{ijb}}{t_{ijb}} e_{ijb}.
\]  

(3)

Constrains are listed in (4) to (7).

\[
\sum_{a=1}^{r} \sum_{ijab} e_{ijab} \leq 1 \text{ for } i = 1,..,n-1, j = i+1,..,n; 
\]  

(4)

\[
\sum_{i=1}^{n} \sum_{a=1}^{r} \sum_{j=i+1}^{n} \sum_{b=1}^{r} e_{ijab} \leq H; 
\]  

(5)

\[
\sum_{a=1}^{r} \sum_{i=1}^{n} \sum_{j=i+1}^{n} \sum_{b=1}^{r} \frac{60 \cdot k_{ijab}}{t_{ijb}} e_{ijab} \geq \sum_{i=1}^{n} \sum_{r=1}^{r} p_{ir} \text{ for } i = 1,..,n-1; 
\]  

(6)

\[
e_{ijab} \in \{0,1\} \text{ for } i = 1,..,n-1, j = i+1,..,n, a = 1,..,r, b = 1,..,s. 
\]  

(7)

3.4. Outputs of Designed Model

Mathematical model gives the number and line routes as a solution (nodes of network, each line interval and trainset). Optimal solution does not have to be operationally satisfying, therefore the results should be interpreted properly (from the technical and operational point of view).

Functions and outputs of designed model were tested on a simple example and applied for operation design on real railway line. In both situations the software FICO® Xpress Optimization in freeware license were used. The outputs of the software confirmed proper model function and necessity of proper result interpretation.

3.5. Application of Model in Research and Reality

Similarly, to the other line routing optimization models, it is appropriate in next research to work on removing some of the simplifications, which are assumed. One of them is consideration of time changes in transport demand by modifying such changes in transport offer, for example changing interval value at some connections. Another option is segmentation of transportation – some lines are not serving all nodes. Development of the model could lead to use also for simple branch networks or integrated networks. We can also modify the model by replacing purpose function and cost by transport performance and durations of transport service, which could bring new sight on transport offer optimization. Observing the importance of line number could also bring interesting results, because verifications of model have showed, that this parameter could be crucial for optimization.

Application of the model could be used as support for transport engineering and infrastructure planning. Output of the model could help with operational decisions during line or section optimization and they can be also used as data for infrastructure changes. Results of the model could help us with evaluation of potential of railway lines or sections.

4. Conclusion

The paper is mainly concerned with the optimization of the transport service in regions by railway transport. These areas are often nodal (heterogeneous, gradient) regions. There is always a centre and surroundings in the nodal region. There are transport relationships with main commuting direction and time-space development of transport demand between the parts of nodal region. Appropriately operated railway network can be optimal part of public transport system. This could be applied even at the time of dynamically expanding transport market, when it is necessary to fight versatility of individual transport which however don’t have to be environmentally acceptable by attractive systems of public transport.

The article suggests optimization of transport operation on a linear railway network by designed model of linear programming. Model suggests optimal line routing, which considers basic operational architecture of the systems and operated transport linages, while there is general operational cost as optimization criterion.

\(^1\) If it’s considered interval higher than 60 minutes, it has to extend operational period as well. In this case it has to assume uneven distribution of transport demand during this period.
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References

Lashing Methods - Mathematical Basis of the Process of Selecting the Number of Lashings

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Abstract

Although all participants of the transport process are aware of the necessity of load securing, this process is not always conducted properly. It is mainly due to the difficulties with determining the appropriate number of lashings. It should be done based on the standard EN DIN 12195-2 or the guidelines certified by the European Commission. Although both documents are based on the same bases, the results of calculations often differ. The discrepancies are caused by different input data and a different lashings selection algorithm. Apart from the load characteristics and the parameters related to a loading method, the formulas presented in the standard contain the correction coefficients. The calculation algorithm in the guidelines, in turn, is based on the analysis of the possible load sliding and tipping. The calculation methods presented in both sources listed above reflect the physical phenomena impacting the load. However, they omit the real interactions in the chain road-vehicle-load and some additional physical interactions occurring between the load and the lashings. The present article presents the procedures of the lashings selection, based on a real case of the load securing. The differences in the number of selected lashings were characterised.

KEY WORDS: frictional lashing, cargo securing, lashing, tension force

1. Introduction

In order to ensure the road traffic security and protect the load from damage, the transported load needs to be immobilised [3, 4]. The load that is able to move against the loading surface may cause the loss of the vehicle’s stability or a change in the distribution of forces on the vehicle’s axes. In the road traffic, the load is - in the majority of cases - immobilised with use of lashings. The variables that occur during the load lashing process are: the lashing parameters (described by the values \( LC, S_T \)), the number of lashings and the lashing method. A superior document that regulates the load lashing process in the standard EN 12 195-1. It includes the descriptions of the basic lashing methods and the formulas that enable to calculate the number of lashings. Based on the standard EN 12 195-1, the lashing guidelines were prepared. They contain a comprehensive guidance related to the lashing methods in relation to specific loads. Tables and formulas presented therein enable not only to select the type of lashings, but also the elements needed for the load securing by blocking. The most detailed and comprehensive guide is the European Best Practice Guidelines on Cargo Securing for Road Transport [10]. The majority opinion of the Expert Group is that either the IMO/ILO/UNICE methods accepted and described in the Annex 8.6 [11] or CEN methods should be accepted as giving a safe level for cargo securing in cross border operations.

The difference in the calculation procedures related to the number of lashings selection was described in [1]. The mathematical analysis of the load lashing with use of the top-over lashing method was conducted. Based on the calculations included in [9], the loads were lashed and the road tests were conducted. The conditions for which a too high number of lashings is assumed were determined. The examples of incorrect calculations for specific lashing angles were presented.

Although there are several regulations concerning securing a load to the vehicle, the information provided therein does not reflect the real situations. The results of an experiment aimed at proving that the input data used to secure a load was incorrect were presented in [8]. In addition, a load pattern showing the issue related to using the mean values of the acceleration coefficients when calculating the inertial forces acting during transport on different types of roads was presented.

A lot of countries and organisations have published their own methods of securing loads to the vehicles. The article [6] presents the analysis of the calculation rules and guidelines related to securing loads. The notions of a stable and an unstable load were defined and the calculation methods for these types of loads were presented. Also, the interface and the working principles of the software enabling to model the load securing process were described. The article [7], treating a similar subject, characterises the research on the impact of the road pavement and the vehicle working conditions on the force generated by the lashing straps and stabilising the load. The Truck Sim software, which contains a library of the typical vehicles and steering systems, was described. The software is connected with an application that models the lashing method developed in the ADAMS software. The analyses of the vehicle’s acceleration in the spatial reference system during the variable pavement parameters and crashing against a roadblock were presented.

The load’s movement during the crash tests with use of different methods of load securing were described in [5].
The accelerations generated during the crashes were observed by the monitoring units aimed at transport monitoring and using the recordings made with the GoPro Hero cameras.

The present article describes the analysis of the correctness of the load lashing, based on a real case (Fig. 1). The correctness shall be understood as using the appropriate number of the lashings characterised by specific parameters, which are necessary to transfer the forces acting on the load while the vehicle is moving. The load was immobilised on a semi-trailer with use of the frictional lashing method (also referred to as top-over lashing), using three lashing straps of the following parameters: $LC = 2000\,\text{daN}$, $SHF = 50\,\text{daN}$, $STF = 400\,\text{daN}$.

**Load:**
- mass: $m = 7700\,\text{kg}$,
- friction coefficient: $\mu = 0.4$,
- lashing angle: $\alpha = 70^\circ$,
- load dimensions: $l = 2.5\,\text{m}$, $h = 1.5\,\text{m}$, $w = 2\,\text{m}$.

![Fig. 1 a - view on the load on the semi-trailer; b - label in accordance with standard EN12195-2](image)

2. **Standard EN 12 195-1**

This standard characterises the basic methods of load lashing: top-over lashing, loop lashing, spring lashing, round turn lashing and direct lashing. For each of these methods the formulas enabling to calculate the number of lashings, provided their characteristics is known ($LC$, $STF$) or the required force value that would press the load against the base at the assumed number of lashings were provided. The formulas are provided in two configurations: in case the load dimensions and the position of the centre of gravity are not known and in case they are known.

A key requirement related to the lashings used for load securing is that they need to be made in accordance with the standard EN 1295-2. The standard determines the safety requirements declared by the lashings producer, especially as far as their strength is concerned. It is possible by creating the required lashing tension that ensures the balance of the external forces acting on the load. The lashing strap can be used when its label with marking is legible. The most important markings are the following:

- $LC$ - the lashing capacity, i.e. the maximum allowed force [daN] on the strap in straight pull;
- $SHF$ - the maximum hand force [daN], i.e. the maximum force that can be applied to the tensioning device/ratchet;
- $STF$ - the standard tension force [daN], i.e. the force with which the load is pressed against the base.

The calculation methods described in the standard EN 12195-1:2010 contain some simplifications:

1. The load placed on the vehicle is acted on by different forces: braking, acceleration and centrifugal, as well as those generated while driving on uneven surfaces. They act on the load and cause changes in the internal forces’ values in the lashing strap, which causes its elongation. As a result, the load is diverted andslided in relation to the base plane. The formulas presented in the standard do not include all the conditions that can have an impact on immobilising the load. In order to compensate for the undesirable phenomena occurring in the lashings, especially the possibility of sliding the load while braking or accelerating the vehicle suddenly, the factor of safety $f_s$ with the value of 1.25 was introduced.

2. The lashing strap over the top of the load is tensed with use of a manual lashing tensioner with a ratchet mechanism. Thanks to that the load is pressed against the load surface with force of the value $STF$, which is to prevent it from sliding. The strap tensioner is placed at one side of the load. As a result, different tension forces are generated at both sides of the strap - the force of a higher value is produced at the side where the tensioner is placed. It is caused by the edge effect. If a tensed lashing strap is bent at the load’s edge, the tension force, generally designated as $F$, will decrease at the edge to the value:
where $\mu$ - the friction coefficient between the lashing strap and the diffraction edge; $\alpha$ - strap diffraction angle at the diffraction edge.

The edge effect of decreasing the tightening force at the fastening is intensified due to the fact that the lashing strap diffracts twice at the same angle $\alpha$. At every diffraction point the initial tension force is decreased by the coefficient $c = e^{-\mu \alpha}$. The calculations [2] show that only a half of the initial tension force $F_T$ generated by the tensioner is produced at the other side of the diffraction edge. Further identical force decreasing occurs at the other side of the load.

1. All calculations described in the standard EN12195-1:2010 are based on the assumption that the load is placed symmetrically with respect to the longitudinal axis of the vehicle. There are no guidelines in case when the load is not placed symmetrically. Moreover, the formulas are strictly related to the specific lashing method. In reality, though, lashing the load is often made with use of several different methods, including blocking.

2. It has been assumed that if the load is homogenous, i.e. made of the layers that stowed on each other and able to move relatively, there is no information considering the calculations algorithm. The calculation method has only been provided in case when the load is made of single vertical rows.

The number of lashings is:

$$n \geq \frac{(c_{x,y} - \mu \cdot c_z) \cdot m \cdot g}{2 \cdot \mu \cdot \sin \alpha \cdot F_T \cdot f_s}.$$  

where $c_{x,y}$ – longitudinal/transverse acceleration coefficient; $c_z$ – vertical acceleration coefficient; $\mu$ – friction factor; $n$ – number of lashing devices; $f_s$ – safety factor of frictional lashing; $\alpha$ – vertical lashing angle; $F_T$ – tension force of lashing device.

The force $F_T$ used in the calculation should range within:

$$0.1LC \leq F_T \leq 0.5LC.$$  

When calculating the number of lashings, the force value $F_T$ may be replaced with the value $S_{YY}$.

After inserting the following values to the formula (2): $c_x = 0.8$, $c_z = 1$, $f_s = 1.25$, $F_T = 8000 N$, as well as the values characteristic for the load, the required number of lashings was calculated: $n = 7$.

In case when the load’s overall dimensions are known and it is assumed that the centre of gravity is in the geometrical centre of the load, the following formula may be applied:

$$n \geq \frac{m \cdot g}{2 \cdot F_s \cdot \sin \alpha \cdot \left( c_z \cdot \frac{h}{w} - c_z \right) \cdot f_s},$$  

where $h$ – height of load; $w$ – width of load.

In this case, the required number of the lashings is $n = 4$.

Notes:

1. It shall be observed that in the formula (3) there is not fraction coefficient $\mu$. The most important issue herein is the possibility that the load may slide or tip because of its dimensions. It was implicitly assumed that a short load with a large base surface will be stable and will require a low number of lashings.

2. The formulas (2) and (3) are related to a homogenous system. The cases not included in the formulas are those when the load consists of several layers stowed one on another, between which the friction occurs (described by the coefficient $\mu$, as in the case described herein).

3. Rearrangement of the formulas (2) and (3) so that they enable to calculate the value of the force $F_T$ may lead to conclusion that the highest value of the tension force will be obtained for the angle $\alpha = 90^\circ$ as the lashing strap is then in the vertical position. However, a detailed analysis of the formulas leads to conclusion that the force value obtained this way is the lowest.

4. Another misunderstanding caused by the friction coefficient. Taking into consideration the arguments that the load may slide, it is often recommended to use a kinematic friction coefficient $\mu_k$. Using kinematic friction coefficient $\mu_k$ of the values lower than the static friction coefficient $\mu$, makes the calculated pre-tension force value higher than when using the $\mu$. Such analysis may lead to incorrect conclusions that may result in applying a lower number of lashing straps.

3. European Best Practice Guidelines on Cargo Securing for Road Transport

The method of selecting the number of lashings has been described in the annex to the aforementioned guidelines and has been entitled: “Model Course 3.18. Safe packing of cargo transport units. Quick lashing guide, road + sea area A.” The algorithms of calculating the number of lashings for frictional, diagonal and top-over lashing, as well as for blocking have been presented therein. The key information the calculation algorithm is based on is the load structure:
homogenous, consisting of layers or rows. The other input data are: the friction coefficient between the load and the base and the overall dimensions of the load. In each case the calculations are made at the assumption that the straps used for lashing will be of the value $S_{TP}$ not lower than 400 daN ($LC = 2000$ daN).

The required number of stays is calculated according to the following procedure (Fig. 2):
- calculating the required number of lashings to prevent the loads from sliding;
- calculating the required number of lashings to prevent the loads from tipping;
- the searched value is the maximum value of the aforementioned conditions.

Even though there is no risk of the load sliding or tipping, it is recommended to use at least one lashing strap per 4 tons of load, according to the guidelines.

Based on the guidelines, the following values are obtained:

The friction coefficient value - sawn timber/wooden pallet $\mu = 0.4$.

For the mass $m = 7.7$ tons, the indicator related to lashing in order to prevent the load from sliding:
- sideways – 3.2;
- forward – 0.5;
- backward – 3.2.

The load requires the following number of stays to prevent it from sliding:
- sideways – $7.7/3.2 = 2.4$;
- forward – $7.7/0.5 = 15.4$;
- backward – $7.7/3.2 = 2.4$.

Moving on, the table shows the information that for the load mass and overall dimensions it is not possible for the load to tip in any direction.

The number of lashings of the standard tension force $S_{TP}$ not lower than 400 daN should amount to $n = 15$.

---

**Fig. 2 Coefficients necessary to select the amount of fastening means [9]**

Notes:
1. In the calculation procedure, a significant value is the value of the friction coefficient between the load and the base. It was assumed that a high value will ensure a stable load position, thanks to which it will be possible to reduce the number of lashings.
2. It was assumed that a short load with a large base surface will be stable. As a result, the combination of these two assumptions may cause the situation that, in extreme cases, no lashings will be needed.
3. A calculated number of lashings does not refer to a specific value $LC (S_{TP})$. The only information provided is that a minimum lashing strength is $S_{TP} = 400$ daN.
4. The simplifications in the selection procedure result in obtaining an overestimated number of lashings.
4. Conclusions

The conducted analysis shows that the process of selection the number of lashings is not an unequivocal activity that lets to obtain similar results. Based on the standard EN 12 195-1, depending on the input data, it is possible to obtain different results. When performing calculations with use of the load mass only, the obtained number of lashings is \( n = 7 \). However, after adding the overall load dimensions, the result changes to \( n = 4 \). Selection of the number of lashings based on the “European Best Practice Guidelines…” gives the results almost twice as high as the maximum result obtained based on the standard – \( n = 15 \). Such discrepancy exists, although the guidelines are recommended by the European Commission.

The people who are responsible for securing the loads rarely perform calculations to obtain the required number of lashings. If the calculations are performed, though, their results are often undermined as too high and unrealistic. Thus, load securing is often schematic and based on the shipper’s experience.

References

Interchanges at one Platform: Influence on Capacity of Railway Infrastructure

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Abstract

Interchange between trains allocated to one platform can improve comfort of passengers and can shorten times needed for this interchange. Demands on capacity of station switch areas can be increased in this case due to train paths possibly crossing number of other tracks. Approaching times of these trains can be extended as well. The paper is focused on these effects. Assessment is based on analytical as well as on stochastic simulation methods. Different indicators for assessment are discussed. Time-based indicators (especially delays) are seen as prior. The final part of the paper is dedicated to discussion, how shortened interchange times can help to operation of railway lines and networks.

KEY WORDS: capacity of railway infrastructure, model, railway transport, simulation, schedule

1. Introduction

Requirements on allocation of selected trains to neighbouring tracks along one island platform are relative common in railway transport. This can be advantage for passengers changing trains, because they don’t have to leave a platform. Comfort of passengers can be improved and time needed for interchange shortened in this way. On the other hand, it can cause increased demands on the capacity of railway infrastructure and on traffic operation itself. Coordinated passenger trains can block possibly suitable tracks for other trains due to this and the space for operative control of traffic became limited. Increased demands can be occurred on capacity of station switch areas as well. Number of platforms can be possibly reduced if the trains are assigned in such improved way.

The hypothesis of this research can be expressed by following statement. There are tools able to quantify the impact of this kind of interchange on station capacity as well as on railway operation itself.

Two types of methods are usually applied in the field of assessment of railway infrastructure – one approach is based on analytic methods, the second on methods of simulation modelling. Both approached will be considered also in this article.

2. Situation in Research Field

Assessment of railway capacity is usually related to so called compression methods. It means that the train paths are fictively compressed – to put one to another as close as possible. The aim is to evaluate, how long time period will remain free in compressed time schedule. This time, when the infrastructure is not occupied (it is empty), is considered as free capacity. The methodology UIC 406 [1] is using compression approach as well.

In spite of the fact that the capacity of railway infrastructure is frequently used concept – the way, how to assess and interpret capacity is not unambiguous. There are a lot of factors influencing capacity so that it is complicated to find an unified approach to it. The factors of train speed, commercial stops, train heterogeneity, distance between railway signals and timetable robustness are discussed by [2].

The factor of different speeds of trains on capacity is mentioned in [3]. Integer mathematical programming model for optimization of capacity utilization is presented as well. This is an important fact. The research is not focused on capacity description only, but also on optimization of operation with the effort to use the capacity in an effective way.

The segment of urban railways is researched by [4]. Productivity and efficiency are the core aspects. Other economic aspects, including pricing of capacity, are mentioned by [5]. The situation in the case of the Czech Republic is mentioned by [6].

Statistical approach to modelling of delay caused by congestions on railway is presented by [7]. Similar statistics are necessary also as the base for stochastic simulation models.

Some materials can be focused on some specific models like the article [8] focused on mathematical optimization of scheduling of vehicles for wheelchair users.

Different point of view – decision making of passengers is taking a part of research mentioned by [9], but this is also an important factor. The interface between passengers and transport system is crucial for suitable providing of transport services.

This analysis is an evidence that there are many factors more or less influencing possibilities to manage and use capacity of railway infrastructure. The capacity assessment must follow them. The point of view of passengers changing
trains is crucial for this article.

Two methods will take a part of this article – optimization of assignment of station tracks to trains with regard to passengers as well as to operational point of view. The second will be stochastic simulation method applied for assessment of operational effects.

3. Optimization of Assignment of Station Tracks

This scope belongs to the field of so-called train platforming problem. This is a mathematical scheduling task assigning station tracks to trains (or vice versa) with an effort minimize the amount of delays possibly caused by time conflicts at station tracks (waiting occurred when other train occupies planned track) or in switch areas. There are articles related to the mathematical formulation of this problem at disposal, because the solution of this problem can have very serious demands on computing capacity. Example of one approach to solution can be in [10].

This paper will not be focused on this algorithm itself, but on a new criterion combining passengers’ and operational demands.

Authors' are using exhaustive search algorithm [11] able to be prove all the variants of assignment of station tracks to trains. This algorithm is based on combination of common assignment problem (known as one of basic linear programming applications) and of scheduling task belonging to co-called reservation systems. On the other hand, this specific application does not be expressed in linear way.

Computing demands of such calculation can be serious in the case of high value of product of number of trains and number of tracks, but several possibilities to reduce these demands are at disposal. Solved time frame can be reduced to the length of period of time schedule (if periodic time schedule is applied). Subsets of tracks suitable for individual trains can be predefined. Possible time gaps in time schedule can be found and optimization solved in divided way to shorter sub-periods. This can be effective especially in the stations with small or 'middle' extent of traffic where time gaps in traffic (operation) can be found and applied for dividing the problem in task. All these measure can cause sub-optimality of final results, but it is about compromise to have this tool at disposal and accepted decrease of quality level of solution.

On the other hand, there are usually some facts in practice, which can help to set these simplifications and interconnect them with practice. For example, some trains not able to depart in given direction can be excluded from using of dead-end track in advance etc.

Exhaustive search algorithm provides one advantage for this solution. The examined alternative can be evaluated by more criterions in parallel way and the subset of candidate variants of assignment of station tracks to trains to be selected can be collected by application of more different points of view.

The first point of view (criterion) is that the solution in conflict-less at station tracks. The second point of view is total consumption of time needed for interchanges. This time is expressed according to station topology, number of stairways needed to be passed, time needed to climb these stairways and estimated speed of walking. Assignment of each individual pair of train and track can be evaluated by the number of points according operational suitability of assignment of given track to given train. This can reflect for example necessity to come to the track by decreased speed or by longer route; need of additional shunting movements; blocking of some infrastructure elements (like platforms by freight trains) etc.

Constraints delimiting set of permissible solutions can be defined as well. Task is implemented in Microsoft Excel supported by using of macros written by Visual Basic for Applications programming language. This can be applied for finding of suitable occupancy plan of station tracks.

The authors are assigning this method to analytics method in spite of the fact that is optimization task. It is due to the two facts. The first is that exhaustive search algorithm work largely in an analytic way, the second is practical point of view. This approach can be related to other analytical processes used in the field of railway transport due to similar extent of needed input data and similar time needed for processing.

4. Simulation Assessment

Microscopic simulation model has been developed for assessment of researched effects by the support of Villon software tool. Simulation is a descriptive modelling approach. Situation must be assessed on defined transport infrastructure and with defined timetable.

There are 8 station tracks in modelled station, 6 of them are equipped by platform edge (able to be applied for passenger trains). There are two island platforms equipped by a pair of tracks so that interchanges between trains allocated to one platform are possible. Trains can go from this station in 3 directions. Double-tracked main line is passing through the station from A to B. Each of these two island platforms belongs to one main tracks of this line (main track – track directly continuing from line through station). The third direction of C belongs to single-tracked regional railway line. This line branches in the switch area in direction B of the main line. Only one station track is dead-end track with limited accessibility. This dead-end track can be used by trains in directions from/to B or C only. This configuration of tracks has been created as an example of station of common extent.

Modelled time period is 120 min long. Total number of trains taking part in the model is 30; 6 of them are passenger trains and 22 freight trains. Freight trains are operated in all directions A, B, C. Freight train are scheduled, but their operation is not periodical (time positions of arrivals and departures in schedule can be irregular).
There are operated regional and long-distance trains on the main line (from A to B and vice versa), each type of train is operated with an interval 120 min so that the collective interval is 60 min in both directions on this line. Regional trains on the line from/to C are operated with interval of 60 min. These trains are a return train from and to direction of C.

Coordinated interchanges are taking place at the platform A (see simplified station scheme in the Fig. 1). Trains from/to C are making connections to all trains from A to B at the island platform 1 so that trains from/to C must cross the switch area in direction B.

These trains are conflict-less in the case of operation strictly by time schedule. Difficulties can occur in the case of delay. For that reason, stochastic simulation generating random delays of trains is applied.

Operation of is station was modelled in two 2 ways. The first is situation where assigned tracks for passenger trains are fixed. Used track cannot be changed in practical operation. The train must possibly wait on assigned track until it becomes free. It means that it is strictly given – for the possibility to ensure planned interchanges between planned platforms and tracks. Second way works with fixed track assignment for all the trains. This is theoretical approach to research what impact can be caused by this measure in its extreme form. On the other hand, practical application of these results can be connected to possible reduction of extent of station infrastructure. It demonstrates the situation when seldom-used elements (like switches, connecting tracks etc.) are replaced with an effort to decrease costs. This can have also an impact to the capacity of lines.

Due to this fact, the assessment is focused not on delay itself, but on increment of delay measured for each train in modelled area. This is the reason why also neighboring line sections are taken into simulation as well. The increment of delay is measured between points where the train enter and leave the model. In the case when a train is originating in modelled station, moment of departure (including possibly occurred delay) is taken into consideration. The moment of stop of a train at station track is considered as leaving moment in the case of a train terminating in modelled station.

The situation without any strictly assigned track to train (control of operation can be without limitation in this point of view) is not discussed here, because estimated effects are usually less important. It follow from authors’ experience with simulation modelling of railway stations as well as it can be documented by using of some analytical methods. On the other hand, it is depended mainly on constructed time schedule (occupancy plan of station tracks).

5. Results of Simulation

The main criterion of simulation is based on delay increments, because it can closely refer about modelled system. If a train is delayed from pervious line segments, the reason of this delay is not connected to evaluated infrastructure. On the other hand, evaluated infrastructure is depended on this surroundings. For these reasons this criterion seems as adequate. Results of simulation by both scenarios mentioned above can be compared by the Table 1.

The results are based on total number of 114 replications that follow correct technological aspects of railway traffic.

<table>
<thead>
<tr>
<th>Set of trains</th>
<th>Delay increment</th>
<th>Simulation scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Fixed tracks by passenger trains</td>
</tr>
<tr>
<td>All trains</td>
<td>39.92 s</td>
<td>45.03 s</td>
</tr>
<tr>
<td></td>
<td>58.38 min</td>
<td>53.33 min</td>
</tr>
<tr>
<td>Passenger trains</td>
<td>Average</td>
<td>78.85 s</td>
</tr>
<tr>
<td></td>
<td>56.32 min</td>
<td>53.33 min</td>
</tr>
<tr>
<td>Freight trains</td>
<td>Average</td>
<td>25.76 min</td>
</tr>
<tr>
<td></td>
<td>58.38 min</td>
<td>44.10 min</td>
</tr>
</tbody>
</table>
The result can be that the average values of delay increments are higher in the case of fixed assignment of all tracks to trains, but the maximal values of delay increments are lower in this case of fixed assignment. Disadvantage is that passenger trains have higher average values of delay increments than freight trains.

Maximal increments of delay are occurred by the trains coming from the direction of C to the platform 1 with need to cross both main tracks of the line A – B. Conflicts occurred on station switch area can be amplified by time conflicts with delayed trains in the single-tracked segment between modelled station and station of C. Maximal values registered for passenger trains mentioned in the Table 1 are caused by this fact. Maximal value of delay increment by the trains on the main line A – B is 11.97 min in the case of fixed assignment of tracks by all trains, but higher value of 17.30 min is recorded for the case of fixed assignment limited to passenger trains.

Interesting results are recorded also for the freight train occupying the same platform track (platform 1) 7.5 min after the long-distance train. Both trains are moving in direction from A to B. When the fixing of assignment is limited to passenger trains, maximal increase of delay is 2.37 min by the second (freight train), average value is -15.4 s. It means that this train can reduce the delay in spite of the fact that the long-distance train is passing short before. Worse values are registered in the case when both trains have fixed assignment of station track. Maximal value of delay increase recorded for the freight train (the second in order) is 6.70 min. It is in proportion to maximal value of delay increase by the long-distance train (the first in order). This value is 11.97 min. Time difference between these trains can help to decrease the value by the second train in order. Average value by the second freight train is 10.76 s. It is worse than the situation when the freight trains have no strict assignment.

The role of possible shortening of interchange time by allocation of trains at one island platform is clear. This time can be about some minutes shorter and departure time can be earlier (if no other conflict in time schedule will be occurred). This can save time for better organization of traffic on the line (sometimes for possibility to apply periodic time schedule – to reach so called system travel time etc.).

6. Conclusions

Reached results of simulation model confirm stated hypothesis. There are tools for evaluation of researched effects presented in the paper. The main conclusions can be following.

The most serious aspect is related to application of fixed assignment of tracks to passenger trains itself. Due to the fact that it is not possible to change the track, delay can be seriously increased especially by these passenger trains. The importance of this effect is depended on occupancy plan of station tracks in each individual case.

Situation in switch areas must be considered very carefully, because these conflicts can cause serious negative effects in operation.

Negative impacts connected to delay can be amplified especially in the case of single-tracked line segments. This documents the relation between station and line capacity as well.

More serious transmission of delays is visible in the case of totally fixed assignment of tracks. It is depended also on the time gap between previous subsequent trains and also on operation reliability of these trains (original primary delay). Possible planning of reduction of extent of infrastructure (able to cause similar infrastructure limitations) must be carefully estimated due to this effects.

Tool supporting construction of occupation plan of station tracks is presented as well, including possible modifications reducing calculation demands.

Naturally, these conclusions are made on one simulated station, but the applied method – microscopic simulation – is providing a guideline for practical assessment of these issues in conditions of assessed specific station as well.

Acknowledgement

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References


Financial Health of Transport Companies: Case Study of Slovak Republic

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Abstract

In today's dynamically changed, clustered and global economy, when the life cycle of the company has higher frequency and companies not only arise, but also disappear is even more important to predict the possibility of future problems of the company. The form and mainly the consequences of possible bankruptcy of the company can vary. Therefore, the consequences of failure are the main platform for research and development of methods and models used for the prediction of bankruptcy, as well as to detect companies’ current financial health. Individual models of prediction of financial health were created in different time and space, so their application in the condition of transport companies in Slovak Republic is questionable. Based on the above mentioned the main goal of presented study is to construct the prediction model for transport companies in condition of Slovak Republic and verify its prediction ability. KEY WORDS: bankruptcy, transport companies, financial health

1. Introduction

The impact of the individual company extinctions and bankruptcies of enterprises is more quantitative than in the past mainly because of the globalization and interdependence of individual national economies. Individual national economies do not operate alone but rather interact intensively with each other. Based on this, not only businesses but also the economies of individual countries are increasingly dependent on each other, so a financial crisis of one country can be transferred to another country with a short delay and will soon become global. An example is the latest financial and economic crisis, which has spread quite rapidly from the US to other countries and had acquired global dimensions and character.

Business failures can be identified in the literature by different terms. We may encounter with the corporate financial health, bankruptcy, financial difficulties, default, credit risk, ex ante financial analysis, early warning systems, etc. The form and mainly the consequences of failure can vary. The consequences of failure are the main platform for research and development of methods and models to predict a business failure in time, as well as to detect its current financial health. While in the centrally managed economies the consequences of failures, respectively bankruptcies of businesses were related to the state as a whole, in market economies they have a direct impact not only on the owners, but on all stakeholders involved in the interaction with the business. Each from the stakeholder group applies a wide range of tools, algorithms and methods, while the goal of these entities is the same, to predict the future development of the company's financial health. In case of adverse results of these companies they would have a significant impact on them.

Therefore, the bankruptcy prediction models – early warning systems allow to identify the level of financial health of a company in terms of its past results towards the future. Individual models are based on the assumption that in the development of the company can be found some differences in comparison with financially good companies some time before the bankruptcy itself.

The prediction of company’s failure or the financial health of the company has been researched by various authors for decades, and their efforts to predict the future financial situation of the company have brought a large number of different prediction models. Individual models of financial health prediction were created in different time and space, therefore their application in the Slovak Republic is questionable. Based on the above mentioned the main goal of presented study is to construct the prediction model for transport companies in condition of Slovak Republic and verify its prediction ability.

2. Literature Review

Since the first and well known studies of Fitzpatrick, Altman and Beaver [1, 2] numerous studies dedicated to the research of financial health of the company have been developed. There are also various research and review studies [3-5]. These models and researches vary from various perspectives. Firstly, each model has been developed in specific condition of individual country and environment. Secondly, the basic data set usually consisted of companies from various economic categories. Thirdly, the main difference is the methodology used for the model construction.

Firstly, univariate analysis was used by Fitzpatrick in 1932 and Beaver in 1964. This was followed by the use of
Multiple Discriminant Analysis, which is considered as one of the most popular methods applied for bankruptcy prediction. Another group of popular methods is the application of LOGIT and PROBIT for detection of the probability of default of the company. These methods were followed by mathematical programming methods, such as Linear Programming, Data Envelopment Analysis, Linear Goal Programming (LPG), Multi-Criteria Decision Aid Approach (MCDA). On the other side in recent years’ popular methods include artificial intelligence, like Fuzzy Rules-Based Classification Models, Survival Analysis, Decision Trees, Rough Set Analysis, Genetic algorithms, Neural networks, Expert systems and Self organizing maps (SOM).

3. Data and Methodology

The data for the presented research were gained from the annual financial reports of Slovak companies (Register of financial statements, Ministry of Finance of the Slovak Republic) covering the year 2016 and 2017. We have selected a set of companies according to two criteria: the size of the company is large and economic classification according to SK NACE is H – Transportation and storage, which includes transport companies. For the selection of companies as bankrupt and non-bankrupt we followed criterions given by Slovak legislation system: the total amount of payable and not payable liabilities is higher that the value of company’s assets, company has at least two liabilities 30 days after due date from different creditors, the value of financial independence indicator is less than 0.04, negative value of earnings after taxes, the value of current ratio indicator is less than 1.

Based on the above mentioned we have applied these criterions on results of financial analysis of given set of companies and removal of detected outliers led to the designation of basic data set from which were chosen data of companies serving as inputs for models construction. The final sample consisted of 37 bankrupt and 56 non-bankrupt companies.

For the model construction we applied logistic regression. The procedure is given by the logit transformation of dependent variable resulting in obtaining the probability of the default of the company $P_1$ towards the probability of no default of the company $P_0 = 1 - P_1$ through the probability ratio $P_1/P_0$, where $P_1$ is computed by the cumulative logistic function:

$$ P_1 = \frac{1}{1 + e^{-(Z)}} = \frac{e^Z}{e^Z + 1}, \quad (1) $$

where

$$ Z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n. \quad (2) $$

Therefore, the logit can be defined as:

$$ \text{logit}(P_1) = \ln \left( \frac{P_1}{1 - P_1} \right) = f(x, \beta) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n, \quad (3) $$

where $\beta$ are values of coefficients $\beta_0, \beta_1, \beta_2, \ldots, \beta_n$ estimated from the data set of companies by maximizing the log-likelihood function. At the centre of the logistic regression is the task estimating the odds ratio $P_1/P_0$ and ln of this relationship indicates logit transformation. Additionally, based on assumed probability the company is classified as default or no default, using a cut-off score (usually 0.5), attempting to minimize the type I and type II errors. The type I error arises when the default company is classified as no default and the type II error arises when the no default company is classified as default. After a logistic regression model has been fitted, a global test of goodness of fit of the resulting model should be performed. According to Hu [12] various R square statistics have been proposed for logistic regression to quantify the extent to which the binary response can be predicted by a given logistic regression model and covariates. The Nagelkerke’s R Square, Cox & Snell R Square and -2 Log likelihood can provide assessing the goodness of fit of the logistic regression model. These statistics show the power of explanation of the model. Cox & Snell R Square is the ratio of the likelihoods reflecting the improvement of the full model over the intercept model (the smaller the ratio, the greater the improvement). Furthermore, Nagelkerke’s R Square adjusts Cox & Snell’s so that the range of possible values is in interval (0,1] while considering smaller as greater. The probability of the observed results given the parameter estimates is known as the Likelihood. Since the likelihood is a small number less than 1, it is customary to use -2 times the log likelihood (-2LL) as an estimate of how well the model fits the data. A good model is one that results in a high likelihood of the observed results. Significance of explanatory variables and appropriate coefficients is provided by Wald test that tests the null hypothesis that the constant equals 0. This hypothesis is rejected if the p-value is smaller than the critical p-value of .05. Hence, we conclude that the constant is not 0.

4. Results

Application of logistic regression through following steps has led to the construction of final bankruptcy
prediction model for large transport companies. According to the provided logistic regression were firstly estimated logit function coefficients variables (see Table 1).

**Table 1**

<table>
<thead>
<tr>
<th>Variables in the Equation</th>
<th>NACE_group</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>net income / equity</td>
<td>grop step 5</td>
<td>.356</td>
<td>.442</td>
<td>.648</td>
<td>1</td>
<td>.421</td>
<td>1.428</td>
</tr>
<tr>
<td>Constant</td>
<td></td>
<td>-.464</td>
<td>.685</td>
<td>.458</td>
<td>1</td>
<td>.499</td>
<td>.629</td>
</tr>
<tr>
<td>Working capital / Total assets</td>
<td></td>
<td>-4.293</td>
<td>1.242</td>
<td>11.951</td>
<td>1</td>
<td>.001</td>
<td>.014</td>
</tr>
<tr>
<td>short-term assets / total assets</td>
<td></td>
<td>3.772</td>
<td>1.173</td>
<td>10.339</td>
<td>1</td>
<td>.001</td>
<td>43.460</td>
</tr>
<tr>
<td>Cash and cash equivalents / Short-term liabilities</td>
<td></td>
<td>-5.239</td>
<td>2.315</td>
<td>5.121</td>
<td>1</td>
<td>.024</td>
<td>.005</td>
</tr>
<tr>
<td>Return on assets</td>
<td></td>
<td>-20.275</td>
<td>5.917</td>
<td>11.743</td>
<td>1</td>
<td>.001</td>
<td>.000</td>
</tr>
</tbody>
</table>

a. Variable(s) entered on step 5: Cash and cash equivalents / Short-term liabilities

The final prediction model indicates, based on Wald’s Z statistic, that explanatory variables that are not statistically significant at the determined level of significance (Sig. > 0.05) were nevertheless included in the resulting model. In the model the variable net income / equity and a constant are insignificant. Table shows, together with the selected explanatory variables and their estimated coefficients, the estimated values of the coefficients Exp(B) in the last column. Based on these coefficients, the following variables have the greatest negative impact indicating the change of odds in individual model for the large transport companies: net income / equity, short-term assets / total assets.

Indeed, the coefficient short-term assets / total assets, in the model takes a high value of Exp(B), which determines its significant impact on the resulting change of the company that it will be bankrupt. The prediction model of the financial health of large Slovak enterprises according to the NACE H classification created for the large companies is characterized by the following relationships.

\[
\pi_{L_{NACE}} = \frac{1}{1 + e^{-(-0.464 + 0.356X_1 - 4.293X_2 + 3.772X_3 - 5.239X_4 - 20.275X_5)}}
\]

(4)

where: \(X_1\) - Net income / Equity; \(X_2\) - Working capital / Total assets; \(X_3\) - Short-term assets / Total assets; \(X_4\) - Cash and cash equivalents / Short-term liabilities; \(X_5\) - Return on assets.

The threshold for marking the company as bankrupt is set to 0.5. If a large enterprise reaches a value greater than 0.5 after adding data to the logistic regression equation, we consider it to be bankrupt and vice versa. The Chi-square value gradually improved, which determined a gradual improvement of the final model, while individual iteration steps were statistically significant (Sig. < 0.05). The last step of the iteration is defined based on the Omnibus test of model coefficients (Table 2), while the last step was statistically significant at the determined level of significance (Sig. < 0.05) and the model improved in comparison to the previous step of the iteration.

**Table 2**

<table>
<thead>
<tr>
<th>Omnibus Tests of Model Coefficients</th>
<th>NACE_group</th>
<th>Chi-square</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>group</td>
<td>Step 5</td>
<td>7.894</td>
<td>1</td>
<td>.005</td>
</tr>
<tr>
<td>Block</td>
<td>55.147</td>
<td>5</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>55.147</td>
<td>5</td>
<td>.000</td>
<td></td>
</tr>
</tbody>
</table>

Nagelkerke’s statistic (Table 3) indicates that the created model reach relatively good values; the model explain more than 60% of the variability of the dependent variable.

**Table 3**

<table>
<thead>
<tr>
<th>Model Summary</th>
<th>NACE_group</th>
<th>Step</th>
<th>-2 Log likelihood</th>
<th>Cox &amp; Snell R Square</th>
<th>Nagelkerke R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>group</td>
<td>5</td>
<td>69.869</td>
<td>.447</td>
<td>.605</td>
<td></td>
</tr>
</tbody>
</table>

a. Estimation terminated at iteration number 9 because parameter estimates changed by less than .001 for split file NACE groups = group.

To assess the applicability of the created model in the practice of large transport Slovak companies, it is
necessary to assess its classification capability. The created model reaches a sufficiently high classification capability (81.7%), while the type I error (12.5%) of the final model meets the quality requirements (Table 4). On the other hand, type II error reaches higher value (27%) but it does not decrease the overall information ability of the model and indicates that the created model is suitable and applicable in the practice of large transport Slovak companies.

<table>
<thead>
<tr>
<th>NACE_groups</th>
<th>Observed</th>
<th>Predicted</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y_2016</td>
<td>0</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>7</td>
<td>49</td>
</tr>
</tbody>
</table>

Overall Percentage 81.7

5. Conclusions

Even though, the issue of bankruptcy prediction is widely spread worldwide, since nowadays there hasn’t been developed any generally accepted bankruptcy prediction model considering specifics of Slovak national environment and specific of transport companies. Therefore, the main goal of presented study was to construct the prediction model for transport companies in condition of Slovak Republic and verify its prediction ability. We have constructed bankruptcy prediction model based on logistic regression on the data set of large Slovak transport companies. Based on the prediction ability of constructed model, which is higher than 80%, we can consider this model as relevant and recommend its use in the practice of specific environment of Slovak transport companies.

Acknowledgement

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References

Modelling of Railway Accidents with AcciMap – Case Study

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Abstract

Accident models are among the first concepts in safety science. Back in 1930-ies so-called domino model proposed by Heinrich explained the reasons for the first accidents at work. Since then, a lot has changed, ranging from the way the work is done, its organisation to the complexity of final outcomes and consumer awareness. Reality is increasingly more difficult to describe with simple cause-effect chains, which is also reflected in the ways of modelling the causes of adverse events. In the article, we presented the basics of accident modelling using the AcciMap method, which is one of the safety science responses to the growing complexity of socio-technical systems. Then we used this method to model one of the major railway accidents that occurred in recent years in Poland. Just several dozen meters from their house, a family of four drove on the level crossing just in front of the train; unfortunately, two children died. We have also compared the conclusions of the analysis with the conclusions contained in the report prepared by Polish National Investigation Board.

KEY WORDS: level crossing, accident modelling, AcciMap, National Investigation Body

1. Introduction

Accidents have been in the focus of safety science for almost a century. The Heinrich manual [3] regarding prevention of accidents at work, published in the 1930s, is often regarded as the first safety science book in the history. This is where the famous domino model comes from, explaining accidents as a sequence of consecutive circumstances or events. The original form of this model is now a curiosity and evidence of cultural change. It is worth recalling that the first domino cube, that initiates the accident chain, stood for the ancestry and social environment [7] – which was consistent with the spirit of those times, when also prohibition was launched [2].

In subsequent years, not only the nomenclature of individual domino cubes changed [5], but also the linear nature of the development of accidents began to be questioned. This was related to the increased complexity of socio-technical systems, combining more and more technically advanced objects with their operators. The word system is used here on purpose, because it is the systemic approach that characterises the last period in the history of safety science [13]. Following the safety science recommendations, safety management systems are commonly introduced; safety systems are used to minimise the risk; as well as means of transport, infrastructure, procedures and railway employees form the railway system.

The system is defined as ‘a combination of people, procedures, facility, and/or equipment all functioning within a given or specified working environment to accomplish a specific task or set of tasks’ [17], whereas the relations between system elements are often much more complex than in the case of domino cubes. As a consequence, models explaining the causes of accidents must also take into account these relations / dependencies. One of the first, and the most well-known models of this type is the Swiss Cheese Model, proposed by Reason in 1990 [10]. It assumes that accidents occur when several conditions or events (that happen independently) simultaneously take place.

The Reason model is criticised by many as too poor (as summarised in [1]), but it is supported by its popularity in practical applications, and after some modifications – allows for system analysis of accidents [16]. Other, more contemporary models are AcciMap proposed by Rasmussen in 1997 [9] and developed by Svedung and Rasmussen in 2002 [15], and the Theoretic Accident Modelling and Processes model [7] proposed by Leveson in 2011. Research and comparison of the possibilities of using, among others, AcciMap and STAMP in accident modelling was the goal of many scientific studies [6, 11], in particular also – those regarding railway transport [12, 16]. We are, however, not aware of any paper that would show the use of AcciMap in the analysis of Polish railway accidents.

Rail transport is characterised by a relatively small number of accidents, especially when people who commit suicides are not taken into account. At the same time, in many cases, it is very easy to identify the person directly responsible for causing the accident, for example a driver who did not stop before the level crossing or a traffic dispatcher who ignored the very precisely written procedures for railway traffic. Often, however, tragic errors of operators (actions taken at the so-called ‘sharp end’) result from negligence at higher organisational levels and/or in more than one business entity [14] – systemic accident modelling should help to emphasise these relationships.
An example of an accident in which problems emerged at several organisational levels is the collision of a railway vehicle with a passenger car in Pniewite, which took place on June 3, 2015. As a result of this incident, two children living in a house located in the immediate vicinity of the level crossing were killed. Their parents intervened earlier in the infrastructure manager company, pointing to very poor visibility conditions at this crossing. Among others for this reason, the incident was investigated by the Polish National Investigation Body (NIB), an independent unit dealing mainly with serious railway accidents. A detailed report describing the results of the conducted investigation is available [8] and was the base for the information presented in this article.

The aim of the article is to analyse the accident in Pniewite by means of the AcciMap model. Section 2 briefly describes the analysed accident and presents the essential elements of the AcciMap model. Section 3 presents and describes the developed AcciMap diagram, whereas its short discussion and conclusions can be found in Section 4.

2. Materials and Methods

2.1. AcciMap Model

In the 1997 paper [9], Rasmussen presented his observations on risk management in a dynamic society, pointing to the lack of a holistic vertical view of this issue. Individual layers, such as government supervision, business management or the human factors, are of interest to various scientific disciplines: political science, economics and psychology, respectively, although all of them take also active part in managing risk. He postulated to strengthen cross-disciplinary research in this area, proposing, among others, graphical method of presenting the results of the accident analysis, named by him AcciMap.

The rules for creating AcciMap have been developed in [15], but they are not rigid; works using this model often introduce small changes, the review of which can be found in [4, 18]. In this work we will use the traditional form of the AcciMap diagram, divided into six layers:

1. Governmental policy and budgeting;
2. Regulatory bodies and associations;
3. Local area government planning and budgeting. Company management;
4. Technical and operational management;
5. Physical processes and actor activities;
6. Equipment and surroundings.

The analysed event is always placed in layer 5, and then the diagram is supplemented with conditions and other events that affect its creation.

In our work, we adopted block types and their meaning as in Fig. 1. At the same time, we assumed that the block inputs are located on their upper and left edges, and the outputs – on the right and bottom edges. Thanks to this, we do not need to use arrowheads, which would negatively affect the readability of the presented information. We have also introduced an original colour block designation. For example: blocks that represent the immediate chain of events before the accident (written in the present tense) are marked in yellow, and inversion of colours – recognisable also in black-and-white print – is used for consciously made decisions of key importance to the course of the accident process (Fig. 1). This is to focus the reading of the diagram on the most important components of the analysed critical event (accident).

In order to create the AcciMap diagram presented in Section 3, the information from the report [8] was used, in particular the primary, intermediate and systemic reasons indicated therein.

2.2. The accident in Pniewite

In Poland, every year there are about two hundred accidents at level crossings, as a result of which about 50 people are killed. Most of these events are quite obviously caused by the inattention of people using the crossings (both drivers and pedestrians), so there is no detailed examination of their causes. This is based on the European Union law, according to which events of this type are not classified as serious accidents, and the determination of their causes is left not to the NIB, but to entities participating in the incident as part of their safety management systems.

The analysed accident in Pniewite [8] took place on the afternoon of June 3, 2015. A passenger train operated by
a light diesel traction vehicle (a rail bus) collided with the VW Sharan car, driven by a woman who lives in a house located a few hundred meters from the level crossing. Her husband and two children aged 3 and 7 were also in the car. As a result of the impact on the back of the car, one of the children was thrown out of the vehicle at a distance of about 20 meters, the other remained jammed inside the vehicle, both were killed. The parents were transported to nearby hospitals (one of them by a helicopter); their lives were saved.

The accident aroused great interest of the media, among others due to the letter the woman had sent to the infrastructure manager before the accident. She described in it difficulties in noticing the approaching train, obscured by the cutting and bushes. The unpaved, steep road leading to the crossing caused difficulties for cars to accelerate, and in the winter conditions some cars were reportedly even immobilised at the crossing, a second vehicle was called for help. The letter was not treated with due attention, its content was not known to those responsible for maintaining the infrastructure, no additional checks were carried out (e.g. concerning visibility triangles). A mere reply was sent that the level crossing meets the standards and nothing can be done.

The situation at the crossing complicated the fact of a significant increase in speed of trains (from 40 to 100 km/h) as a result of completed modernisation works. These works were formally only reconstructive in character and therefore they did not require a formal building permit and were not fully supervised. Railway crossings were not covered by the scope of works and they were not adjusted to the applicable regulations – according to which access roads to crossings must be paved and much less steep than in the analysed case. The conducted investigation indicates that the acceptance of works was carried out mainly on the basis of documentation, without detailed measurements of the spot.

The NIB also pointed to a number of indirect and systemic causes that contributed to the occurrence of the event. These include i.e. (1) not appointing of the level crossing safety commission, which should verify the way how the crossing is secured in connection with the increase of speed, (2) failure to carry out risk assessment related to speed change, (3) acceptance of the proposed revitalisation project by the Commune Office in Lisewo – local authority that did not pay attention that the access roads to level crossings are excluded from the project.

The NIB report also includes recommendations addressed primarily to the infrastructure manager, requiring the visibility at the analysed crossing to be improved, but also changes aimed at responding more effectively to similar issues in the future. The implementation of these recommendations was subject to the supervision of the Polish National Safety Authority (NSA), and the measurements performed during one of the inspections are presented in Figure 2.

![Fig. 2 The measurements performed during one of the inspections](image)

One of the supervision activities over the way the recommendations of the National Investigation Body are implemented by the infrastructure manager, performed by the employees of the National Safety Authority. The inclination and technical state of the access road were documented; in the distance there is the house belonging to people injured in the accident.

In addition to the NIB's investigation, the prosecution also investigated the case. According to press reports, the investigation was discontinued due to the fact that the road leading through the level crossing formally did not exist; there was no one to be held responsible for what had happened. Currently the crossing is closed, because a road was built that leads to a higher category crossing in the vicinity.

3. Results

As a result of the analysis of the NIB report regarding the railway accident in Pniewite [8], we have prepared the AcciMap diagram shown in Fig. 3.

The accident with its immediate causes (high speed of the train, the entry of the car directly in front of the train) were placed on the level of physical processes and actor activities. The reasons for the entry of the car resulted from the equipment and surroundings: low category of the crossing (without active protection) and improper visibility – the oncoming train was covered by vegetation and terrain. Visibility problems should be noticed and resolved at the technical and operational level, and the accident confirmed the fact that infrastructure had not been properly supervised.
Fig. 3 Diagram of AcciMap for the considered accident; dashed line indicates elements not included in the NIB report.

**Governmental policy and budgeting**
- Regulations allowing for large-scale works without obtaining permits.

**Regulatory bodies and associations**
- Lack of effective control by National Safety Authority.
- Lack of effective control over the performance of annual inspections by the Construction Supervision.

**Local area government planning and budgeting, Company management**
- Modernisation of railway infrastructure
- Contracting modernisation works in a way that prevents major changes in the infrastructure, so that no building permit is needed.
- Acceptance of the modernisation plan by local authorities in a manner without any comments regarding the access needs to crossings.

**Risk management**
- Unconditional approval by the infrastructure manager of a modernisation plan inconsistent with the current regulation: violation of the SMS procedure.
- Decision to increase train speed from 40 to 303 km/h.
- Permissible speed of trains: 300 km/h.

**Technical and operational management**
- Supervision over infrastructure.
- Carrying out modernisation works that were not compliant with the current regulation.

**Physical processes and actor activities**
- Improperly made final acceptance after modernisation (no measurement of the visibility triangle).
- Inefficient current control of infrastructure technical state.

**Equipment and surroundings**
- Lack of annual construction inspection.
- Too much vegetation.
- Improper shape of cutting, incorrect profile and surface of the access road leading to the level crossing.
- Crossing is in lowest category.

**Equipment and surroundings**
- Limited visibility of trains.

**Equipment and surroundings**
- The train travels at a speed of 96 km/h before the collision.
- Late noticing the car by the train driver.

**Equipment and surroundings**
- The train brakes to 53 km/h.
- The car enters the crossing directly in front of the train.

**Equipment and surroundings**
- Collision between the train APN 59735 and YW Sharan passenger car.
- Death of two people, material losses.
It should be noted, however, that the main decisions affecting the occurrence of the accident, the approval of the modernisation plan and the increase of the permissible speed of trains, took place at the level of company management. It is also at this level that activities in the field of risk management should be undertaken (responding to reported hazard sources) and in the field of cooperation with other organisations (e.g. the Police).

Drawing up the AcciMap diagram based on the contents of the NIB report clearly shows that this report does not include the two highest levels: government policy and regulatory authorities. However, it is relatively simple to propose conditions created at those levels that had an impact on the decisions made by the company – they were marked with a dashed contour (Fig. 3).

4. Conclusions

AcciMap is proposed in the safety science body of knowledge as an example of a method facilitating communication about identified causes of accidents. It is emphasised that this is not a method for investigating the causes of adverse events, but for analysing them [18], and as a disadvantage of AcciMap a small reliability is named. In our opinion, one of the reasons for this situation is the lack of an explicit description of the meaning of blocks used to draw diagrams. Labelling different types of states, events and decisions in the same way may result in the diagrams being only readable for people who have already known the causes of accidents beforehand.

The principles of drawing and reading blocks presented by us are a proposal to unify the way of drawing AcciMap diagrams. We noticed that this increases the repeatability and speed of the information acquisition from diagrams – it makes them more intuitively understandable. The proposed solutions for preparing AcciMap diagrams should positively influence the popularity of the method among people professionally involved in investigating the causes of accidents.

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References

Quantified Probability Estimation of Traffic Congestion as Source of Societal Risks

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Abstract

In view of the high degree of uncertainty in estimating the probability of societal risks occurrence the paper aims to define and verify a possible approach to predicting the probability of congestion as a source and activator of societal risks. The paper describes the characteristics of the parameters and uncertainty in estimating the societal risks level and the process of determination of the traffic congestion probability using statistical tools. The result of the solution is a probability table of congestions occurrence on a specific urban agglomeration communication determined on the basis of statistical survey of traffic intensity and its evaluation.

KEY WORDS: societal risks, traffic congestion, Pearson's chi-square test, probability estimation

1. Introduction

Among other factors, the source of societal risks may be also road transport infrastructure, where it can trigger traffic congestions in case of under sizing its capacity due to real traffic intensity. Traffic congestion is essentially a cluster of vehicles as a result of exceeding the permissible traffic flow intensity or as a result of a traffic accident. Traffic congestions can be a source of multiple negative impacts, such as e.g. time losses and the associated increase in costs, limited area availability, higher energy demandingness but also an increase in the negative impact on environment, threatening the safety of traffic participants and etc [1].

To assess the degree of severity of societal risks means to analyse them in terms of the probability (frequency) of their occurrence and their possible consequences that they can cause by their activation. Due to the lack of statistical data, risk assessors often have to work with a high degree of uncertainty [2, 3]. In the works [4-6] it is possible to find the expression of the societal risk rate by means of so-called f-D curve. Such a curve represents a functional dependence between the probability of an adverse event expressed as the average frequency with which the event can be expected and its anticipated consequences.

The aim of the paper is to define and verify a possible approach to predicting the probability of congestion as a source and activator of societal risks. The paper describes the characteristics of the parameters and uncertainty in the estimation of the societal risk rate and the process of objectifying the determination of the probability of traffic congestion by means of statistical tools, such as Pearson’s $\chi^2$ (chi-square) probability continuous distribution test. The result is a probabilistic table of traffic congestion on a particular urban agglomeration communication, determined on the basis of statistical survey of traffic intensity and its evaluation.

2. Societal Risk and Uncertainty of its Quantitative Expression

Due to the heterogeneity of approaches to risk categorization, there are many societal risks classifications. However, they all have in common that these are risks of anthropogenic nature, i.e. risks arising from human activity or related to man. Societal risks can affect an individual, in this case we are talking about individual risk or can have impact on groups of people, i.e. related to the majority or minority and population with an impact on society as a whole. For all these categories, the collective term 'societal risk' may be used.

Assuming that any risk (technical, technological, natural, ...) affects the categories of societal risk to a greater or lesser extent, it can be said that all risks are societal. Based on general risk definitions (e.g. [7, 8]) which mostly refer to risk as a quantitative or qualitative expression of the threat, degree or degree of threat or the probability of a negative event and its consequence. From a mathematical point of view, the risk can then be defined by the linear dependence of the consequences and the probability that the assumed negative event will occur, in the form of a function:

$$r = f(p,d),$$

where $r$ is the societal risk size; $p$ is the probability of occurrence of risk and $d$ is the consequence of societal risk.

The extended definition of risk also includes values such as $e$ - time exposure, i.e. duration of conditions for the occurrence of a negative event and the value $o$ representing the possibility of using protective measures at the threat stage. The risk function can then be expressed in a form:

$$r = f(p,d,e,o).$$
In most applications, the risk size is simply expressed as the conjunction of the individual variables achieved by evaluating all of the parameters on the selected evaluating scale. Such an approach will also be used in the estimation of societal risk, as the expression of the function of five variables would be problematic.

It is necessary to realize that the analysis of societal risk is contrary to the analysis of e.g. the technical risks (where the probabilities and consequences of relevant risks are rather determinable) implemented with great uncertainty. This uncertainty is mainly due to the stochastic nature of the processes and factors involved (especially their number, character, level, interconnection, etc.) [9, 10].

Uncertainty is also based on subjective or objective barriers that prevent evaluators from clearly quantifying the probability and consequences of an adverse event in the form of societal risk. The determinants of the uncertainty (factors) of such an assessment can generally be divided into:

- **factors of probability value determination with error** - probability deviation $\Delta P$;
- **factors of determining the magnitude of consequences with an error** - deviation of consequences $\Delta D$.

If, when assessing the level of societal risk, the level of absolute knowledge (certainty) of such determinants is maximal, i.e. 100% certainty, total error $\Delta P = 0$ and $\Delta D = 0$, and value of so-called the uncertainty correction is $N = 1$. Conversely, if the level of knowledge of mentioned determinants is minimal, i.e. close to zero (never equal to zero - since it is a nonsense to assess a risk that we know nothing about or if we know about the existence of a risk, it is no longer a zero level of knowledge), $\Delta P$ and $\Delta D$ will acquire real values. These errors will be reflected in the relationship for calculating the size of societal risk through the variable "correction by uncertainty" in the form:

$$N = \frac{1}{\mu_1, \mu_2, \ldots, \mu_n, \mu_{D_1}, \mu_{D_2}, \ldots, \mu_{D_m}},$$

where $N$ is the correction of the risk level by uncertainty, $\mu_1, \mu_2, \ldots, \mu_n$ are the determinants of uncertainty affecting the determination of the probability value with the finite number $n$ for a particular societal risk and $\mu_{D_1}, \mu_{D_2}, \ldots, \mu_{D_m}$ are determinants of uncertainties affecting the determining the magnitude of the consequences with a finite number of $m$ for a particular societal risk.

Determinants $\mu$ take values from the interval $(0,1)$. The interval is closed from the right, open from the left, since to evaluate the probability and consequences of a particular societal risk under the conditions of 100% uncertainty or to evaluate something that does not exist or exist but we do not know about it, has no meaning. The actual number of determinants of a particular societal risk depends on the type of risk. If some of the determinants $\mu$ - despite their existence - are not taken into account, they will be considered determinants of certainty, i.e. $\mu(P, D) = 1$. Partial, e.g. 50% knowledge of determinants of uncertainty then increases the level of estimated societal risk to double. Taking into account the above mentioned facts, the function $r$ or value $R$ of societal risk is:

$$r = f(p, d, n) \quad \text{or} \quad R = P \times D \times N.$$  \hspace{1cm} (4)

The subject of the general risk analysis according to ISO 31000 [11] is the assessment of the risks in terms of their probability and possible negative consequences, while the uncertainties just described are a specificity in the process of societal risk assessment. In the next part of the paper there will be mentioned a procedure allowing to eliminate the possibility of traffic congestion as a possible source of societal risks. It can be assumed that the activation of the source of risk - traffic congestion - causes the existence of societal risks, such as time losses, higher transport / transit costs, increased burden on the environment and so on [12]. This makes it possible to identify the probability of traffic congestion with the probability of occurrence of these societal risks.

### 3. Estimation of Probability of Traffic Congestion Using the Probability Distribution of Vehicles in the Section

The aim of the research is to confirm or disprove on a specific source of societal risks - traffic congestion - possibility of a sufficiently accurate probability estimation of its occurrence using some probability distributions of continuous random variables.

A suggested procedure for estimating the probability of traffic congestion is shown in Fig. 1.

![Fig. 1 Procedure for determining the probability of traffic congestion](image-url)
For traffic congestion, we will consider the event of stopping traffic due to the sudden increase in its intensity on the section of Centrálna street and Pod Hájom street in Žilina in direction to the city in the place in its intersection (Fig. 2).

The statistical survey was carried out by observation during the working day, at the time of morning peak from 6.00 to 9.00 o'clock and the selected statistical unit was a two-minute time interval, a total of 90 values were recorded. The statistical sign represented the number of vehicles that passed through the monitored road section over a given time interval (Fig. 3).

The abovementioned distribution of the absolute number of cars in consecutive two-minute time intervals could be used to calculate the probability of traffic congestion if the limit number of cars, that would cause such a delay on a particular road section that could be considered traffic congestion, would be known. The probability of its occurrence would be equal to the number of cars in a particular interval and the number of cars that would cause an undesired stoppage of traffic for a certain period of time. From the visual assessment of the course of the traffic intensity graph at time intervals, it is necessary to decide which probability distributions of continuous random variables will be tested for compliance with our probability distribution of the number of cars passing through the path section under consideration. We will test the following three distributions: normal, log-normal and gamma.

For verification, good match test was chosen (Pearson chi-square test) whose principle according to [13] is to compare the calculated test criterion \( \chi^2 \) with its critical value at the significance level \( \alpha = 0.05 \), and the corresponding degrees of freedom. If the value of the test criterion is less than the critical value, we accept the null hypothesis \( H_0 \) on the agreement of the empirical distribution with the theoretical - assumed distribution. In this way it is possible to confirm the assumption that the probability of vehicle abundance and thus the emergence of traffic congestion can be estimated by some of the known theoretical probability distributions [14]. Otherwise, we reject the null hypothesis and accept the alternative hypothesis \( H_1 \) which confirms the opposite. Before testing, it was necessary to sort out the number of vehicles in time intervals (Table 1).
The first was tested the consistency of the distribution of the empirical file with the normal probability distribution [14]. Parameters of the empirical file: mean value $\mu = 41.51$ and dispersion $\sigma^2 = 66.45$.

<table>
<thead>
<tr>
<th>Classes</th>
<th>Number of cars</th>
<th>Number of time intervals</th>
<th>Probability of cars number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper limit</td>
<td>Lower limit</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>&lt; 22</td>
<td>27 &gt;</td>
<td>8</td>
</tr>
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<td>2</td>
<td>27 &gt;</td>
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</tr>
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<td>3</td>
<td>32 &gt;</td>
<td>37 &gt;</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>37 &gt;</td>
<td>42 &gt;</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>42 &gt;</td>
<td>47 &gt;</td>
<td>17</td>
</tr>
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<td>6</td>
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<td>17</td>
</tr>
<tr>
<td>7</td>
<td>52 &gt;</td>
<td>56 &gt;</td>
<td>9</td>
</tr>
</tbody>
</table>

The test characteristic criterion value was 8.79, with a critical value of 0.94 at four degrees of freedom. The result of the test showed that we accept the null hypothesis of agreement of the empirical distribution with the theoretical normal distribution at a significance level of $\alpha < 0.06$. At such considered significance level, it can be confirmed that the number of cars in two-minute intervals is a random event that can be described by the normal probability distribution with the above parameters.

The second tested probability distribution of the continuous random variable was gamma distribution with the specified parameters: $a = 25.92$ and $b = 0.62$. The chi square test characteristic value was 26.48. The coincidence of the distribution of continuous time intervals frequency according to the number of cars with tested gamma distribution was determined by the critical value of the test characteristic, which was 0.9998 for four degrees of freedom.

The zero hypothesis $H_0$ could only be accepted in this case assuming the significance level $\alpha < 0.0002$. For the error probability level of 0.05, this hypothesis was rejected. As a result, it could be concluded that distribution of the number of time intervals according to the number of cars is not consistent with the gamma distribution of the gamma random variable with the respective parameters. The sorted file was then tested by $\chi^2$ goodness-of-fit test for normal distribution, gamma distribution, and log-normal distribution (Table 2).

The theoretical frequency values of TP and $\chi^2$ test for individual tested distributions

<table>
<thead>
<tr>
<th>Normal distribution</th>
<th>Gamma distribution</th>
<th>Log-normal distribution</th>
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</thead>
<tbody>
<tr>
<td>TP</td>
<td>$\chi^2$</td>
<td>TP</td>
</tr>
<tr>
<td>4,70</td>
<td>2,31</td>
<td>1,98</td>
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<td>4,11</td>
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<td>0,31</td>
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<tr>
<td>20,31</td>
<td>0,54</td>
<td>19,03</td>
</tr>
<tr>
<td>13,60</td>
<td>0,85</td>
<td>12,07</td>
</tr>
<tr>
<td>7,59</td>
<td>0,26</td>
<td>9,59</td>
</tr>
<tr>
<td>$\Sigma$ 90,00</td>
<td>8,79</td>
<td>90,00</td>
</tr>
</tbody>
</table>

The last tested distribution was the log-normal distribution, whose calculated parameters were as follows: mean $\mu = 3.71$ and dispersion $\sigma^2 = 0.19$. The test characteristic $\chi^2$ was determined at level 35.84. At four degrees of freedom, the critical value of the test characteristic was 1, which resulted in the rejection of the null hypothesis about the consistency in all cases as the significance level was $\alpha > 0$. Probability density functions of all tested distributions, along with the histogram of traffic intensity probability of the monitored road section, i.e. the relative frequency of the intervals according to the number of vehicles are shown in Fig. 4.

The results of testing the conformity of the absolute frequency of cars (traffic intensity in two-minute intervals) and selected theoretical probability distributions of the continuous random variable showed that at the selected significance level $\alpha = \min 0.05$, the probability of a specific value of traffic intensity (vehicle frequency) on a given road section and at a given time can be determined based on the normal probability distribution with parameters $\mu = 41.51$ and $\sigma^2 = 66.45$. The last tested distribution was the log-normal distribution, whose calculated parameters were as follows: mean $\mu = 3.71$ and dispersion $\sigma^2 = 0.19$. The test characteristic $\chi^2$ was determined at level 35.84. At four degrees of freedom, the critical value of the test characteristic was 1, which resulted in the rejection of the null hypothesis about the consistency in all cases as the significance level was $\alpha > 0$. Probability density functions of all tested distributions, along with the histogram of traffic intensity probability of the monitored road section, i.e. the relative frequency of the intervals according to the number of vehicles are shown in Fig. 4.

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In calculating the probability of traffic congestion at the i-interval, the absolute numbers of vehicles in time intervals were considered for traffic intensity \( I \) and the limiting frequency of cars that cause traffic congestion [15] for maximum permeability of a given road section \( P_{\text{max}} \).

The probability of a particular traffic intensity Fig. 4 Test probability distributions and histogram of relative frequencies by vehicles number

For the probability of traffic congestion considered only to the level of traffic intensity at the limit of maximum permeability of the road section is valid:

\[ p_s = \frac{I}{P_{\text{max}}}. \] (5)

Traffic intensity, i.e. the maximum number of vehicles at the selected probability level of their occurrence can be determined (e.g. in MS Excel) using the inverse function to the distribution function of the normal distribution with the calculated parameters \( \mu \) and \( \sigma^2 \) [16, 17]. The probability of traffic congestion with changes in the permeability of a road section e.g. because of the planned construction activity, traffic accident or other event [18], presents Table 3.

<table>
<thead>
<tr>
<th>Probability on inverse distribution function of normal distribution</th>
<th>0.95</th>
<th>0.85</th>
<th>0.75</th>
<th>0.65</th>
<th>0.55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic intensity ( I )</td>
<td>54.92</td>
<td>49.96</td>
<td>47.01</td>
<td>44.65</td>
<td>42.53</td>
</tr>
<tr>
<td>Permeability of road section ( P_{\text{max}} )</td>
<td>30.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>40.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>50.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.94</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>60.00</td>
<td>0.92</td>
<td>0.83</td>
<td>0.78</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>70.00</td>
<td>0.78</td>
<td>0.71</td>
<td>0.67</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>80.00</td>
<td>0.69</td>
<td>0.62</td>
<td>0.59</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>90.00</td>
<td>0.61</td>
<td>0.56</td>
<td>0.52</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>100.00</td>
<td>0.55</td>
<td>0.50</td>
<td>0.47</td>
<td>0.45</td>
</tr>
</tbody>
</table>

It is clear from the values in Table 3 that if the maximum permeability of the road section under consideration - Pod Hájom / Centrálna street – for some reasons will be reduced to 60 vehicles, with a probability of 0.95 (probability of error 0.05), according to the normal distribution, traffic intensity will be to about 55 vehicles, which at that moment would represent a probability of traffic congestion of up to 0.92.

4. Conclusions

We are of the opinion that with sufficient degree of certainty of the investigated event – e. g. in the case of statistical detection or observation, the probability of a random event can be determined, with sufficient accuracy, on the basis of appropriate probability distributions with correctly determined parameters.

However, the findings cannot be fully generalized to all congestion conditions. It can be argued that at time intervals \( t_i + 2 \text{ min} \), at peak hours (from 6.00 to 9.00) the number of vehicles, passing through Pod Hájom – Centrálna...
street in two-minute intervals, are governed by normal probability distribution with relevant parameters which can be used to calculate the probability of traffic congestion and thus the probability of occurrence of societal risks.

Based on the obtained results, it can be concluded that the application of the probability distribution of a continuous random variable to calculate the probability of a particular societal risk is realistic. Future solutions to this issue could be based, for example, on the statistics data of cars speed passing through a given road section to determine the number of vehicles stopping traffic flow. In this case, the advantages of software solutions [15] in the field of transport engineering could be applied.

Acknowledgement

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References

Computational Assessment of the Impact of the Pneumatic Piston Engine Valve Timing Phases on its External Parameters

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Abstract

The study presents the influence of the valve timing on the operation of a pneumatic piston engine. Within the scope of simplifying assumptions, a mathematical model was developed. It combines a mechanical part with a pneumatic one. The calculations were carried out using the Matlab-Simulink software. In the comparative analysis, the full load engine characteristics were determined at the variable inlet angle. The calculations carried out proved the validity of the thesis about the need to shift the inlet symmetry relative to Top Dead Center (TDC). Previous studies have suggested that a functional inlet system symmetrically may cause lower values of external parameters. This is due to the fact that the inlet air is compressed at the end of the stroke near TDC. It has also been shown that moving the inlet symmetry gives power gains and decreases in Brake-Specific Air Consumption (BSAC) in different ranges. The adaptive inlet control is suggested, depending on the rotation speed. Finally, the full load engine speed characteristics were determined at the specified inlet valve timing shift being the intermediate value between the maximum and minimum power of the BSAC.

KEY WORDS: mechanical engineering, combustion engines, fuel supply, testing, passenger car

1. Introduction

Constant reduction of exhaust emission standards issued by combustion engines used in transport forces the search for new propulsion sources. In global terms, a reduction of GHG (GreenHouse Gas) is suggested. Emissions from the transport sector (EU) should reach up to 60% by 2050 compared to 1990 and by ca. 20% by 2030 compared to emissions in 2008 [1]. It is suggested to use alternative sources of energy [2]. The latest emission regulations, including WLTP (World Harmonized Light Vehicle Test Procedure) [3] and RDE (Real Driving Emissions) [4], force car makers to use increasingly expensive exhaust after treatment systems. Under the new rules, cars will be tested in the laboratory and in real road conditions. The small engines for non-road mobile machinery [5] remain, which require adaptation to new legal regulations [6].

Analyzing the classic gasoline engine, for years there has been a steady progress in work on improving the organization of combustion processes, such as ATAC (Active Thermo-Atmosphere Combustion) [7], CAI (Controlled Auto-Ignition) / HCCI (Homogeneous Charge Compression Ignition) [8], HPDI (High Pressure Direct Injection) or RCCI (Reactivity Controlled Compression Ignition) [9]. Diesel engines have recently lost their reputation for emission problems. Alternative fuels are successfully implemented, for example LPG (Liquefied Petroleum Gas) [10, 11] biogas [12, 13] and others. The electric drive is used, which is the most prospective in terms of exhaust emissions from the vehicle, eliminating the harmfulness of electricity production.

A pneumatic drive is an alternative to an electric drive or an advanced combustion source. In the case of pneumatic engine [14], the actuator and the crank system can be used in the simplest version [15, 16]. In addition, research is conducted on the use of pneumatic vane [17, 19] and rotary [19] engines. Sometimes only the systems [20]. Hybrid systems [21, 22] are also being created.

The pneumatic engine is developed by many companies, including MDi [23], Engineair [24]. Pneumatic piston engines is a two-stroke cycle motor with a forced rotation direction during start-up [25]. The future sees the use of piezoelectric valves [26, 27] allowing for more precise dosing of air. It should also be remembered that electromagnetic valves are characterized by unevenness and non-repeatability of action [28, 29]. A number of experiments and strengths in pneumatic engines. They are directly related to engine processes [30], or they can be selected from general research [31, 32, 33].

The research proposes a mathematical description of the operation of a pneumatic piston engine with variable inlet regulation. This model can be further developed and defined in terms of new variables, such as the inlet and outlet system, compression ratio or unconventional crank system.

2. Subject of the Calculation

The object of research was the pneumatic piston engine with parameters presented in Table 1. This was a modification of the Romet 50 type 019 combustion engine. In the place of the spark plug, a ball valve supplying compressed air was installed. The valve was opened by a pin installed in the plunger. In addition, the compression ratio was lowered using the pad under head.
3. Calculation Methodology

The scheme presented in Fig. 1 was adopted for the model description. At the beginning it was necessary to formulate the simplifying assumptions. They were divided into two parts: mechanical and pneumatic. The simplifications have been introduced as follows:

a) mechanical parts:
   - the torque transfer system was perfectly stiff;
   - the influence of elastic vibrations was omitted;
   - energy flow flows without loss;
   - the pressure course depends on the timing and input and output pressure as well as the position of the piston.

b) pneumatic parts:
   - the air was regarded as a thermodynamically ideal gas, while being viscous and compressible;
   - the flow takes place without internal friction and heat exchange with the surroundings;
   - the state of the air was constant in a given volume and depends on time;
   - the joints of the individual elements of the tested object were perfectly airtight;
   - the air properties were assumed to be uniform in the local volume and in the entire cross-section of the flow through the local resistance;
   - the air temperature was constant in the process.

![Fig. 1 Scheme of the mechanical and pneumatic system](image)

The equation of torque instantaneously generated by the one-cylinder engine at a constant load and angular crankshaft speed can be presented in the form [34] (Eq. 1). In two stroke, one-cylinder engines the work cycle involves one full crankshaft revolutions (angle 2π). The S(α) function for the one-cylinder engine will be [35] (Eq. 2):

\[
T_c = R A_p S p_c - R^2 m_c S (\cos \alpha + \lambda \cos 2\alpha) \omega^2 ,
\]

\[
S = \frac{\sin(\alpha + \beta)}{\cos \beta} = \frac{\lambda \sin 2\alpha}{2 - \lambda \sin^2 \alpha} + \sin \alpha ,
\]

where \(\alpha\) – the angle of crankshaft rotation; \(R\) – the crank radius; \(A_p\) – piston area; \(p_c\) – pressure in cylinder; \(L\) – the length of the connecting rod; \(\lambda\) – the connecting rod coefficient \(L/R\); \(\omega\) – angular crankshaft speed.

When the instantaneous torque is greater than the average one, the instantaneous angular crankshaft speed increases, when is smaller – decreases. The angular crankshaft speed was calculate from [36]:

<table>
<thead>
<tr>
<th>Engine technical data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engine type</strong></td>
<td>pneumatic, two-stroke</td>
</tr>
<tr>
<td><strong>Number of cylinders</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Timing system (throughput): inlet / outlet</strong></td>
<td>(\max(\mu A)<em>{in} = 30e^{-6} \text{ m}^2 / \max(\mu A)</em>{out} = 62e^{-6} \text{ m}^2)</td>
</tr>
<tr>
<td><strong>Displacement</strong></td>
<td>(4.980e^{-5} \text{ m}^3)</td>
</tr>
<tr>
<td><strong>Bore</strong></td>
<td>(38.000e^{-3} \text{ m})</td>
</tr>
<tr>
<td><strong>Stroke</strong></td>
<td>(44.000e^{-3} \text{ m})</td>
</tr>
<tr>
<td><strong>Connecting rod length</strong></td>
<td>(88.500e^{-3} \text{ m})</td>
</tr>
<tr>
<td><strong>Compression ratio</strong></td>
<td>4.000</td>
</tr>
<tr>
<td><strong>Weight of the components involved in the reciprocal motion</strong></td>
<td>0.25 kg</td>
</tr>
</tbody>
</table>
The mass moment of inertia of the rotating elements of the engine will be [36]:

\[ J_E^\Sigma = 0.64 m_B R^2 \]  

(4)

where \( J_C \) – the crankshaft mass moment of inertia; \( J_F \) – the flywheel mass moment of inertia; \( m_B \) – the replacement mass of the part of the connecting rod rotating on radius \( R \) of the \( x \)-th crank.

For the mathematical description of pneumatic parts, the lumped elements method was used [37]. The change of pressure in a cylinder with variable volume can be described:

\[ \frac{d p_v}{d t} = \frac{\kappa R T}{V_c} \left( \dot{m}_c - \dot{m}_{out} - \frac{p_c}{R T_{air}} \frac{d V_c}{d t} \right), \]

(5)

where

\[ \dot{m}_{in} = \rho_{in} \left( \mu A \right) \sqrt{\frac{R T}{p_{in}}} \psi_{max} a \frac{p_{in} - p_c}{p_{in}}; \quad \dot{m}_{out} = \rho_{out} \left( \mu A \right) \sqrt{\frac{R T}{p_{out}}} \psi_{max} a \frac{p_c - p_{out}}{p_{out}}, \]

(6)

where \( p \) – pressure; \( V \) – volume; \( \mu \) – throughput; \( T \) – air temperature; \( R \) – gas constant; \( \kappa \) – adiabatic exponent; \( \psi_{max} \) – maximum value of the function St Venant and Wantzel; \( \sigma \) – dimensionless function of flow; \( \rho \) – pressure ratio; \( a \) – constant parameter value of Metlyuk-Avtushko function; \( p_{in} \) – inlet pressure; \( p_{out} \) – outlet pressure; indexes: \( air \) – the air; \( c \) – cylinder; \( in \) – inlet; \( out \) – outlet.

The differential Eq. 5 was solved numerically with the implicit trapezoidal method combined with reverse differentiation using Matlab-Simulink. The mechanical parameters were calculated from the Eq. 1 and Eq. 3, denoting as \( n \) is the rotation speed of the engine.

\[ n = \frac{\omega}{2\pi} \]

(7)

The calculation procedures have been written in the Matlab-Simulink code (Fig. 2).

Fig. 2 Block diagram (a), exemplary curves of calculated values (b) and an indicator diagram (c)

4. Necessary Parameters to Initiate the Calculation

To initiate the calculation, the input parameters must be known along with the boundary conditions, as shown in Table 2.
Necessary parameters to initiate the calculation

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Boundary conditions (t = 0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet pressure</td>
<td>1.000e5 Pa</td>
</tr>
<tr>
<td>Atmospheric pressure</td>
<td>10.000e5 Pa</td>
</tr>
<tr>
<td>Air temperature</td>
<td>293.150 K</td>
</tr>
<tr>
<td>Adiabatic exponent</td>
<td>1.400</td>
</tr>
<tr>
<td>Max. value of the SVW funct.</td>
<td>0.578</td>
</tr>
<tr>
<td>Factor of the MA function</td>
<td>1.130</td>
</tr>
<tr>
<td>Angle of crankshaft rotation</td>
<td>0 rad</td>
</tr>
<tr>
<td>Displacement of pistons</td>
<td>0 m</td>
</tr>
<tr>
<td>Volume of cylinder</td>
<td>combustion chamber</td>
</tr>
<tr>
<td>Pressure in cylinder</td>
<td>1.000e5 Pa</td>
</tr>
<tr>
<td>Throughput of the timing system</td>
<td>(μA)_{in} = depends on the variant</td>
</tr>
<tr>
<td>(μA)_{out} = 0 m²</td>
<td></td>
</tr>
</tbody>
</table>

For calculation initialization purposes, it was necessary to determine the timing system. The basic modification of the calculated one-cylinder pneumatic engine allows for a symmetrical setting of the inlet with respect to TDC (Top Dead Centre) and the outlet with respect to BTC (Bottom Dead Centre). As shown in [38] symmetry of the intake with respect to TDC, the effect of "wrapping" the pressure (A in Fig. 2c). It may result in a loss of power resulting from air compression before TDC.

The imperfection of the engine's air supply shown in [38] showed the way of searching for a solution to this problem. It was decided to "seemingly" way the inlet leaving the outlet in the same place. Eight variants of the valve timing were proposed. They were regulated by the intake from the position symmetrical with respect to TDC to the position of the total opening cycle after TDC (Table 3). This can be practically accomplished with a solenoid valve whose cycle will be regulated against TDC.

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Variants of the timing change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full opening angle, deg</td>
</tr>
<tr>
<td>Variants</td>
</tr>
<tr>
<td>Start of the opening angle</td>
</tr>
<tr>
<td>α_{start}, deg</td>
</tr>
<tr>
<td>Engine speed, rpm</td>
</tr>
</tbody>
</table>

A graphical interpretation of the timing regulation was shown in Fig. 3.

![Fig. 3 Proposed variants of the valve timing](image)

5. Results and Discussion

Each time it was necessary to approximate the mean torque value (T_{mean}) several times. This was caused by the situation resulting from the conditions of supplying compressed air (valve timing) and the angular crankshaft speed of the crankshaft. These conditions determine the value of torque, and for the correct calculation of the angular speed, the average value of T_r is needed. Therefore, the angular speed obtained from the calculations differ slightly from the set ones. The calculations were carried out for 11 full revolutions of the crankshaft. The analysis rejected the first rotation due to incomplete work in this (B in Fig. 2c). This was due to boundary conditions of the pressure in cylinder at the start calculation - atmospheric (Table 2).

The offset of the inlet valve timing reduces the "wrapping" of the pressure around the TDC, which can contribute to the increase of the power generated by the engine. It was visible on the compilation of indicator diagrams that the displacement of the inlet valve timing phase brings the intended purpose. The disappearance the "wrapping" of the pressure in the vicinity of TDC (A in Fig. 4 – variants I and II) increases the surface area of the cycle. Too large displacement of the inlet valve timing results in a delayed pressure increase (B in Fig. 4 – variants VI, VII and VIII). For energy assessment, the area of the indicator diagrams is important, which translates into the average indicated pressure and, as a result, the torque of the engine.
For the further analysis a formula for calculating engine power was described:

\[ P = T_r \cdot 2\pi n \]  

(8)

and BSAC (Brake-Specific Air Consumption):

\[ BSAC = \frac{m_{in}}{P}. \]  

(9)

The calculation results are summarized in the full load engine characteristics (Fig. 5). Taking into account the power generated by the engine, for the lower rotational speeds (500 ... 2000) rpm the angle of the inlet should be set for variant VI (0 deg), for higher (3000 and 4000) rpm for variant IV (−21 deg). BSAC obtains the lowest values in the scope of variants III...V.

Fig. 5 The full load engine characteristics

Fig. 6 The full load engine speed characteristics
Finally, it was assumed the base inlet set value variant V (−10 deg) and for this value the full load engine speed characteristics was determined. The supply relative pressure was 10 e 5 Pa and the rotation speed range (500...4000) rpm. As seen in Fig. 6, the max. power is 1.4 kW (at 3000 rpm) and the max. torque is 5.4 Nm (at 2000 rpm). The maximum value of the power of the pneumatic engine is lower than in the case of the original internal combustion engine \( P_{\text{comb,max}} = 1.84 \text{ kW at 5000 rpm} \), while the maximum torque exceeds the internal combustion engine \( T_{\text{comb,max}} = 2.95 \text{ Nm at 5000 rpm} \). The maximum values of both parameters are achieved by the pneumatic motor at lower rotational speeds. However, it should be remembered that the presented mathematical model contained many simplifications and can’t be directly compared to the actual object. Only the prototype of the pneumatic motor can verify the proposed changes in the valve timing.

6. Conclusions

The mathematical description of the piston pneumatic engine presented in study allows an approximate analysis of its operation. The base was a modified one-cylinder internal combustion engine. Previous studies have suggested that a functional inlet system symmetrically to the Top Dead Center (TDC) may cause lower values of external parameters. This is due to the fact that the inlet air is compressed at the end of the stroke near TDC.

An attempt was made to assess the impact of the inlet phase shift (in the adopted range) on external parameters. The test results showed that variable inlet regulation (respect to rotation speed) would be most effective, as it is in the combustion engine (variable valve timing). The displacement of the inlet does not give power increments and decrease of BSAC in the same ranges. Therefore, in the final variant, it was proposed to place the inlet of about 10 deg before TDC. On this basis, the full load engine speed characteristics were determined. It has been demonstrated in the adopted model simplifications that the pneumatic engine can be effective.

Pneumatic motors are an alternative, clean drive source. The advantage of this solution is the release of air into the atmosphere, which can be very slightly contaminated with oil from the compressor or lubrication engine system. We do not have to collect air before "refueling", we can compress them directly in the process. Currently, vehicles with this type of drive have a problem with collecting enough air (tanks) and emit noise, which is not the case with an electric motor.

Acknowledgment

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References

Safety Issues in Fully Autonomous Cars: A Turkish Perspective

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Abstract

The main objective to build autonomous cars is to reduce the number of road traffic accidents. However, people may not feel completely safe in and around autonomous cars since the control of the car is taken from the occupants. There have been accidents involving autonomous cars, even with casualties. The unconventional seating plans suggested for autonomous cars can put the occupants at more risk unless new restraint systems are designed. There will also be a transition phase of mixed traffic flow which will involve both autonomous cars and conventional cars; this can complicate the decision making process of autonomous cars. Safe transportation with autonomous cars also requires good road infrastructure. Personal data security and hacking are also other concerns that occupants have to deal with. In order to investigate the cultural attitude towards the safety of fully autonomous cars in Turkey, 21 males and 20 females aged between 11 and 60, were interviewed and 12 questions were asked. Only 30% of the participants said they would feel completely safe in an autonomous car. This study can be useful for researchers who study cultural differences in the attitudes of societies towards autonomous cars. What’s more, the presented ideas for seating and restraint systems can be of help for designers.

KEYWORDS: autonomous cars, vehicle safety, survey, cultural attitudes

1. Introduction

It is a well known fact that 90% of road traffic accidents are due to human error [1]. The idea behind developing autonomous cars is to take control from the human driver and hence increase road safety, enhance the flow of road traffic, enhance fuel economy, enable other tasks to be done other than driving in the car and provide transport for vulnerable occupants (disabled people, children and the elderly). Shared autonomous cars can reduce the amount of parking required. Sharing these cars can reduce the number of car ownership hence may decrease traffic jams.

Autonomous cars can be involved in accidents or cause accidents [2, 3, 6] and in some cases lead to death as known from the media reports [2, 3]. There will certainly be a transition phase in which both autonomous and conventional cars will be in the traffic. Even autonomous cars will sometimes be used in the manual mode when all cars are autonomous. In a recent study regarding autonomous car accidents in California [6], rear-end collisions have been recorded to be the most frequent accident in which conventional cars impacted autonomous cars; such accidents occurred mainly at intersections where in 15% of the cases, the autonomous vehicle was culpable; only in 3 cases out of 26, autonomous technology was able to detect and react before the impact. This recent study [6] indicated that in a mixed traffic flow, autonomous cars have a higher rate (about 10 times more) of being involved in an accident in comparison to conventional cars. Autonomous cars have been tested on urban roads in developed countries where road infrastructure is good but the performance of autonomous cars has to be questioned in rural roads and in countries where traffic culture is different and traffic law violation is higher.

Autonomous cars can accommodate different seating plans [4] for the occupants since other tasks such as eating, sleeping, reading can be performed instead of driving. For this reason, moveable and removable seats can be designed. The restraint systems of conventional cars are designed for forward facing seats. It is expected that using seats at different orientations and reclining the seats will require different or extra restraints and the public should be willing to use these additional restraints [4]. Unconventional seating positions can increase the injury risk of occupants in case of an accident [10]. For instance, an occupant sitting on a rear facing seat can experience higher risk of whiplash in a frontal impact considering the fact that statistically frontal impacts do happen at higher severities than rear impacts as seen in the crash test conditions of EuroNCAP [8].

Hackers (cyber attacks) are a potential problem regarding the security and crash safety of the occupants. Hijacking of expensive vehicles and abduction of important people are issues to be concerned about. Autonomous cars will connect with other vehicles and infrastructure and this could make the car become vulnerable to cyber attacks. In a recent literature review on cyber threats [5], it is mentioned that counterfeit GPS signals can be generated to mislead GPS devices; wireless connection between sensors and electronic control units of a car can be compromised; LiDAR (light detection and ranging) sensor can be jammed by directing bright light onto the vehicle; malicious code can damage firmware updates at source; personal data stored in the car could be used by third-parties for advertisement and theft; security can be compromised by ransomware and phishing attacks considering the existence of embedded e-mailing, web browsing and bluetooth capabilities; signal jamming attacks can be performed to block the communication of the car and if the car detects a cyber attack, how will the technically inexperienced driver react safely to this situation? Countermeasures against
these cyber attacks can involve encrypted communication on the vehicle’s communication network, sensor redundancy, encrypted remote updates of firmware using wireless technology, and activating a safe mode for the driver to regain control of the car [5]. Apart from these threats, car sensors may not work efficiently and correctly in bad weather conditions. Besides, the driver may need to take control of the car in complex traffic conditions where the car computer may not resolve the situation [9].

Considering these issues regarding the security and safety of occupants, a survey was conducted to ask the opinions of Turkish people about mainly the safety problems regarding fully autonomous cars (SAE level five). It is observed that there is a some lack of trust in autonomous cars and a high percentage of participants feared cyber attacks.

2. Survey Questions and Answers

21 males and 20 females aged between 11 and 60, were interviewed and 12 questions were asked. The participants were mostly university students with an average age of 24.9 and with a standard deviation of 10.6 years. 60% of males and 81% of females had driving licence. The interviewees had sufficient knowledge on the safety of autonomous cars, informed the participants of the need for autonomous cars, presented them different opinions concerning the questions asked and allowed the participants to discuss about the questions with each other. In each interview, there was a single participant or a group of 2 participants. The duration for each interview was 20 to 30 minutes.

Question 1: Would you like to have a different seating plan in an autonomous car? How would you like it to be?

64% of male participants and 70% of female participants favoured a different seating plan. The preferred activities in the car were watching television, playing games, sleeping and reading. While some opted for rotatable, foldable and expandable seats, some preferred only forward and rear facing seats as in trains. The participants who did not want a change in the conventional seating plan expressed that changing the current restraint systems that had been optimised for so many years would not be a good idea and emphasised that the current child restraint and child seat system should be preserved. One male participant considered limited on the rotation of the seat at higher speeds.

Question 2: Would you feel completely safe in an autonomous car? What are the reasons for your answer?

30% of male participants and 28% of female participants said they would feel completely safe. The reasons for not trusting autonomous cars are the lack of trust in machines such as computers which can malfunction at times, the state of technology not being sufficient, potential cyber attacks, sensors’ limited working capacity and malfunction due to environmental conditions, insufficient infrastructure in rural roads, the potential difficulty in the decision making of computers in complex traffic scenarios, difficulty to protect occupants in unconventional sitting positions, considerable number of Turkish drivers who are not obeying the traffic rules, and underdeveloped infrastructure on some roads in Turkey. One participant who is a university professor noted that sensors could not detect everything; fog could compromise autonomous navigation systems based on LiDAR technology (which utilizes laser beams); radars could get affected by rainfall; GPS could be spotty and added that the range of sensors were limited such as cameras with a limited seeing range of 30 metres in good weather. Some participants expressed that the risk of pedestrian impacts might never be reduced considerably in Turkey considering the violation of traffic rules by the pedestrians. Many participants said that they would feel safer in traffic where all cars were autonomous.

Question 3: For comfort and safety, how would you design restraint systems for autonomous cars considering unconventional seating plans?

Many participants indicated that a seat-centric restraint system in which seatbelt and airbag are integrated into the seat, would be the best solution. For sleeping on a reclined seat, extra seatbelts were suggested to keep the occupant on the seat. Some suggested extra and enlarged airbags for arbitrary seating positions. There were ideas to design airbags that could be deployed from the roof surrounding the occupant in all directions; some airbags could be deactivated or the seat. Some suggested extra and enlarged airbags for arbitrary seating positions. There were ideas to design airbags that could be deployed from the roof surrounding the occupant in all directions; some airbags could be deactivated or expanded seats, some preferred only forward and rear facing seats as in trains. The participants who did not want a change in the conventional seating plan expressed that changing the current restraint systems that had been optimised for so many years would not be a good idea and emphasised that the current child restraint and child seat system should be preserved. One male participant considered limited on the rotation of the seat at higher speeds.

Question 4: Would you support the idea of rotating the seat base into a favourable position 1 or 2 seconds prior to impact so as to better protect the occupant?

This idea was suggested in reference [10]. 68% of male participants and 58% of female participants supported this idea. The participants who opposed this idea expressed that the arms and the feet could get stuck during this sudden rotation of the seat base, the rotation of the seat base could displace the head and the torso with respect to the seat causing ineffective interaction with the airbag, risk of occupant injury could increase if seatbelt was not fastened and the occupants could drop hot, sharp and heavy objects during this sudden rotation.

Question 5: Should under 18 years olds use autonomous cars on their own?

84% of male participants and 75% of female participants opposed under 18 years olds to use the autonomous cars by themselves. Some said that people who owned a conventional driving licence should be allowed to use the car on their own. Some participants suggested that teenagers between 15 and 18 years old could use the car by themselves on the condition that they got parental approval. Many participants stressed that under 18 years old were inclined to take risks and be adventurous if they were left on their own.

Question 6: Who should be kept responsible if the autonomous car is involved in an accident?

71% of male participants and 75% of female participants thought that the car company must be kept responsible if the autonomous car was at fault. Some argued that the occupant must be responsible if he/she took control of the car.
after the accident. One participant indicated that an accident could occur during switching from autonomous mode to manual mode and such cases have been observed in real life [6]. The causative factor for the accident to happen could be related with the software and/or hardware, hence some participants believed that people who built the hardware and/or software must be kept responsible. In order to determine the cause of the accident, some participants suggested the investigation of black-box (or event data recorder (EDR)) data. Some believed that if the crash was unavoidable, then the car company should not be kept responsible. One participant emphasised that in many inevitable pedestrian impacts, the pedestrians were at fault. A few participants reminded that if the accident occurred as a result of poor road infrastructure, then the municipality must be kept responsible. One participant also stressed that other factors such as the neglect of car maintenance, adverse weather conditions must also be taken into account.

Question 7: How should autonomous cars behave if it is dangerous to travel in adverse environmental conditions such as hail, tornado and fire?
Considering that the autonomous car may refuse to operate under such circumstances, 71% of male participants and 85% of female participants expressed that the occupant must take control of the car (manual mode) to save lives and run away from the disaster. The car sensors may malfunction under these extreme conditions. One participant who is a university professor noted that some sensors did not work at very high temperatures and there were gaps in sensor algorithms. The participants suggested the use of an emergency button or a message from a weather/traffic control centre to override the autonomous car’s refusal to operate in such an emergency case. In such cases, the responsibility belongs to the driver.

Question 8: In emergency cases (like going to a hospital), should the autonomous car violate traffic laws such as speeding? If the crash is unavoidable, how should the autonomous car behave to save lives?
70% of male participants and 67% of female participants considered that in such emergency cases, the manual mode must be activated and traffic laws could be violated. A few participants suggested that traffic law violation should only be at low or medium level. Some noted that the occupant should inform the traffic control centre of the emergency case by wireless technology and get approval prior to law violation and the police would afterwards check the authenticity of this request by investigating the case. If the crash is inevitable, participants said that the autonomous car should make a risk analysis so as to take an action which minimised injury and death risk for both the occupants and vulnerable road users. They said that the car should manoeuvre itself to hit lifeless objects first but this could increase the risk of injury to car occupants. The structure of the car and restraint systems can protect the occupants in the car but for vulnerable road users such as pedestrians, the car could change its direction as suggested and even external airbags could be deployed from the car body to cushion the pedestrian. If there is no way of avoiding a pedestrian impact, then participants expressed that it would be a very difficult moral issue to differentiate between people and decide who should die. One participant suggested that it should be compulsory for the pedestrians to use footbridges and subways to cross the roads but this requires more such passages to be built. Another participant suggested that the autonomous car could be programmed to drive itself in emergency mode in which the car could travel at higher speeds like a professional race driver.

Question 9: Would autonomous driving degrade the driving skills of the user?
All of the participants noted that there must be a manual mode so that the occupant could take control of the car however 29% of male participants and 53% of female participants expressed that prolonged use of the car in autonomous mode would degrade the driving skills of the user.

Question 10: Are hackers a serious threat facing autonomous cars?
90% of male participants and 85% of female participants felt that hacking (cyber attacks) was a real and serious problem. Some participants feared that hacking could have serious consequences such as hijacking cars and assassination attempts. Participants stressed that better security systems must be developed and in case of a cyber attack, the system should warn the occupant who could switch to manual mode. The participants who did not worry too much about hacking believed that the risk of stealing conventional and autonomous cars would be equal, there would be better protection and such cases have been observed in real life [6]. The causative factor for the accident to happen could be related with the software and/or hardware, hence some participants believed that people who built the hardware and/or software must be kept responsible. In order to determine the cause of the accident, some participants suggested the investigation of black-box (or event data recorder (EDR)) data. Some believed that if the crash was unavoidable, then the car company should not be kept responsible. One participant emphasised that in many inevitable pedestrian impacts, the pedestrians were at fault. A few participants reminded that if the accident occurred as a result of poor road infrastructure, then the municipality must be kept responsible. One participant also stressed that other factors such as the neglect of car maintenance, adverse weather conditions must also be taken into account.

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infrastructure that was required to work efficiently with autonomous cars. Many participants stressed that state subsidies and tax cuts could help the proliferation of autonomous cars on the roads.

3. Discussion

In this study, 21 males and 20 females aged between 11 and 60, were interviewed and 12 questions were asked regarding safety issues in fully autonomous cars. This paper presents the Turkish perspective on this issue. The selected participants had a mean age of 24.9 and with a standard deviation of 10.6 years who were familiar with the recent technology and who will constitute a high percentage of autonomous car users in the future.

About 66% of the participants favour changes in the seating plan in autonomous cars. However, only 30% of the participants said they would feel completely safe in an autonomous car. Participants were also asked to conceive ideas for restraints to protect occupants in different seating positions and postures; most of them suggested a seat-centric restraint system. 77% of the participants did not approve under 18 year olds to ride in autonomous cars alone. 72% of the participants believed that when an accident occurred, the responsibility belonged to the car company. 70% of the participants thought that the autonomous car should violate traffic rules in cases of emergency. All of the participants felt that the occupant should take control of the car when it was really necessary such as a malfunction of the system or an emergency situation. Only 40% of the participants thought the occupants would lose their driving skills under prolonged usage of autonomous cars. 87% of the participants considered that hackers posed a great risk to the safety of autonomous cars. 75% of the participants believed that autonomous cars should report to the police any violation of law by other cars. 90% of the participants said that road traffic could become much safer when all the cars were autonomous but stressed the importance of road infrastructure in achieving this. 74% of the participants thought that autonomous cars would be sold widely on the market before year 2050.

In this paper, the attitudes of males and females are also compared in detail. In general, similar percentages of males and females shared the same opinion for the questions asked. However, there are some differences in opinions as follows. More females than males thought that using autonomous cars would lower their driving skills appreciably. More males than females favoured the idea of sudden rotation of the seat base to better protect the occupant prior to impact. More females than males thought that autonomous cars should report violations of traffic rules by other cars. More females than males expressed that there would be a safer transportation when all cars were autonomous.

4. Conclusions

The survey presented in this paper looked at the attitudes of mostly young Turkish people towards the safety of autonomous cars. There is still a lack of trust for the safety and security of autonomous cars since only 30% of the participants expressed that they would feel safe in an autonomous car. People desire better and safe technology, advanced restraint systems for different seating positions, more reliable sensors, better driver education to safely switch between autonomous and manual modes, and mature road infrastructure to comply with autonomous cars. The integration of rotatable seats into the cars will require larger occupant compartments and even larger parking spaces. The great majority of participants said that transportation would be much safer when all cars were autonomous but manual mode was highly requested as a safety feature hence there will be instances where cars in manual and autonomous modes will coexist. Strong law enforcement must exist for the use of autonomous cars, for instance a user must not be allowed to drive fast in manual mode to reach his/her workplace. There must be new traffic laws regarding autonomous cars and loopholes must be closed. Drivers must change their mindset to comply with the traffic laws in using autonomous cars as well.

References

Estimating Costs of Electricity Consumption of the Manufacturing Plant and the Possibility of Reducing them by Implementing a Photovoltaic System

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Abstract

The article presents a method of reducing the costs of electric energy of a selected manufacturing plant by using on grid PV system. The designed 118 kWp photovoltaic system will be installed on the roof of the production and storage hall of the plant, carry out the production and assembly of railway traffic control equipment, power engineering and sheet metal processing. The plant works in a single-shift system, so energy will be consumed on the current needs of the plant. The implementation of the above project won’t only contribute to the reduction of energy purchase costs, but will also have a positive impact on the environment through the reduction of carbon dioxide. In addition, energy savings will have a direct impact on the reduction of production costs, improvement of the financial result and, consequently, will also contribute to the growth of the company competitiveness.

KEY WORDS: electricity consumption, manufacturing plant, PV system

1. Introduction

Data analysis of The Energy Regulatory Authority shows an ongoing dynamic increase in prices of electric power for companies. The current trend may last until the next decade because it is related, among others, to charges for permits for greenhouse-gas emission, increase in coal price and the necessity of intensive modification of power system. Higher power prices contribute to the fact that entrepreneurs keep looking for new ways of reducing power energy consumption costs [1-6], e.g. through implementing installations using renewable energy sources [7-12]. Considering justifiability of such investments one needs to take into account especially the type and amount of electrical devices used and working time in the facility.

The most important traits of PV systems is a short time of realization of such investment and decreasing prices of photovoltaic systems’ components resulting from increasing market competition. The cost of an installed unit of power is also related to the total system power. The smaller the system, the higher the cost, and along with the increase of production capacity, the unit price decreases. A photovoltaic farm does not have movable elements so active elements’ wear is minimal, which raises reliability. What is more, it does not need a lot of servicing so there are no additional operation costs. [7-12]

Electric power costs and purchase of materials and energy constitute almost half of enterprises’ costs. Because of the above and the characteristics of devices and machines that have a big electric power demand, an attempt to reduce electric power costs of a chosen industrial plant through the use of a photovoltaic system has been made.

2. Analysis of the Costs of Electricity Consumption of the Selected Industrial Plant

Calculations included power consumption in a chosen production department of an existing industrial plant and belonging to it office spaces. Plant work takes place in a single-shift (8h) mode, from Monday to Friday, if needed also on Saturday, but with a reduced number of receivers. The contract with electric power supplier takes into account three time zones with different rates for a kilowatt-hour and a flat rate.

On the basis of the invoices issued by the supplier, average prices for a kilowatt-hour in a given $C_m$ month have been calculated (Fig. 1).

\[ C_m = \frac{K_m}{E_m} \]  

(1)

where $C_m$ - a mean kWh cost in a given month [zl/kWh]; $K_m$ - monthly invoice value [zl]; $E_m$ - power consumed in a given month [kWh].

Next, on the basis of kWh monthly prices, an average annual $C_a$ price has been calculated by summing up following monthly prices.

From the calculations, a mean annual electric energy unit price on the level of 0.40 zl/kWh has been determined.
3. Design of PV installations

The designed photovoltaic system placed on the roof of a warehouse of a plant handling production and assembly of railway traffic control devices and power control devices and metal sheet processing involves installation connected to the power grid. The benefits of the above solution are: the cost of building the system and economic reasons. A system connected to network is much cheaper than building an autonomic islanding installation (the cost of purchase of power grid storages). In a high power installation this cost could burden the budget planned for the investment. Whereas surplus of energy produced by a photovoltaic system connected to the grid can be sold, which contributes to quicker return on capital employed.

According to data acquired by a measuring point in Radowiec Duży (lubelskie voivodeship), values of annual solar sun exposure in horizontal orientation come to 1114 kWh/m². The measuring point and destination are 12 km away. In the given location there are no shaded spots and the nearest, four-storey buildings are 40 meters to the east and 60 meters to the south from the designed installation. The nearest three ash stand is trimmed periodically to 5 meters, which eliminates the possibility of casting shadow on solar cells.

In the designed system, in order to transform solar energy to electric energy, photovoltaic panels made from 72 monocrystalline modules were used – Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open circuit voltage</td>
<td>$V_{oc}$ [V]</td>
<td>47.2</td>
</tr>
<tr>
<td>Short circuit current</td>
<td>$I_{sc}$ [A]</td>
<td>9.8</td>
</tr>
<tr>
<td>Maximum power</td>
<td>$P_{max}$ [Wp]</td>
<td>360</td>
</tr>
<tr>
<td>Maximum power voltage</td>
<td>$V_{mpp}$ [V]</td>
<td>38.9</td>
</tr>
<tr>
<td>Maximum power current</td>
<td>$I_{mp}$ [A]</td>
<td>9.3</td>
</tr>
<tr>
<td>Module efficiency</td>
<td>$\eta_m$ [%]</td>
<td>18.5</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>$T$ [°C]</td>
<td>-40 $\rightarrow$ +85</td>
</tr>
<tr>
<td>Dimensions (L/H/W)</td>
<td>[mm]</td>
<td>1956/992/40</td>
</tr>
</tbody>
</table>

In order to assess the right number of solar panels to be installed, their area was calculated ($1.94 \text{ m}^2$) by multiplying the height of the solar panel by its width. The area on which rows of photovoltaic panels will be installed, will be a south part of the roof of the production hall. Dimensions of the building are: length - 90,05 m, width - 2 m and height to the roof - 0,77 m and to eaves - 0,50 m. Decline of the roof is 15°. There is a gable roof so half of the roof’s surface will be used and rows of PV panels will be installed on the south slant. On the basis of the above data, the surface of the roof has been calculated - 962,75 m², on this area photovoltaic panel systems will be placed.

On the occupancy area, installation of 328 solar panels has been planned. Knowing the surface of a single panel, the surface of the whole generator has been assessed, which is 636,32m². The calculations proved that the occupancy area is sufficient for the projected number of solar panels.

The installation should be performed so that decline between the panels’ surface and roof is 15°, so that optimal sun exposure and self-cleaning are possible. Placing the panels with 30° angle from the ground will allow to remove residues, dust and other impurities from their surface during fall. Lingering impurities may have a negative influence on the efficiency of the cells through limiting the amount of rays of light accessing their surface.

Photovoltaic panels will be places in seventeen sections. Sixteen will be equipped with four rows, with five panels in each of them. While in the last section there will be two panels in each row. An additional construction that will have to be put on the occupancy area are service ladders and corridors (0.5 m width) that allow access to installation elements during the exploitation.

![Fig. 1 Average electricity cost of an industrial plant during the year](image-url)
Horizontal intervals between the rows of panels have been chosen with the help of the PVSol program, thanks to sun and shadow exposure simulation, and they equal 1 m. Such placement allows a maximum use of the occupancy area, and a maximum shading through the front rows is up to 0.1%.

The designed photovoltaic panel system will consist of 328 monocrystalline modules, 360 Wp each, which sums up to 118 kWp of the total power installed. Modules in each string will be connected in series and then plugged to an inverter.

In each frequency inverter two rows, each with 18 modules, will be connected parallelly to the MPP1 input. Meanwhile, to the MPP2 input, there will be connected single arrays including 19 modules, excluding the fifth and sixth frequency inverters, to which rows with 18 modules will be plugged. Because of the above, the current and voltage values for the given inverter inputs on the DC side (Table 2) have been calculated. Values for the first to fourth frequency inverter are identical because the amount, type and structure of panel connection for the MPP1 and MPP2 inputs are the same in each frequency inverter.

<table>
<thead>
<tr>
<th>Inverter 1-4</th>
<th>Inputs</th>
<th>U [V]</th>
<th>I [A]</th>
<th>P [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPP1</td>
<td>700.2</td>
<td>18.52</td>
<td>12.96</td>
<td></td>
</tr>
<tr>
<td>MPP2</td>
<td>739.1</td>
<td>9.26</td>
<td>6.84</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inverter 5</th>
<th>Inputs</th>
<th>U [V]</th>
<th>I [A]</th>
<th>P [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPP1</td>
<td>700.2</td>
<td>18.52</td>
<td>12.96</td>
<td></td>
</tr>
<tr>
<td>MPP2</td>
<td>700.2</td>
<td>9.26</td>
<td>6.84</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inverter 6</th>
<th>Inputs</th>
<th>U [V]</th>
<th>I [A]</th>
<th>P [kW]</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
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<td></td>
</tr>
</tbody>
</table>

Based on the values in Table 2, the drive inverter whose basic data is contained in Table 3 has been selected.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum DC power</td>
<td>20440 W</td>
</tr>
<tr>
<td>Minimum input voltage</td>
<td>150 V</td>
</tr>
<tr>
<td>Maximum input voltage</td>
<td>1200 V</td>
</tr>
<tr>
<td>Maximum input current MPP1/MPP2</td>
<td>33A / 33A</td>
</tr>
<tr>
<td>Maximum output current</td>
<td>29 A</td>
</tr>
<tr>
<td>Maximum efficiency</td>
<td>98.4 %</td>
</tr>
</tbody>
</table>

Next, a minimum number of modules (six) for one circuit has been determined, dividing the value of mains voltage by cell voltage in the maximum power point in 70°C. Later, a maximum number of modules falling on one circuit (twenty-two) has been calculated by dividing a maximum DC voltage of an inverter by the voltage of open circuit. Whereas in order to assess a maximum amount of circuit inputs that will be connected to a frequency inverter, a maximum DC of the frequency inverter by the short-circuit current of the modules. The received value shows that one can connect maximally three circuits connected in series. AC power of the frequency inverter is shown by the equation (4).

\[
P_{ac} = 0.97\left(P_{MP_{P1}} + P_{MP_{P2}}\right).
\]  

(4)

The current flowing from the inverter to the cable connector (I_{AC}) is determined by equation (5).

\[
I_{AC} = \frac{P_{ac}}{\sqrt{3} \cdot U \cdot \cos \phi}.
\]  

(5)

For the first to fourth frequency inverters power determined from the formula (4) amounts to 19,21 kW and current to 28,65A. Meanwhile for the five and six frequency inverters power amounts to 18.86 kW and current to 28,56A.

Each photovoltaic solar array will be connected in series (rated current for each of them is 9,26A). In calculations an assumption has been made that the length of the cable between the frequency converter and solar panels will be 2 x 70 m. Whereas allowed loss in cables is 1%. In the designed installation there will be two types of solar arrays. The first will contain eighteen panels, the other one nineteen panels.

A section of an array containing 18 panels is 3.37 mm^2 and for an array containing 19 panels it is 3.19 mm^2.
Because of the above, sink nodes in the frequency inverters will be connected to the cell arrays with a cable with a 4mm² diameter in order not to exceed 1% loss.

When more than two arrays of solar panels are used, one needs to put protection on both poles. It is necessary in case of a double earth fault relay. When choosing security methods on the DC side, one needs to take into account a long-term load of current with value 25% higher than the short-circuit current (12,24A). According to the calculations on both poles of each of the arrays, one needs to use, in front of the frequency inverter inputs, on the side of DC, gPV cylindrical fuses with voltage 900 V and maximum current value 12 A.

When exposed to external factors and with limited possibility of electromagnetic shielding, photovoltaic systems need a special protection. One then has to use devices limiting SPD overvoltage. The above protection’s role is to secure the PV installation against atmospheric overvoltage: indirect, direct and switching overvoltage. Protection should be used on the DC and AC system side. Because the distance between the row of panels and a frequency inverter is bigger than 10 m, a double overvoltage security system needs to be used, by placing limiters not farther than 10 m behind the row of PV panels and in front of the inverter [15].

Using the type 2 overvoltage limiters should be combined with a potential equalization bar, which diameter should be at least 6 mm². One also needs to perform equipotential bonding between supporting construction elements with an aluminium wire with 10 mm² diameter and attach it to the potential equalization bar with a 6 mm² diameter wire.

In a PV system one can use an SPD type 2 overvoltage limiter with 1100 V. What is more, each of the frequency inverters will require supplying a 2 × 20 m wire from the main distribution board.

In order to limit loss, in a wire below 1% frequency inverters will be connected to a sink node with a 16 mm² diameter wire. In the discussed configuration, the wire that will be used for the connection fulfills requirements related to current carrying capacity because the maximum AC input current is 29 A. Because of the above, a B32 overcurrent circuit breaker has been chosen. The AC side of each of the frequency inverters will also be secured with an SPD type 2 overvoltage limiter with 230/400 V rated voltage. Below, a block diagram of the designed solar panel system has been presented (Fig. 2).

Many factors influence the amount of energy created, such as: proper solar panel placement, choosing a sun exposed place, no shading, efficiency of modules, loss in wires, temperature differences and loss connected to internal elements of the panels. Capabilities of electric energy production of a PV system (Fig. 3) throughout a year have been determined on the basis of simulations performed in the PVSol program (shadowing, sun exposure, angle of rays of sunshine every day) and on the basis of calculations allowing to assess efficiency of particular system element.
On the basis of a forecast of energy yield of the designed photovoltaic system (with the help of a 118 kWp generator), value of annual electric energy produced on the level of 128,20 MWh has been determined.

Fig. 4 presenting monthly power consumption on a yearly basis contains data concerning: office workplaces, welding shops, paint shops, heaters, laser punch presses or cutters and also bending brakes and lightning on-site. It also takes into account data concerning devices located in wheel lathe room, locksmith's shop, room for control cabinet installation and also in storages and rest and refreshment rooms.

4. Simplified Economic Calculation and Ecological Effect

Taking the following costs into account: installation and yearly savings connected to electric energy purchase (formula 6), payback time (SPBT) necessary for regaining investment expenses spend on the PV system realization has been determined (formula 7).

\[ C_{\text{as}} = E_{\text{py}} \cdot C_{\text{a}} , \]  

where \( E_{\text{py}} \) – annual electricity production of the PV system; \( C_{\text{a}} \) – average annual price per kWh.

On the basis of market price it has been determined that a setup installation cost \( C_{\text{py}} \) will be around 389 282 zl.

\[ \text{SPBT} = \frac{C_{\text{py}}}{C_{\text{as}}} \approx 7,7 \text{ roku} . \]  

The cost of 1 kWp of PV installation has also been determined:

\[ C_{1\text{kWp}} = \frac{C_{\text{py}}}{P} \approx 3299 \text{ zl / kWp} , \]  

where \( P \) – power of the PV system.

Using solar panels also influences reduction of carbon dioxide emission to the atmosphere. In order to determine ecological effect, consisting in reducing the emission [16] resulting from power consumption of the discussed industrial plant throughout a year, a formula has been used (9).

\[ \text{emissions } CO_2 = E_C \cdot EF , \]  

where \( E_C \) – annual energy consumption [MWh]; \( EF \) – emission factor (for hard coal is equal 0,364 MgCO2·MWh⁻¹).

Based on the above formula, it can be concluded that by using the above PV installation, CO₂ emissions to the atmosphere can be reduced by 52 170 kg.

5. Conclusions

A growing demand for electric energy and constant growth of its production costs and sales price (power energy costs for industrial plants are 30% higher in Poland than in Germany) and acting in the best interest of environment contribute to the fact that more often installations using renewable energy sources are used. A solution that might be practical in all conditions can be a photovoltaic system, because it does not require such specific location conditions as the ones that need to be fulfilled for other renewable energy sources. The PV system is especially economic for subjects with a bigger energy consumption and it allows to avoid a raise in power energy prices. Installation costs can be included in the plant’s costs, reducing the amount of income tax. Apart from economic benefits, the photovoltaic system improves social and ecological image of the industrial plant.

On the basis of a yearly forecast of PV system electric energy and the sum of energy meters’ indications it has been determined that the installed solar system will cover demand for energy of the analysed company almost in 50%. Taking the above into account and almost eight years of investment payback time, the proposed solar system seems to be a good complement for present ways of supplying the building with electric energy. Because of the fact that work time of the plant corresponds with the best time for energy production, power will be completely used for the current needs of the plant. The PV system can constitute a protection in case of power outages during extreme weather conditions, failure or planned maintenance operations.

Frequently brought up arguments against using solar systems are the possibility to produce energy only throughout a day and environment pollution during the production of photovoltaic panels. Where it comes to a negative influence on the environment, it is significantly smaller than producing power using standard sources.

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Multi-body Dynamic Model Analysis of Failures in Passenger Off-road Military Vehicle Gearbox

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Abstract

The combat vehicle gearbox generates vibration signals which corresponded accurately with the behavior of gearbox. There are several solution techniques that are used to determine technical condition of gearbox based on the vibration signal. The multi-body dynamic solution has been used widely for a long time to simulate, analyze and determine the technical condition of gearbox. The aim of this paper is to introduce the dynamic of gearbox and the simulation process of passenger off-road military vehicle gearbox is performed based on the multi-body dynamic software MSC.ADAMS. The gearbox failure is simulated when the misalignment of bearing occurs. The result is used to analyzed the variation of vibration in both of the bearing and the gear. The vibration analysis is performed in both time domain and frequency domain in order to analyze the gearbox failure.

KEY WORDS: multi-body dynamic model, gearbox failures, vibration analysis.

1. Introduction

The combat vehicle is constructed for advance movement especially in a heavy terrain. The transmission mechanical system has to work under the heavily dynamically stress while the overcoming of heavy terrain (mud, snow, obstacles etc.). It is required that the combat vehicle has to work with the high performance and reliable transmission [1]. The gearbox has an important role in transmission system that helps to transfer the torque from the engine to wheels at different ratios. The gearbox consists of complexed components such as gears, shafts, bearings, and gearbox housing. During the operation, the gearbox generates a gear noise and vibration signal that can relate to the technical condition of gearbox. The study about the behavior of gear using vibration signal is called vibration diagnostics. Vibration monitoring is conducted to evaluate the “health” of the machine during sustained operation. Depending on the machine type and critical components to be monitored, and the suitable condition indicator is selected. The objective of vibrodiagnostics is to recognize an “unhealthy” condition in sufficient time to take into the condition-based maintenance before the machine parts defects occur. Several type of condition monitoring systems is performed to analyze the vibration signals. In the past decades, there are great number of researchers who using the test rig to investigate the vibration signal of gearbox. For example, the spectral analysis technique was used to identify the gearbox failures (e.g. imbalance, misalignment, mechanical looseness, bearing defects, gear defects) [2]. Another good example is that the waveform can be detected not only the location of failures but also when it occurred [3]. The experiment could be used effectively to evaluate the technical condition of gearbox. However, it requires the knowledge of experts, the long-term testing procedure, and high investment cost.

To overcome the disadvantage, the simulation method has been used widely to analyze the gearbox behavior. There are number of simulated methods, such as mathematical modelling (e.g. Matlab Simulink), finite element method (e.g. Ansys), and multi-body dynamic solution (e.g. MSC. Adams). Among these methods, the last one this the most proper technique for the vibration signal analysis. Several researchers who develop the multi-body dynamic model to simulate the gearbox. For example, the gear tooth breakage model is simulated based on a nonlinear contact force and the model is investigated to show the variation in the contact force at the gear tooth break position [4]. The multi-body dynamics model of spiral bevel gear is created based on Solidworks and transferred in to ADAMS to simulate. The angular velocity, torque, and contact force are obtained by simulation calculation [5]. However, these models were only simulated for specified failure, the different failure mode and the working condition of gearbox have not been noticed. The paper presents the dynamic model of gearbox, and the model is solved by the multi-body dynamic simulation method based on the MSC.ADAMS software. The misalignment of bearing is simulated in order to analyse the influence on the bearing and gear.

2. The Dynamic of Gearbox

In practice, the gearbox generates a gear noise and vibration during its operation. The gear noise is a vibrational phenomenon which response to some form of excitation. In general, the vibration is emitted from the meshing gear, and then it is transmitted through the mechanical component, such as gears, shafts, or bearings. After that, the gearbox housing is stimulated and vibration is converted into airborne. In fact, the gearbox is affected by working conditions, for example, excessive loads, insufficient lubrication, or manufacturing errors. Consequently, when the failure occurs, the transmission
error is generated. The combined model that consists of the dynamic of gears, shafts, and bearings is developed in order to simulate the vibration in the gearbox.

2.1. Modeling of Gear Dynamic

In general, it is possible to consider that the vibration part is similar to the spring - mass - damper system. This system involves three fundamental properties, namely a mass \( (m) \), stiffness \( (k) \) and damping \( (C) \). The dynamic system is assumed as the coordinates for describing of the vibration motion. It is called multi - DOF system (degree of freedom), or an N - DOF system, where N is the number of coordinates required. The simple coordinated system of the couple gears consists of 6 DOF, in which each gear has 3 DOF that have one rotation and two translations (Fig. 1) \[6\].

![Fig. 1 Dynamic model of gear system with six DOF](image)

The equations of motion for this model can be expressed as follows. The equation of motion in the ‘x’ direction for the pinion and gear \[6\]:

\[
m_p \ddot{x}_p = -K_{xp} x_p - C_{xp} \dot{x}_p + F_p \quad ; \tag{1}
\]

\[
m_g \ddot{x}_g = -K_{xg} x_g - C_{xg} \dot{x}_g + F_g \quad . \tag{2}
\]

The equation of motion in the ‘y’ direction for the pinion and gear \[6\]:

\[
m_p \ddot{y}_p = -K_{yp} y_p - C_{yp} \dot{y}_p - N \quad ; \tag{3}
\]

\[
m_g \ddot{y}_g = -K_{yg} y_g - C_{yg} \dot{y}_g + N \quad . \tag{4}
\]

The equation of motion in the ‘θ’ direction for the pinion and gear \[6\]:

\[
I_p \ddot{\theta}_p = r_p N + T_p + M_p \quad ; \tag{5}
\]

\[
I_g \ddot{\theta}_g = -r_g N - T_g + M_g \quad . \tag{6}
\]

Here \( m_p/m_g \) - mass of the pinion/gear; \( I_p/I_g \) - mass moment of inertia of the pinion/gear; \( K_{xp}/K_{yp} \) - radial stiffness in the x/y directions of the pinion; \( K_{xg}/K_{yg} \) - radial stiffness in the x/y directions of the gear; \( C_{xp}/C_{yp} \) - radial damping in the x/y directions of the pinion; \( C_{xg}/C_{yg} \) - radial damping in the x/y directions of the gear; \( K_m \) - equivalent mesh stiffness; \( C_m \) - mesh damping coefficient; \( T_p/T_g \) - torque applied on the pinion/gear; \( r_p/r_g \) - radius of pinion/gear; \( F_p/F_g \) - friction forces for pinion/gear; \( N \) - equivalent tangential force.
2.2. Modeling of Rolling Element Bearings Dynamic

In practice, the gearbox model is simplified while bearings and gearbox housing are modelled as simple springs with contact stiffness. The simple model can be used as the effective tools for simulation. However, the representation of these components will obtain the more complete and accurate simulation model. This model with the bearing and gearbox housing is necessary to get the interaction amongst components of gearbox [9]. The main fundamental components of the rolling element bearing are the outer race, the inner race, the cage and rolling elements. In the bearing dynamic model, the contact between elements cause forces and torques. The major cause of vibration results from the rolling element bearing, in which the load zone associated with the distribution of radial loads. For the modeling of bearing, contact forces and torques are determined based on the theory Hertzian contact stress. There are number models that were used to study the dynamic of faults in the rolling element bearings. The two DOF rolling element bearing model show the relation between the load and deflection (Fig. 2) [7].

\[
\delta_i = (x_i - x_p) \cos \phi_i + (y_i - y_p) \sin \phi_i - c - \beta_i C_d, \tag{7}
\]

here \(\delta_i\) – contact deformation (under compress); \((x_i - x_p), (y_i - y_p)\) – the displacement relation of inner race to outer race in ‘x’ and ‘y’ direction, \(\phi_i\) – the angular position; \(c\) – clearance; \(j\) – rolling element \(j\) [7].

The rolling element is deformed only when this is located in the bearing zone, hence the contact force is produced. The switch function \(\gamma_j\) is written as follows:

\[
\gamma_j = \begin{cases} 1 & \text{if } \delta_j > 0 \\ 0 & \text{otherwise} \end{cases} \tag{8}
\]

The angular position of rolling elements \(\phi_i\) is functions of time increment \(dt\) and this can be defined as follows [7]:

\[
\phi_j = \frac{2\pi(j - 1)}{n_b} + \omega_c dt + \phi_0, \tag{9}
\]

here \(\phi_0\) – the previous cage position; \(\omega_c\) – the cage speed; \(n_b\) – number of bearing ball.

\[
\omega_c = \frac{D_b}{D_p} \omega_s, \tag{10}
\]

here \(\omega_s\) – the angular speed of the shaft; \(D_b\) – diameter of ball; \(D_p\) - the pitch diameter of the bearing; \(\phi_0\) – the initial angular position of the bearing cage.

The ball raceway contact force is calculated using traditional Hertzian theory [7]:

\[
f = k_b \delta^n, \tag{11}
\]

here \(f\) – ball raceway contact force, \(k_b\)– load deflection factor, \(n\) – exponent (\(n = 1.5\) for ball bearing, and \(n = 1.1\) for roller bearing).

The total force in ‘x’ and ‘y’ direction can be calculated as follows [7]:

![Fig. 2 a - Rolling element bearings and load distribution; b - Two degree of freedom model [7]](imageURL)
\[ f_x = k_n \sum_{j=1}^{m} r_j \delta_j^{3.5} \cos \phi_j; \] \[ f_y = k_n \sum_{j=1}^{m} r_j \delta_j^{3.5} \cos \phi_j; \]

2.3. Frequencies of Bearing Defect

The bearing is a complicated dynamic system that consist of inner race, outer race, cage and rolling element. Because the surface stiffness of element is different, the defects can occur in any parts of the bearing. As a result, the high frequent vibration will be increased. Following equations are used to determine bearing (Fig. 3) defect frequencies [8].

\[ f = \frac{n}{2} f_r \left( 1 - \frac{BD \cos \beta}{PD} \right); \] \[ f = \frac{n}{2} f_r \left( 1 + \frac{BD \cos \beta}{PD} \right); \]

\[ f = \frac{PD}{2BD} f_r \left( 1 - \left( \frac{BD \cos \beta}{PD} \right)^2 \right); \]

\[ f = \frac{1}{2} f_r \left( 1 - \frac{BD \cos \beta}{PD} \right); \]

here \( n \) – the number of bearing balls or rollers; \( f_r \) – frequency given by the relative revolution (speed) of the inner and the outer ring; \( DP \) – the diameter of bearing ball or roller; \( PD \) – pitch diameter; \( \beta \) – contact angle; \( D \) – outer diameter; \( d \) – inner diameter.

3. Simulation Gearbox Using Multi-body Dynamic Model

The multi-body dynamics simulation helps study the dynamic of moving parts, and how loads and forces are distributed throughout the mechanical system. In the multi-body dynamics model, the parts (rigids or elastics bodies) can be modelled with kinematic constraints (e.g. joints) or force elements (e.g. spring dampers). Unilateral constraints and Coulomb friction can be also used to model frictional contact force between bodies. The basic simulation process consists of five main steps. First, the physical model that has accurately geometries (e.g. length, width, depth, dimension, distance) is created. Generally, the model is created by professional 3D-CAD designed software. Next, the physical characteristics, such as inertia properties, mass, and dynamic friction coefficient are set. Then, the kinematic definitions, e.g. translational and rotational are fulfilled. After that, the model is simulated with initial conditions. Finally, the results are analyzed and evaluated. The multi-body simulation software MSC.ADAMS is used to simulate the dynamic of gearbox (Fig. 4).

The combat vehicle gearbox that was chosen for simulation is equipped with the military vehicle. This is a mechanical gearbox that has four forward speeds and a reverse. Shafts and gears were made from steel, and bearings were considered as SKF bearing in the mechanical dynamic handbook. The gearbox fault is simulated in at bearing SKF 6208 that located in the input shaft. Parameters of the bearing that is used for simulating misalignment is show in the Table 1.
After the multi-body dynamics model is established, the model is simulated. The simulation process is performed in two case, the one is the health condition while another is the misalignment failure. The failure is simulated based on the misalignment of bearing that equipped in the driver shaft in the ‘x’ direction with the value 1 mm. This bearing that used to simulate the misalignment is SKF 6208 that located in the second position in the Fig. 4. Results is displayed the translational acceleration of bearing in order to identify the effect of failure on mechanical gearbox system. Both simulated cases are investigated in the operation condition that similar to the realistic state in which output of engine speed is set at 2000 rpm in accordance with maximum torque 166.7 Nm. The Joint Motion is used to simulate the angular velocity of the input shaft, in which STEP function is set to increase in 1s. The setting of simulated mode is performed with the time being 3 s.

| Outer diameter | \( D \) | 80 mm |
| Inner diameter | \( d \) | 40 mm |
| Width | \( B \) | 18 mm |
| Pitch circle | \( PD \) | 60.012 mm |
| Diameter of a rolling element | \( BD \) | 13.2726 mm |
| Contact angle | \( \beta \) | 0 |
| Number of rolling elements | \( n \) | 8 |

4. Result and Discussion

The Fig. 5 shows the translational acceleration of bearing in the time domain in two cases: the health condition (upper) and the bearing misalignment (lower). In both cases, the vibration signal is distinguished in three periods \( t_1, t_2, t_3 \) that related to the angular velocity of input shaft. The waveform in the first and the second periods in both cases are similar. In the first period \( t_1 \), the speed of input shaft increases slowly, hence the waveform shows a fairly stable value. In the second period \( t_2 \), when the velocity rises dramatically up to 2000 rpm, the energy roars up remarkably with two peaks at the 0.5 s and about 0.9 s. However, the energy in this period does not stabilize. In the last period \( t_3 \), the angular velocity of input shaft remained a constant at 2000 rpm. Although the graph experiences the fluctuation, however waveform is periodic with an event per revolution. When the bearing misalignment occurs, the overall energy grows high impacting with two high peaks that indicate a bearing misalignment defect. It is obviously that, when the fault occurs, the peak of energy increases slightly. It is difficult to detect the instantaneous signal in the time domain. However, for the overall vibration signal, the signal is significantly clearly. This technique is chosen for analysis the failure for long-term operation.
Fig. 5 The contact force of bearing in time domain

Table 2

<table>
<thead>
<tr>
<th>Bearing defect frequency</th>
<th>Estimated frequency (Hz)</th>
<th>Simulated frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPFI</td>
<td>159.98</td>
<td>158.33</td>
</tr>
<tr>
<td>BPFO</td>
<td>106.6</td>
<td>95.66</td>
</tr>
<tr>
<td>BSF</td>
<td>71.66</td>
<td>70.16</td>
</tr>
<tr>
<td>FTF</td>
<td>12.9</td>
<td>9.8</td>
</tr>
</tbody>
</table>

To overcome the disadvantage of time domain analysis, the frequency domain is used to identify the vibration signal in the short time. In this technique, the vibration signal is transformed to frequency by Fast Fourier Transforms function. The spectrum in Fig. 6 exhibits a typical pattern of bearing vibration signal. High amplitude peaks related to the bearing defect frequency. Estimated frequency and simulated frequencies of bearing are showed in the Table 2. When the failure occurs, the amplitude of vibration signal increases gradually. The increases of high amplitude peak indicated the bearing misalignment defect in the gearbox.

Fig. 6 The velocity of gear in time domain
5. Conclusions

In this paper, the dynamic of gearbox is analyzed, in which, the gear couple with six degree of freedom and the rolling element bearing model with two degree of freedom are developed. The simulation method is performed based on the multi-body dynamics software MSC.ADAMS. The combat vehicle gearbox that is chosen for simulation is equipped on the passenger off-road military vehicle. The multi-body dynamics model of gearbox is simulated in two case, the one is heath condition, and the other case is the bearing misalignment. The translational acceleration of bearing is analyzed in time domain and frequency domain. The waveform shows the periodic with an event per revolution. The overall vibration signal of bearing can be used to identify the gearbox fault. The spectrum displays the typical pattern of bearing frequency defect. The frequency of bearing defect can be used to indicate the level of gearbox failure.

References

Passenger and Freight Transport Performances in the Regional Railway Line and Their Impact to the State Budget Requirements – Case Study in Slovakia

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Abstract

The goal of the measurements in the Fourth railway package is increasing of competition in railway transport, ensuring full financial transparency and removing any risk of cross-subsidy provision between infrastructure manager (It is financed from national budget largely) and provision of railway passenger and freight services. Growth of the rail passenger and freight transport performances increases of the effectiveness of regional railway line but the ratio between passenger and freight transport in the regional railway line affect the state budget requirements. The paper compare development of freight and passenger transport performances in the selected regional railway line and suggest the measures for regional railway transport separately in the region with predicted different economic potential which will be reflected to effective use of public resources.

KEY WORDS: freight railway transport, passenger railway transport regional railway lines, revenues, subsidies, transport performances

1. Introduction

Regional railway transport as a fundamental transport mode in the integrated transport system should perform quantitative and qualitative requirements of passengers on the one hand but on the other hand should performs requirements of freight carriers. There can be a problem with the allocation of train path for freight transport in case of insufficient rail infrastructure capacity which may mean an increase in the requirements for the state budget.

Regional railway transport can be operated in the main or regional railway lines (they are the main and the secondary lines by infrastructure manager of the Slovak Republic). Regional railway lines are different by traction equipment, safety installations, signaling plants, number of stations etc. This all affects practical carrying and track capacity which can be a problem in the region with high economic potential. The aim of our paper is to compare the transport performances in the regional railway line and point at the problem with insufficient/unused capacity on the example of selected regional lines.

2. Literature Review

Public transport, in terms of the concept of transport service quality, is more than just a social service for those who have no other option, but whose aim is to achieve overall transport accessibility in the region [1]. Regional rail passenger transport provides transport services between a sub-region of urban centers within the natural, demographic and geographically bounded areas with exact transport relations, and in some cases may also act on cross-border transport [2]. Railway suburban transport must be the main transport system of every region because the public transport is one of the most important public services [3].

Regional railway transport should be an important part of the transport policy of each country. Maulat and Krauss analyzed how new instrument of public policy is used locally in the case of regional railway transport projects [4]. It is very important to be able to evaluate different policies for planning purposes regional rail transport [5] because regional accessibility influences the configuration of spatial socio-economic structures [6].

Regional railway lines are perceived by authors differently. By Gao and Yan regional line mainly provides services for metropolitan region (usually suburban areas), and it is generally long radiation and branch-type rail network ingress and egress of the city [7]. Local railway lines are those which do not belong to any network of national significance and which are characterized by relatively low technical parameters (a low minimum curve radius, a high maximum gradient and low quality of the track) [8]. In some regional railway lines can be a problem with capacity mainly in the big agglomerations and industrial centers. Rotoli and all taken up this question in their paper. They researched (among other things) whether the congestion on some parts of the network become an extremely limiting issue for passenger or freight trains [9]. Singhania and Marinov identified if there is potential for adding more freight trains to the existing schedule [10]. Liberalization and competition in railway transport can increase the transport performances in the regional railway lines which subsequently require their revitalization [11]. Problems of railway infrastructure capacity in some line can be caused signaling plant in the modernization infrastructure [12].

However, railway system requires subsidies which are more or less heavily in many countries mainly to promote their use versus private cars [13]. Link studied the impact of including service quality into an analysis of efficiency
differences between the German public transport authorities in using their available public funds [14]. Kurosaki and Alexandersson presented possibilities to allocate public spending to unprofitable passenger railway services in Japan base on study of the Sweden experiences [15]. Wegelin and von Arx analyzed transaction costs of different governance forms in regional public rail transport by comparing Germany's competitive contract awarding model with Switzerland's direct contract awarding model [16].

Subsidies into regional railway passenger transport increase the transport performances and effectiveness of the regional railway lines. But how about the capacity of regional railway line and state budget overall requirements? It is different problems in the insufficient and unused capacity of railway line.

3. Regional Railway Transport in the Slovak Republic

Regional railway transport is an inseparable part of transport system in the Slovak republic and therefore its priorities addressed within Transport policy. The global strategic objectives have been summarized as following:

- Providing equivalent access to settlements and industrial zones to support economic growth and social inclusion in all Slovak regions (national and European scale) via non-discriminatory access to transport infrastructure and services.
- Sustainable development of the Slovak transport system focusing on the generation and effective use of funds in relation to the real needs of users.
- Increase the competitiveness of passenger and freight transport (vs. road transport) by setting operational, organizational and infrastructural parameters leading to an efficient integrated multimodal transport system supporting the economic and social needs of the Slovak Republic. Increase the quality of transport planning in the Slovak Republic by the definition of the optimal target value of the modal split in the Slovak Republic and specification of steps and tools to achieve it.
- Improved safety and security of transport, leading to sustainable safe mobility on safe infrastructure, introduction of new technologies/processes using preventive and control mechanisms.
- Reduced negative environmental and negative socioeconomic transport impacts (including climate change) as a result of environmental monitoring, effective infrastructure planning/implementation and a reduced number of conventionally-fueled vehicles, and use of alternative fuels [17].

Regional railway lines have a specific position in regional railway transport. Their effectiveness is lower compared to railway corridors or a main railway line, but it is should be operated from the social point of view [18]. We deal of the regional railway transport on the regional railway lines in the next part of our paper. Infrastructure manager divides the railway lines into six categories for the purpose of charging. We have taken into account as regional railway lines the secondary lines (Category 3 – Secondary lines, Category 4 – secondary lines with simplified traffic control) and other lines for passenger transport (Category 5 - Narrow gauge lines TEŽ (Tatra Electric Railway) and OZ (Cog Electric Railway, Category 6 - Special railway classified for the purpose of charging: TREŽ (Trenčín Electric Railway)).

Charging scheme for access to the railway infrastructure shall comprise the following components:

- Charges for the minimum access package:
  - maximum charges for ordering and allocation of capacity – \( U_1 \);
  - maximum charges for traffic management and organization – \( U_2 \);
  - maximum charges for ensuring serviceability of railway infrastructure – \( U_3 \);
  - maximum charge for the use of electrical supply equipment for supply of traction current – \( U_4 \).

- Charges for track access to service facilities:
  - maximum charge for the access to passenger stations, its premises and facilities including facilities for travel related information – \( U_{521} \);
  - maximum charge for the access to ticket sales points at passenger stations \( U_{522} \);
  - maximum charges for the access to train formation stations and train formation equipment and to freight terminals owned or administered by regulated entity – \( U_{523} \);
  - maximum charge for access to storage sidings \( U_{524} \) [19].

<table>
<thead>
<tr>
<th>Category line</th>
<th>( U_1 )</th>
<th>( U_2 )</th>
<th>( U_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in € per train km without VAT</td>
<td>in € per train km excluding VAT</td>
<td>in € per thousand gross tone km excluding VAT</td>
</tr>
<tr>
<td>Regularly trains</td>
<td>Trains according to demand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>0.0487</td>
<td>0.1207</td>
<td>0.884</td>
</tr>
<tr>
<td>4.</td>
<td>0.0319</td>
<td>0.1112</td>
<td>0.774</td>
</tr>
<tr>
<td>5.</td>
<td>0.0272</td>
<td>0.0981</td>
<td>0.588</td>
</tr>
<tr>
<td>6.</td>
<td>0.0096</td>
<td>0.0096</td>
<td>0.445</td>
</tr>
</tbody>
</table>

Source: Authors by [19]

Tables 1 and 2 show charges for the minimum access package and charges for track access to service facilities in...
the secondary and other lines. Charge $U_4$ shall apply on condition that a train run has been performed on an electrified railway line (regardless of the form of power supply) and active motive power unit of electric traction is integrated in a trainset. The fee is 0.228 € per thousand gross tone km without VAT.

### Table 2

Charges for track access to service facilities in the Slovak Republic

<table>
<thead>
<tr>
<th>Category of transport point</th>
<th>Passenger trains</th>
<th>Freight trains</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$U_{SZ}$</td>
<td></td>
</tr>
<tr>
<td>Slow trains</td>
<td>$A_{OD}$</td>
<td>$A_{ND}$</td>
</tr>
<tr>
<td>0.510</td>
<td>49.631</td>
<td></td>
</tr>
<tr>
<td>Other trains</td>
<td>$B_{OD}$</td>
<td>$B_{ND}$</td>
</tr>
<tr>
<td>0.480</td>
<td>20.987</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$C_{OD}$</td>
<td>$C_{ND}$</td>
</tr>
<tr>
<td>0.460</td>
<td>13.424</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$D_{ND}$</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*Source: Authors by [19]*

Within the item concerning maximum charge for the access to passenger stations, its premises and facilities including devices for travel information, annual timetable is substantial under which traffic points are defined from which passenger trains depart (departure traffic point), traffic points where trains terminate and traffic points where trains stop. The term “stop” shall also be considered to mean a stop on request – in such case the possibility of stop shall be considered as a scheduled stop. Charge is calculated only for actually realized performances, i.e. if the train runs only over a part of the path, the charge applies only to that part of the path; if the train is cancelled over the whole path, the charge shall not be applied. For the purposes of setting the charges for access to train formation stations and train formation facilities and to freight terminals operated solely by ĽSR, actual train run and the changes in train composition over the whole train run is substantial, i.e. the charge applies for actually realized performances [19].

Maximum charge for the access to location for ticketing services in passenger stations $U_{SZ}$ is paid per one square meter of a sales office for one month - the price is 2.35 € for station category A and 2.00 € for station category B excluding VAT. In order to determine charges for the use of storage tracks - $U_{SZ4}$, substantial is the length of stay of a wagon on the ĽSR tracks is longer than the charge-free stay (36 hours after arrival of the wagon by train to traffic point and 36 hours before the wagon leaves traffic point). The fee is 0.195 € per wagon excluding VAT by conditions described in the Network Statement [19].

Charges for access to the railway infrastructure are the important part of infrastructure manager revenues [20] (in 2018 the share was 20.2%). Increasing of these revenues can bring increasing of regional railway lines effectiveness. Tables 3 and 4 show the performances and revenues in the regional railway lines.

### Table 3

Transport performances and revenues in the regional railway line – passenger transport

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of train</th>
<th>Train km</th>
<th>Gross tones km in thousand</th>
<th>Revenues in €</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>155 037</td>
<td>4 268 305</td>
<td>255 226</td>
<td>5 051 662</td>
</tr>
<tr>
<td>2014</td>
<td>155 821</td>
<td>4 233 958</td>
<td>262 384</td>
<td>5 081 216</td>
</tr>
<tr>
<td>2015</td>
<td>160 030</td>
<td>4 427 500</td>
<td>305 280</td>
<td>5 319 651</td>
</tr>
<tr>
<td>2016</td>
<td>164 312</td>
<td>4 499 072</td>
<td>331 278</td>
<td>5 466 876</td>
</tr>
<tr>
<td>2017</td>
<td>161 003</td>
<td>4 453 674</td>
<td>305 832</td>
<td>5 391 332</td>
</tr>
<tr>
<td>2018</td>
<td>162 630</td>
<td>4 567 944</td>
<td>310 017</td>
<td>5 408 754</td>
</tr>
</tbody>
</table>

*Source: Authors by [21]*

### Table 4

Transport performances and revenues in the regional railway line – freight transport

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of train</th>
<th>Train km</th>
<th>Gross tones km in thousand</th>
<th>Revenues in €</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>13 149</td>
<td>327 955</td>
<td>172 791</td>
<td>493 916</td>
</tr>
<tr>
<td>2014</td>
<td>12 910</td>
<td>319 918</td>
<td>179 809</td>
<td>446 459</td>
</tr>
<tr>
<td>2015</td>
<td>12 062</td>
<td>322 808</td>
<td>166 075</td>
<td>363 747</td>
</tr>
<tr>
<td>2016</td>
<td>11 271</td>
<td>317 219</td>
<td>189 152</td>
<td>342 781</td>
</tr>
<tr>
<td>2017</td>
<td>11 190</td>
<td>326 661</td>
<td>172 701</td>
<td>267 276</td>
</tr>
<tr>
<td>2018</td>
<td>11 806</td>
<td>325 118</td>
<td>151 392</td>
<td>338 688</td>
</tr>
</tbody>
</table>

*Source: Authors by [21]*

As can be seen in Tables 3 and 4 transport performances as well as revenues in the regional railway lines are much higher in passenger transport than in freight transport. Effectiveness of regional railway lines will increase in the
case of increasing passenger transport performances but state budget requirements will also increase because in the Slovak republic passenger transport performances in these lines are provide under public service obligation.

4. Results and Discussions

As can be seen in previous chapter transport performances in the regional railway lines are much higher in passenger transport than in freight transport. However, transport performances and revenues in the passenger and freight transport are different by individual regional railway line. We researched the impact of standard of living (the average wage was taken into account) to the transport performances and revenues in the selected regional railway line. In this paper we chose the railway line which have different standard of living. Table 5 shows the transport performances and revenues in the Žilina – Rajec railway line. This track is located in the region with average standard of living.

Table 5

<table>
<thead>
<tr>
<th>Year</th>
<th>Passenger transport</th>
<th>Freight transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Train km</td>
<td>Gross tones km in thousand</td>
</tr>
<tr>
<td>2013</td>
<td>142 363</td>
<td>8 673</td>
</tr>
<tr>
<td>2014</td>
<td>155 197</td>
<td>8 934</td>
</tr>
<tr>
<td>2015</td>
<td>154 996</td>
<td>9 290</td>
</tr>
<tr>
<td>2016</td>
<td>155 378</td>
<td>8 901</td>
</tr>
<tr>
<td>2017</td>
<td>154 500</td>
<td>8 804</td>
</tr>
<tr>
<td>2018</td>
<td>155 339</td>
<td>8 974</td>
</tr>
</tbody>
</table>

Source: Authors by [21]

Track Žilina – Rajec is the one of tracks where the transport performances are increasing in the passenger as well as in the freight transport. The ratio of passenger transport is very big in favor of passenger transport which means that the revenues in this line are mainly direct or indirect subsidies. A similar trend is on regional lines in regions with increasing standards of living. It will be able to a big problem in these line in regard of their capacity. Table 6 shows the transport performances and revenues in the Bardejov – Kapušany pri Prešove railway line. This track is located in the region with lower standard of living.

Table 6

<table>
<thead>
<tr>
<th>Year</th>
<th>Passenger transport</th>
<th>Freight transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Train km</td>
<td>Gross tones km in thousand</td>
</tr>
<tr>
<td>2013</td>
<td>227 819</td>
<td>12 737</td>
</tr>
<tr>
<td>2014</td>
<td>250 277</td>
<td>13 904</td>
</tr>
<tr>
<td>2015</td>
<td>250 799</td>
<td>26 967</td>
</tr>
<tr>
<td>2016</td>
<td>251 326</td>
<td>36 813</td>
</tr>
<tr>
<td>2017</td>
<td>250 760</td>
<td>35 758</td>
</tr>
<tr>
<td>2018</td>
<td>250 293</td>
<td>27 221</td>
</tr>
</tbody>
</table>

Source: Authors by [21]

As can be seen in table 6 the ratio of passenger transport is very big in favor of passenger transport analogous to Žilina – Rajec track but reason is completely different. Bardejov – Kapušany pri Prešove track is located in the region with lower standard of living and track utilization coefficient is approximately 60% instead of 85% in the Žilina – Rajec track. A similar development is in other regional lines, resulting in two basic problems. Regional railway lines are used mainly for passenger transport in the region with growing economic because demand increase and in these lines capacity is insufficient. It not often available capacity for freight transport. On the other hand, regional railway lines are used mainly for passenger transport in the region with economic stagnation because potential for freight transport is not there. In both cases regional railway lines operation requires direct or indirect state subsidies.

5. Conclusions

The problem of regional railway transport is very closely linked to the economic development of the region.
Slovak Republic canceled the traffic or reduced the number of connections in some regional railway lines in 2003. As the economic development of the regions has grown more or less over time, regional rail transport is not only being gradually renewed, but on the contrary, there is a problem with its capacity on some lines. Regional railway lines operation should be considered in terms of synergy effects i.e. take into account other social benefits such as congestion in the roads, environmental aspect, social aspect etc.

Acknowledgement

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References

Traction Energy and Fuel Consumption Evaluation Methodology in Urban Traffic

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Abstract

Energy consumption reduction is a common challenge for many industries. Energy consumption reduction on urban streets also contribute to lower emissions level and cleaner city air. To evaluate the influence of traffic organization and car technologies on traction energy and fuel consumption test drives were run in Riga city on selected route including three main arterial streets in both directions at various day hours having traffic densities from free flowing traffic to congestion driving. The fuel consumption is calculated from car OBD data. The position on the street grid and car speed for data synchronisation and OBD speed data calibration is recorded by GPS logger. The energies are calculated from OBD logs and car specifications. This paper deals with methodology of test results processing. The route has been divided in street sections. The shortest sections selected are between traffic lights on successive street intersections. The longest sections selected correspond to street sections where traffic management system provides a green wave for traffic in any driving direction. The problem analysed is that the traction energy consumption is affected by car speeds at section endings therefore various terminations of sections have been compared to reduce or take into consideration the different speeds. The shorter street sections are suitable for local energy consumption evaluation and selection of specific section terminations are not useful, the longer sections may allow to evaluate traffic management systems and sections with closer car speeds at termination points may be more advantageous. The research findings will be used for further development of urban traffic analysis.

KEY WORDS: traction energy consumption, city driving, fuel consumption

1. Introduction

Energy consumption reduction is a common challenge for all European countries. In 2016, energy consumption in transport for EEA-33 was 34 % higher than in 1990 although in Latvia it remained more or less unchanged [1]. Energy consumption reduction on urban streets may also contribute to lower emissions level and cleaner city air. Traffic organization and vehicle technologies both contribute to energy and environmental savings. The needed balance between mobility, safety and environment in traffic simulation and planning is emphasized and modelled in [2]. Some traffic planning models especially emphasize a fuel based traffic signal optimization models [3]. Certain attention is given to travel planning, like off-line energy-optimal speed planning for road vehicles on a given route is developed in [4] and path planning algorithm considering the effects of traffic lights and fuel consumption is developed in [5]. More global solutions may include developing intelligent transportation systems in smart cities as explored in [6]. Researchers also analyse how vehicle technologies and driving patterns affect energy consumption [7].

To evaluate the vehicle technologies and traffic control influence on car fuel and energy consumption in real-driving conditions, to locate the spots with a higher energy consumption that have to be taken into account when monitoring the city environment, a series of tests have been performed. This paper deals with methodology of test results processing on various test route sections.

2. Materials and Methods

The urban driving tests were performed in Riga city on a pre-planned route containing three street sections with a length between 2.3 and 2.8 km where traffic is controlled by coordinated traffic lights in a way that a green wave GW is formed in one direction while the traffic flow against the green wave AGW is quite restricted. The route has been defined in [8]. Forty-one laps were run on the 25 km test route. Various cars have been tested on the selected route but data analysed in this paper were obtained by driving 1.6i-16V petrol Opel Zafira A, 2004 only. The tests were carried out at weather conditions without heavy rain or any snow or ice on the roads avoiding periods when any road works have been done or traffic accidents happened along the route. Fuel consumption and vehicle speed was recorded by Auterra DashDyno SPD OBD logger. A GPS logger RaceLogic DriftBox with 10 recordings per second was used to mark the street sections between the junctions in the driving route and to calibrate the OBD speed data. Driving distance calculated from car speed recording time, fuel consumption FC obtained from the fuel rate and car speed. The road load forces calculated from car coast-down, city street vertical alignment and car technical characteristics. Air temperature was
recorded but not used in analysis since the interest is in value variations not in the absolute value of fuel and energy consumption.

The fuel and electrical energy consumption depending on engine and drivetrain can be analysed in stages, where some of them may be overlapping. 1 – The primary energy is converted into mechanical or/and electrical energy. 2 – The mechanical energy can be accumulated in the form of kinetic energy (mostly by increasing the speed of the vehicle and depending on gear selected also the angular speed of rotational parts, in rare cases using kinetic energy storage systems) or potential energy (going uphill). 3 – The mechanical energy generated or accumulated is finally used by the vehicle when overcoming rolling resistance and air drag or when braking without energy recovery it is converted to heat. 4 – The mechanical energy accumulated during braking may be recovered mostly to electrical energy or with very few mechanical braking energy recovery systems, to kinetic energy. The total fuel consumption and energy consumption also greatly depends on fuel heating value and energy conversion efficiency in the engine, powertrain and in braking energy recovery system.

In this article it is distinguished between traction work TW (1) which relates to energy conversion stages 2 and 3 and energy consumption EC (2) relating to stages 3 and 4. Traction work TW is generated by fuel or electrical energy consumption and includes accumulated energy.

\[
TW = \int_{t_0}^{t_f} \left( F_r + F_d + F_g + F_i \right) ds ,
\]

where \(TW\) – traction work, J; \(F_r\) – rolling resistance, N; \(F_d\) – air drag, N; \(F_g\) – grade force, N; \(F_i\) – force of inertia calculated from acceleration, N; \(ds\) – distance, m.

Energy consumption includes the final irrecoverable usage of energy (since the test car was not equipped with any energy recovery systems, stage 4 was not accounted for while the braking energy was calculated to be used for assessment of usability of energy recovery technologies) and does not include the accumulated energy.

\[
EC = \int_{t_0}^{t_f} \left( F_r + F_d + F_g \right) ds ,
\]

where \(EC\) – energy consumption, J; \(F_b\) – braking force, N.

Any other usage of electrical energy except for traction was not analysed in the study. In practical calculations \(ds\) used instead of \(ds\) where \(ds\) depends on data logging timing having no less than one recording in 0.3 seconds giving on average \(ds\) below 1 m with maximum at about 4 m.

The traction work and energy consumption including the split between energies used for overcoming each separate road load factor along with average speed, fuel consumption and other parameters were calculated for distances starting from each \(ds\) to each lap. To find the street sections where higher traction work has been done which relate to the location of the higher energy consumption, signalizing about the problems in traffic management, and to analyse the impact of traffic lights control on energy consumption, all route was split into sections between traffic lights.

A simplified example of car speed change along the route for three street sections SC1 to SC3 is shown on Fig. 1. Originally the route was split in sections between traffic lights or STOP lines and corresponding street junctions where the sections from and to STOP lines are shown as FT1 on Fig. 1. The problem with this split is that for the cars stopped at the traffic lights the speed when crossing the STOP line (blue dot) would be essentially lower than if the car has not stopped at the stop line.

Therefore the distance shift \(S\) was proposed to find a shift where the speed (green dot) at the start and end of the section FTS1 gives less difference in vehicle kinetic energy. For both FT and FTS sections the speed at the section ends
would differ from 0 unless the stop has been made at the exact spot.

For \( TW = EC \) the section has to start and end at zero speed. For this four different section types has been examined. Sections (later called – section type) AA where for each section the first stop after the section start and after the section end are found, sections AB between the first and last stops inside the section, sections BA from the last stop before the section to the first stop after the section and sections BB including the last stops inside and in the following section. Both for FT and BAAB sections they were combined in length up to the length where the coordinated traffic light control exists, like BA13 includes all three sections from 1 to 3, the distance from the last stop before the first section and to the first stop after the last section.

The longest sections examined are for the full length of coordinated traffic control sections on Caka, Brivibas and Valdemara streets in each direction – along the green wave GW and against the wave AGW, for BA, BB and AA sections including also the first stop before and after the coordinated section. When analysing the characteristics changes as a function of the time of the day each street has been studied both separately and analysing all GW or AGW sections together.

The precision of the test results is limited by OBD and GPS technology. Due to the constantly changing traffic flow, multiple measurements for the same conditions are not possible. Since the test goal is not to retrieve precise absolute values but to evaluate change pattern, only mean values of the parameters are given in the paper.

3. Results and Discussion

Each street section between traffic lights was analysed for car stoppage locations. Fig. 2 shows the distribution of car standstill locations in each street section.

![Fig. 2 Position of stopping spot within street section](image)

To find the distance after the STOP line where most probably the stopped cars have accelerated the difference in speed squared values which is proportional to the difference in kinetic energy for all laps for all FT coordinated sections were calculated. The average results split by coordinated sections are shown on Fig. 3. The minimum difference in kinetic energy is observed at 50 to 60 metres.

![Fig. 3 Distance shift for minimum difference in kinetic energy](image)

Similar analysis was done for kinetic energy difference for a percentage of distance length and the minimum kinetic energy difference was located at around 25\% of section length. For later calculations it was decided that for sections with the length below 200 m the shift \( S \) of 25\% would be applied and for longer sections the shift of 60 metres used.

The influence of distance shift on driving characteristics can be observed on Fig. 4 to Fig. 6. In graph legends and in the text a shorter name of the streets is mentioned. The street section with coordinated traffic lights from Marijas Street turning into Aleksandra Čaka Street is called here as Čaka Street and Krišjāņa Valdemāra Street is called Valdemāra.
Street. English letters only are applied also to other streets.

For the fuel consumption (Fig. 4) the distance shift has much more influence in AGW direction where more car stops occur. There is almost negligible influence for GW direction on Valdemara Street.

![Fig. 4 Average fuel consumption FC along Valdemara street sections with and without distance shift: red – AGW; green – GW](image)

For traction work graphs on Fig. 5 the distance shift gives lower figures where more acceleration occurs at unshifted section start and higher figures where braking and acceleration from the same stoppage are contained in the same section.

![Fig. 5 Average traction work TW along Caka and Marijas street sections with and without distance shift: red – AGW; green – GW](image)

The comparison between Fig. 5 and Fig. 6 allows to analyse the difference between the traction work and energy consumption.

![Fig. 6 Average energy consumption EC along Caka and Marijas street sections with and without distance shift: red – AGW; green – GW](image)
For AGW direction the cars on average gain kinetic energy on section from Pernavas and Erglu, but the energy is spent on stopping at Tallinas street. Then again traction work is done and corresponding pollution emitted on next two sections, but energy used while braking at Matisa or Brunenieku Street. There are energy consuming junctions at Stabu and Gertrudes Streets with corresponding gain of kinetic energy at Lacplesa which most likely is consumed when stopping at Dzirnavu Street. For the GW direction the higher traction work is done and energy consumed when entering the GW section, because it is not coordinated with previous sections. Then due to the green wave when driving at allowed speed limit there is quite low consumption up to the end of the section where higher consumption is due to the following left turn.

The traction work peaks are indicating higher air pollution areas while the energy consumption peaks point to sections where vehicle drivers may have problems of foreseeing vehicle braking and having higher speed than optimal for the given street section.

The further calculations were performed for street sections using distance shift.

The sample of change of traction work TW for both GW and AGW directions for all three streets at full coordinated section length during the time of the day is shown on Fig. 7. For this graph both data points and periodical 8th order polynomial regression lines are shown. For most of the further graphs since there are too many data points for short street sections the regression lines only are displayed. To avoid confusing the variability of parameters at the given time of day with the evaluation of appropriate regression line, the R squared values for the regression lines were calculated but not shown in the paper.

![Fig. 7 Traction work TW change during the time of the day: FTS – section type](image)

Testing the applicability of different section types for consumption analysis it was find out that for shorter street sections only FT or FTS type sections can be used. Fig. 8 demonstrates that during the night hours there are too few stops for AA, AB, BA and BB type sections to give a steady result. The FTS values are lower because all other section types necessarily includes stops on the both ends.

![Fig. 8 Traction work TW change during the time of the day for street sections between traffic lights: FTS, AA, AB, BA and BB – section type](image)

Additional factor for inferiority of section types with stops (AA, AB, BA, BB) is the section distance ratio which at some points even exceed 5 as shown of Fig. 9, therefore does not much characterize the street section under investigation. The distance ratio is defined as a relation of the length of the section examined to the length of corresponding FT or FTS section.
Much better length ratios are for the sections at full coordinated length (Fig. 10). The higher ratios during the night hours for AGW sections are explained by GW sections adjacent to AGW sections.

There was more interest about the section type usability for full length of the coordinated sections. Even for a full length of coordinated section types AA, AB and BB have a very limited application. BA type section can be used to reflect the stops if they occur near to the section ends.

This can be seen on Fig. 11 for AGW and Fig. 12 for GW direction. For GW direction the fit is better because there are AGW sections adjacent with guaranteed stoppage. Even for GW the AB section type has very limited use due to lower frequency of stops on the GW sections.

The conclusions from this paper would be used in further analysis of traffic in Riga city and for evaluation of simulated influence of different vehicle technologies on driving characteristics.
4. Conclusions

When dividing a street into sections for energy consumption analysis it may be appropriate to select section lengths including both braking and acceleration for the same stoppage.

For the evaluation of longer street sections including several possible braking and accelerating sequences the difference in kinetic energy at the ends of street sections may be avoided by extending the sections to the nearest stop if the extension does not make essential deviation in section length.

Shorter street sections may be better characterised if the difference between traction work and final energy consumption is considered.

References

Detection of Railway Cargo Shifts Using Laser Triangulation

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Abstract

The use of modern data acquisition and analysis techniques allows the creation of new, innovative solutions in the area of railway transport systems. The ability to identify rolling stock elements and to control the arrangement of transported cargo enables detection of irregularities, prediction of potential hazards and implementation of procedures to ensure the safety of the transport process. The article discusses the issue of automatic identification of moving objects using 3D imaging technology. The paper presents research carried out by the author, focused on the use of laser triangulation for the recognition of transported cargo, verification of their presence and location on the wagon, detection of undesirable shifts, lack of load or the appearance of unknown objects. The research stand and applied research methods are presented.

KEY WORDS: object identification, laser sensors, evaluation of the shape and position, recognition of rolling stock and loads

1. Introduction

Changing the position of the load or the observable contour of the wagon body is a emergency to the safety of transport. Unfavorable events, such as:

- displacement of the transported cargo on the wagon loading surface;
- tipping or rotating the load;
- displacement of bulk cargo;
- lack of the load;
- deformation of the wagon's sides;
- opening the wagon door.

May be the result of improper distribution or attachment of transported loads, acts of vandalism, undesirable events occurring during the gravity shunting of wagons in marshalling yards (especially during braking and overtaking on the directional tracks). They can also occur while the train is moving as a result of rapid changes in speed or inadequate traffic speed to limitations imposed by the infrastructure conditions. During the standing of the train, unknown new objects or people may appear, for example during attempts to steal a load, attempts to cross the border illegally or act as a terrorist.

Occurrence of a hazard may lead to a dangerous event, e.g. exceeding the gauge of the structure and collision with infrastructure elements, people in the vicinity or other vehicles, falling cargo from the wagon.

Occurrence of a dangerous event gives rise to specific losses: loss of people’s health or life, damage to property (rolling stock, elements of infrastructure, other cargoes), degradation of the natural environment, impediments to the functioning of the railway transport system, financial losses, organizational problems.

Improve of security is possible through [1]:

- reduce of hazards;
- counteracting the activation of hazards;
- counteracting the occurrence of losses.

Technical measures (construction solutions, shaping the reliability of objects, the use of diagnostics), organizational solutions (e.g. implementation of appropriate exploitation procedures), as well as legal-administrative, educational, scientific etc. can be used for this purpose.

Limiting the described hazards is possible through appropriate protection of transported loads, follow procedures describing the course of the marshalling process, control activities. Due to the occurrence of random phenomena, complete elimination of hazards is not possible. Therefore, it is necessary to use solutions that will prevent their activation.

In view of the increase in train speed, the intensity of railway traffic and the number of transported loads, there is a gradual decrease in the role of man in the control and management of transport [3]. The efficiency and safety of the transport process are increasingly dependent on access to information. It is necessary to build elements of railway infrastructure equipped with sensors that provide relevant data to the decision center, as well as to identify hazard and automatically transmit alarm information.

2. Detection of the Hazard State

Among the technical measures improving the level of transport safety, diagnostic solutions can be distinguished.
Monitoring the position of transported loads and the shape (contour) of individual wagons in the train set allows to automatically detect emerging irregularities. For this purpose, after the wagons are loaded and the train is formed, patterns of observed objects should be created (Fig. 1). Creating a pattern (model) may involve determining the shape or characteristics of each object, defining the size of the space fragment covering individual objects, as well as memorizing their sequence (sequence of charges on the wagon, sequence of wagons in the train).

Fig. 1 Creating a pattern (model) of transported loads or wagons

At diagnostic points located along the train route, the wagons and loads should be monitored by the sensor system. The results of observations should be sent online to the traffic control center and compared with the pattern (model) created after the train was formed.

Detection of deviations from the created pattern (change of shape or position in relation to the original state) should generate an alarm signal indicating the emergence of a hazard state (Fig. 2). Appropriate reaction to an alarm signal enables taking actions preventing the activation of the detected threat.

Fig. 2 Monitoring the status of loads or wagons in a moving train

The system of automatic identification of objects can be an element of intelligent train management and control system using information exchange between infrastructure elements (Intelligent Train Control & Dispatching System - ITCDS), in particular Intelligent Emergency rescue & Safety supervision System IESS, for detection of threats and automatic transmission alarm information.

3. Methods of Detecting Cargo Shifts

In the laser laboratory of the Railway Research Institute a measuring stand was built to examine the possibility of identifying the elements of rolling stock [2]. The main elements of the station are: a measuring track, a mobile research plane and a hardware and software platform equipped with laser sensors.

The test plane moving on the measuring track enables the experiments to be carried out using objects of various shapes and dimensions.

The drive of the research plane is carried out using a linear motor, servo amplifier and planetary gear. The drive and control system enables the adjustment of motion parameters of the test plane (direction and range of motion, speed, number of repeat measurement cycles).

Measuring station is equipped with a set of laser sensors including: point sensors of mid-range distance, 2D scanner, advanced measuring automation light grids (measuring curtain), a set of triangulation distance sensors equipped with a real time surface compensation function (RTSC) and a vision system composed of configurable, autonomous laser sensors using a laser triangulation method (Fig. 3).

The element of the research stand is also a module for measuring the speed of real objects (rolling stock), integrated structurally and functionally with the hardware and software measuring platform. The platform allows the implementation of experiments both in the laboratory (using a measuring track and a mobile research plane) as well as in the natural environment, in the conditions of actual implementation of freight transport.

Research on the identification of rolling stock elements are realized using two basic methods: shape assessment of selected fragments of the surface of objects and 3D scanning.
The first method uses point sensors of mid-range distance (including triangulation distance sensors), a 2D scanner and a measuring curtain. The computer application prepared for research purposes enables creating mathematical models of observed objects. The trained model allows to distinguish and identify moving individual objects and to analyze their sequences.

The application functions in the Matlab programming environment with the use of necessary libraries, in particular Neural Network Toolbox, extending the Matlab environment with the functions of designing, implementing, visualizing and simulating neural networks. The graphical interface of the application gives the possibility to choose objects to be identified, located in the field of view of measurement sensors, and to enter the values of the parameters of the experiments carried out. Reading of measurement data from individual sensors is carried out in a synchronous manner, simultaneously from all sensors used in the experiment. At the same time, the application allows you to freely select a subset of sensors used in the identification process.

In the second research method, the identification of moving objects is carried out using a vision system, consisting of configurable, autonomous laser sensors, using the laser triangulation method.

Applied configurable, autonomous laser sensors and a specialized measurement module enable the recording, analysis and visualization of measurement results. Such a measuring system allows detecting and locating objects and also task of determining object dimensions (length, width, height, area and volume).

To identify objects, the measuring application tools are used, such as:
- Blob Finder (it allows, for example, counting objects and determining their dimensions, measuring the surface and volume);
- Measure distance (lets you detect whether or not an object has been displacement or rotated);
- Point as a base for measuring distances to selected characteristic points of the object (detection of changes in the position of these points).

Using the Blob finder tool allows to define the size and position of the space fragment in which the object should be located.

Fig. 4 shows the observed real object and in Fig. 5 the image seen by vision sensor and the defined fragment of the space in which the object should be located.

Changing the position of the object (e.g. tipping or rotating the load on the wagon platform) causes the object image to be extended beyond the originally defined space fragment (Fig. 6). Detection of the object's shift (load) consists in finding a change in the size of its surface (seen by the vision system) and the contour out of the object beyond the defined area of the space fragment.

Detection of the change of the load position (hazard) also allows Measure Distance and Point tools. They allow to define base points related to the wagon and characteristic points on the surface of each of the objects. Detection of the change in the distance between these points indicates the shift of the object on the wagon loading surface or the change of the position of the objects relative to each other (Figs. 7 and 8).

The computer application automatically determines the centers of areas of objects seen through the sensor (Fig. 7). Fig. 8 shows the distances calculated by the application: Distance 1 (between Points 1 and Point 2) and Distance 2 (between Point 1 and base Point 3 defined on the measuring plane).
Fig. 4 Observed real object on the measuring plane

Fig. 5 Image of the observed object seen through a vision sensor

Fig. 6 An image of a shifted object

Fig. 7 Images of observed objects (OBJECT 1 and OBJECT 2) and centers of areas (Point 1 and Point 2) seen through the vision system

Fig. 8 Distances between centers of areas of the objects and the base point on the measuring plane (wagon loading surface)

Fig. 9 An image of the OBJECT 1 shifted beyond the defined fragment of space

Fig. 10 Change in the value of Distance 1 and Distance 2 as well as the surface of the OBJECT 1 seen by the sensor
Similarly, as shown in Fig. 5, for each of the objects it is possible to define independently a fragment of the space in which the object should be located. The observed effects of the OBJECT 1 shift are presented in Figs. 9 and 10.

Shifting the cargo on the wagon platform causes detection of the exit of object's contour beyond the defined (at the stage of creating the model) fragment of space, change the surface of object's image seen by the sensor and change of distance: Distance 1 (between Point 1 and Point 2) and Distance 2 (between Point 1 and Point 3).

4. Conclusions

The performed experiments confirmed the effectiveness and usefulness of the research methods described in the article to identify hazards arising during the transport of loads by rail transport.

A measuring system composed of laser rangefinders, a measuring curtain and a 2D scanner allows identifying moving objects and recognizing their sequences. Creating and training object models (loads, wagons) require defining the measurement range and multiple observation of a set of different objects. The quality of the model - the pattern depends on the number of observations of selected objects made during the training process. The effectiveness of the identification of objects depends on the proper selection of the spatial configuration of the sensors [4] and the degree of training of the model. In practice, this method is easier to use to identify objects with defined shapes (e.g. wagons, their components and subassemblies, loads of typical shapes, etc.).

The use of a vision system and scanning technology does not require model training by repeated observations. The image of the object (cargo, wagon) is created as a result of one observation. To create a pattern (model) it is necessary to define by the application user the characteristic quantities (variables, constraints) describing the model and declare their permissible values.

Research works aimed at assessing the effectiveness of both methods in different measurement conditions are ongoing. An interesting direction of research will be to determine the possibilities of using the advantages of each of them and building an integrated identification system. The works carried out indicate that both measuring systems can be useful for identifying hazards consisting in changing the position of loads or changing contours of wagons body.

Acknowledgment

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References

Vehicle Routing of Special Urban Transport Service

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Abstract

Special Urban Transport Service (SUTS) is used by people in wheelchairs, those who use crutches, temporarily or permanently disabled including people with reduced mobility or elderly persons. These passengers need specific conditions for their transportation. That causes higher operation costs of SUTS due to a lot of factors: special modified vehicles, special way and time of reservation process (through a dispatcher), individual mode of transport (door-to-door), time-limited operation or reduced ticket price for passengers. One important aspect that affects operating efficiency of SUTS is coefficient of vehicle occupancy and related route scheduling. The paper is focused on optimisation of vehicle routes and its impact on total operation costs of SUTS. Method of exhaustive search for vehicle routing optimisation is described in this paper as well as the model for evaluation of total operation costs. Economic and technological data of SUTS from the year 2017 are used as input data for optimisation. Outputs of optimisation are compared to the situation in SUTS Pardubice (2017).

KEY WORDS: optimisation, people with reduced mobility, special urban transport service, trip clustering

1. Introduction

Two kinds of extreme types of public transport scheduling (organisation) include regular service and demand-responsive service. Regular service has a fixed timetable and fixed routes. Routes are scheduled on the basis of transport demand analysis in the given area to transport maximum number of passengers. Demand-responsive service may be realised on any route and with flexible timetable. This service is arranged upon request including individual approach to the customer. This type of scheduling does not aim at satisfying all requirements of customers regarding time and destination. Disadvantage of the demand-responsive service lies in reduced predictability of transportation range and lower capacity of vehicles.

Compromise solution between regularly scheduled service and irregular demand-responsive service is achieved when it is operated on fixed routes with flexible timetable. This system has been used on some bus lines of regular public transport service: buses run to villages with low transport demand only upon request (booking call). This system can be useful also for people with reduced mobility when using nonbackbone bus lines of urban public transport means with stops near Health Centres, Welfare facilities or Organizations for People with Disabilities.

To satisfy requirements of disabled people or other passengers (e.g. older people with crutches), the concept which combines regularly scheduled and demand responsive transport (fixed routes with flexible timetable) can help. Transport is carried out as regularly scheduled with possible deviations from the route [1]. Timetable specifies only the route of the bus line but times of departures from less frequented stops are deliberately omitted. Only departure times from transfer points or other important stops are defined there. Passengers travelling from stops between them have to wait for the service in the interval between departure from the previous stop and arrival at the following one. Travel time between stops is set in a more tolerant way to observe departure times from all such stops even if buses serve them rarely. Therefore possible isochrones of route deviations are specified when scheduling these routes. If the stop is equipped with a digital information panel, it is possible to inform passengers about the deviation from schedule. Disadvantage of this concept lies in longer travel time for passengers travelling only from stop to stop and greater deviations from the schedule compared to regularly scheduled urban public transport. This can also have an impact on transfer time between SUTS and public urban or long-distance passenger transport [2].

Densely populated cities attempt to use urban public transport in maximum extent also for people with reduced mobility. Demand-responsive service (door-to-door service) can be provided in big cities and agglomerations. Transport problems for PRM do not have to be brought only by quality of transport. People with reduced mobility often prefer individual transport to public regardless higher costs. There are not only physical but also psychological barriers. As the survey carried out in Poland and the Czech Republic [3] showed, these include also shyness (disabled people can be uneasy around others) or inappropriate behavior of drivers and / or other passengers. These issues are dealt by social sector helping PRM with social integration and teaching the society right attitude to them.

2. Trip Clustering

Costs of demand-responsive services with flexible routes and timetable can be optimised e.g. by clustering [4]. The municipality of Pardubice have one specially modified car Fiat Ducato with capacity 5 – 9 seats available [5].
Optimisation process aims at increasing annual coefficient of vehicle occupancy using exact methods (e.g. exhaustive search) or heuristics (evolutionary algorithms, genetic algorithms, vehicle-routing problems, e.g. Clark-Wright method). Cargo transport optimisation tasks occur in literature more frequently [6], [7]. The extent of this service provided by Pardubice municipality (1car) enables using exact method of route optimising. All feasible solutions of the task are found first. Because of high computational demands, it is necessary to identify limiting conditions (maximum number of passengers, trip origins and destinations, i.e. graph vertices). To serve one customer, it is necessary to pass through two graph vertices, whose order is not interchangeable (first it is necessary to collect the customer at the pick-up address and take them to the destination address). Next step implies evaluation of all feasible solutions based on the set criteria using multi-criteria analysis (WSA method). In this case the following criteria were selected to evaluate variants of feasible routes:

- total travel time/costs of transport (min.);
- travel time/costs deviations per passenger trip (min.);
- coefficient of vehicle utilization (max.).

The results bring percentage evaluation of individual feasible solutions based on selected values of criteria. The route with the highest score of WSA is considered optimal. Disadvantage of this kind of solution lies in high computational demands when searching for all feasible solutions and limited range of vertices to pass through. To solve optimisation of SUTS routes in Pardubice, we selected maximum of 8 vertices (when clustering routes of maximum 4 customers, we get 40320 route permutations, out of which 2521 are feasible). This range is sufficient for optimisation of routes for only one time window (feasible time range for the route is max 2 hours). Daily vehicle routing and scheduling consists of calculation of optimal routes for every time window. Calculation of optimal routes between time windows is not carried out in this case.

3. Impact on Technological and Economic Indicators

Optimization results were compared to selected days of registered routes in 2017. Table 1 presents values of the actual distance travelled (traffic performance in km) in comparison with optimised route of a selected day. First two cases (days) bring positive impact – vehicle kilometres travelled reduction. The last case (the last line in the Table 1) shows worse results for optimised route compared to the actual route. That was caused by low number of passengers on selected day when almost every customer occurred in a different time window. Therefore, the software was not able to cluster more passengers because it only clustered trips in one time window.

<table>
<thead>
<tr>
<th>Number of passengers</th>
<th>Number of km (actual situation)</th>
<th>Number of km after optimisation (MS Excel)</th>
<th>Number of km after optimisation (ODL studio)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 March 2017</td>
<td>18</td>
<td>150</td>
<td>125.3</td>
</tr>
<tr>
<td>2 March 2017</td>
<td>20</td>
<td>140</td>
<td>131.5</td>
</tr>
<tr>
<td>3 March 2017</td>
<td>12</td>
<td>110</td>
<td>115.5</td>
</tr>
</tbody>
</table>

The last column in Table 1 shows information about the route optimised by ODL studio software (Open door logistic studio) applying single-objective optimisation (minimisation) using total vehicle route costs.

Fig. 1 Vehicle occupancy on a selected day

Fig. 1 shows vehicle occupancy on original and optimized route by means of ODL studio software compared to trips from 1 March 2017. This process results in grouping of up to 4 passengers into feasible time window 16:24 – 17:24 h. Travel time can be too long for some passengers, which might be viewed negatively. Such long travel times can be eliminated in the ODL studio software only when the routes are manually adjusted by the user.

Fig. 2 displays various scenarios for annual number of transported passengers (pass-km). Provided that there is a direct correlation between traffic performance (veh-km) and transport performance (pass-km), it is possible to fit straight
lines to the chart showing average annual occupancy of the vehicle. Maximum capacity of the SUTS vehicle in Pardubice is 5 wheelchair users. Blue dashed line shows maximum annual vehicle occupancy (occupancy coefficient = 1). This vehicle occupancy value is theoretical and it cannot be achieved with demand-responsive way of transportation. Red line represents average vehicle occupancy in 2017 (10%). Traffic performance 35 000 veh-km corresponds to 17 500 pass-km (transport performance). This situation is marked by the blue spot. If the average vehicle occupancy increases by 10% while maintaining the same traffic performance (veh-km), the transport performance (pass-km) increases by 50%. We can make a realistic assumption when introducing dispatch management - increased vehicle occupancy to 15%, while cutting down the number of travelled km (traffic performance) by 10% (yellow spot).

![Transport performance for different levels of vehicle occupancy](image)

**Fig. 2 Number of transported passengers (transport performance) and vehicle occupancy**

### 4. Tariff Changes

Fig. 3 displays how traffic performance (veh-km) depends on overall economic balance (difference between costs and revenues from passenger tickets without municipality subsidies). Blue line shows total vehicle operating costs in dependence on kilometres travelled per year (traffic performance). In 2017 total operating costs of SUTS Pardubice reached 989 568 CZK (ca. 38 430 €). Dashed lines show total vehicle operating costs including revenues from passenger tickets.

![Ticket price 15 CZK](image)

**Fig. 3 Financial loss (STUS 2017)**

SUTS ticket price in Pardubice is 15 CZK (0.58 €) for one trip in Zone I (city zone) regardless the number of kilometers travelled by one customer. The blue spot displays vehicle operating costs of 921 807 CZK (35 798 €) where the average annual vehicle occupancy is 10% and traffic performance 35 000 veh-km. Every time the vehicle occupancy increases by 10% (dashed lines), the costs reduce by 67 350 CZK (2 616 €), which is the value corresponding to overall annual revenue from fares.

According to this model, STUS total operating loss was 221 807 CZK (ca. 8 610 €) in 2017 when subsidized by municipality in the amount of 700 000 CZK (ca. 27 200 €, which is marked by red solid line in Figs. 3 and 4). To make a profit, it would be necessary for the operator to increase vehicle occupancy to 30% and cut down traffic performance.
(veh-km) to 11 500 (yellow spot in Fig. 3) while maintaining the ticket price and amount of subsidies. Transport performance of the year 2017 (17 500 transported passengers) remains the same with these parameters of annual indexes.

Fig. 4 displays proposed fare increase from original 15 CZK (ca. 0.25 €) to 30 CZK (ca. 1.17 €). Proposed fare increase stems from comparison of fares in other cities in the Czech Republic [8]. Under the same circumstances (30 CZK as the ticket price, traffic performance of 35 000 veh-km, average vehicle occupancy of 10%, annual subsidy of 700 000 CZK), there would be loss in the amount of 155 904 CZK (6 063 €). To make a profit, 20% vehicle occupancy and cut down traffic performance (to ca. 17 500 veh-km/year) would be sufficient while increasing the price to 30 CZK and keeping the subsidies in the amount of 700 000 CZK. It is clear from the graph that in this situation the operator could make profit of 1 750 € maintaining annual transport performance 17 500 pass-km.

Fig. 4 Financial loss of STUS after fare increase

5. Conclusions and Discussion

Pardubice municipality believe that STUS significantly contributes to improvement of life quality for people with disabilities. Therefore they spend a considerable amount of money annually subsidising this service. Possibilities for optimisation of operating STUS and their impact on passengers and operators were analysed in the context of the student grant project. The proposed solution for routing is based on the concept of flexible routes and flexible timetables. For this model, clustering is presented as an option of optimisation together with economic effects of higher vehicle occupancy coefficient when maintaining or increasing fares. To keep annual transport performance (pass/km) and make a profit, it would be necessary to increase vehicle occupancy to 30 % and simultaneously cut down traffic performance (veh-km) by ca. 2/3 when keeping fares and subsidies on the same level. The annual transport performance (17 500 pass-km) reached in 2017 would remain the same. On the contrary, if fares increase, 20 %vehicle occupancy would suffice when reducing travelled km by ca. 50 %.

References

Feasibility of IIoT Application in Railway Signalling and Interlocking Systems

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Abstract

The paper covers main aspects of Internet of Things (IoT) design and architecture, showing directions of application for the observed technology in railway systems. The focus of the study is directed towards security and reliability of Industrial Internet of Things (IIoT) devices and communication links between them, as well as the necessity of given factors is evaluated for different railway operation scenarios. Examples of IIoT implementation on railroads in different countries are reviewed, while requirements for railway signalling and interlocking principles are considered. Conclusions about the viable implementation of IIoT systems on the Latvian Railway are given.

KEY WORDS: internet of things, industrial internet of things, IoT, IIoT, railway, signalling, interlocking

1. Introduction

Internet of things (IoT) is a concept of a computer network built on the basis of devices, which are connected to real-world objects (“things”), equipped with the means for interaction with one another or with components of external networks, performing tasks of telematics.

International Telecommunications Union (ITU) has released several recommendations regarding the Internet of Things technologies. According to the ITU recommendation Y.4000 (Y.2060) titled “Overview of the Internet of things”, IoT is described as a “global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies” [7]. The same document gives a clear definition for the term “thing” and “device” in the context of IoT:
- thing is an object of the physical world (physical things) or the information world (virtual things), which is capable of being identified and integrated into communication networks;
- device is a piece of equipment with the mandatory capabilities of communication and the optional capabilities of sensing, actuation, data capture, data storage, and data processing.

In recent years, IoT technologies became widespread not only in the consumer electronics segment, as a part of “smart home” systems, but also in the industrial field. Industrial devices have higher requirements in reliability, security and therefore are attributed to the Industrial Internet of Things (IIoT).

ITU defines Industrial Internet of Things as an “IoT based enabling approach for industrial transformation, by taking advantage of existing and emerging information and communication technologies” [8].

Industrial Internet should not be confused with the regular Internet. While both technologies serve a purpose of providing wide area networking, Industrial Internet is primarily focused on the data acquisition from the physical hardware (machines, sensors), large data stream transfer for the analytics, storage and system management, without being exposed to a global network.

2. Communication Technologies for IoT

IoT devices without a proper way of interacting with a central node or with one another, as in machine to machine (M2M) communications, cannot perform IoT-specific tasks like control, management, and data gathering efficiently. Therefore, the communication capability of an IoT device, as stated in the definition, is compulsory in any use-case.

There are numerous connectivity options for IoT systems both wired and wireless. The choice of communication technology depends on the given requirements of a system and the need for providing varying levels of reliability, security, scalability, etc.

The list of commonly used IoT communication technologies [10] is given in Table 1.

IoT systems also use different messaging protocols on top of the communication ones. In general, IoT devices are designed to be compact, have low power consumption (many of them are battery operated) and hence are equipped with low computing power hardware. These features are the reason why a limited selection of memory-efficient or even specialized messaging protocols can be utilized in the first place. Protocols, which are most commonly used in IoT systems [11], are listed in Table 2.
### Table 1

Comparison of IoT communication technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Standard</th>
<th>Data rate, Mbps</th>
<th>Radio frequency, MHz</th>
<th>Transmission medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethernet</td>
<td>IEEE 802.3</td>
<td>10–400 000 (Ethernet–Terabit Ethernet)</td>
<td></td>
<td>coax, twisted pair, optical fiber</td>
</tr>
<tr>
<td>MoCa</td>
<td>MoCA 1.0–2.5</td>
<td>100–2500 (MoCA 1.0–2.5)</td>
<td>-</td>
<td>coax</td>
</tr>
<tr>
<td>PLC / BPL</td>
<td>IEEE 1901</td>
<td>200 (BB-PLC), 500 (HD-PLC)</td>
<td>-</td>
<td>power line</td>
</tr>
<tr>
<td>Wi-Fi</td>
<td>IEEE 802.11</td>
<td>11–9608 (Wi-Fi 1–Wi-Fi 6)</td>
<td>915–928, 2402–2494, 3657.5–3690, 5030–5875, 5850–5925, 57240–70200</td>
<td>radio</td>
</tr>
<tr>
<td>WiMax</td>
<td>IEEE 802.16</td>
<td>37–376 (WiMAX rel 1–rel 2.0)</td>
<td>2000–66000</td>
<td>radio</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>IEEE 802.15.1</td>
<td>0.721–48 (Bluetooth 1.0–5.1)</td>
<td>2402–2480</td>
<td>radio</td>
</tr>
<tr>
<td>Cellular</td>
<td>GSM, UMTS, LTE-A</td>
<td>0.0096–1000 (GSM–LTE-A)</td>
<td>380–3700</td>
<td>radio</td>
</tr>
<tr>
<td>LTE-M</td>
<td>LC-LTE, eMTC</td>
<td>1</td>
<td>450–3800</td>
<td>radio</td>
</tr>
<tr>
<td>NB-IoT</td>
<td>LTE Cat NB1, LTE Cat NB2</td>
<td>0.25</td>
<td>452.5–2200</td>
<td>radio</td>
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<tr>
<td>6LoWPAN</td>
<td>IEEE 802.15.4</td>
<td>0.04–0.25</td>
<td>868–868.6, 902–928, 2400–2483.5</td>
<td>radio</td>
</tr>
<tr>
<td>ZigBee</td>
<td>IEEE 802.15.4</td>
<td>0.25</td>
<td>784, 868, 915, 2400</td>
<td>radio</td>
</tr>
<tr>
<td>LoRa</td>
<td>LoRaWAN</td>
<td>0.05</td>
<td>169, 433, 868, 915</td>
<td>radio</td>
</tr>
<tr>
<td>Z-Wave</td>
<td>ITU G.9959</td>
<td>0.1</td>
<td>868.4–926</td>
<td>radio</td>
</tr>
</tbody>
</table>

### Table 2

Comparison of IoT messaging protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Standard/ specification</th>
<th>Architecture</th>
<th>Communication protocol</th>
<th>Encryption</th>
<th>QoS</th>
</tr>
</thead>
<tbody>
<tr>
<td>MQTT</td>
<td>ISO/IEC PRF 20922</td>
<td>Publish/subscribe</td>
<td>TCP</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>AMQP</td>
<td>ISO/IEC 19464</td>
<td>Point-to-point, publish/subscribe</td>
<td>TCP, UDP</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>DDS</td>
<td>OMG DDS</td>
<td>Decentralized publish/subscribe</td>
<td>TCP, UDP</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CoAP</td>
<td>RFC 7252</td>
<td>Client/server</td>
<td>UDP</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>XMPP</td>
<td>RFC 3922, RFC 3923, RFC 5122, RFC 4854, RFC 6120, RFC 7622</td>
<td>Client/server</td>
<td>TCP</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>OPC UA</td>
<td>IEC 62541</td>
<td>Publish/subscribe</td>
<td>TCP</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>HTTP / HTTPS</td>
<td>RFC 1945, RFC 2616, RFC 7231, RFC 2818</td>
<td>Client/server</td>
<td>TCP</td>
<td>Yes</td>
<td>-</td>
</tr>
</tbody>
</table>

### 3. Basic IIoT Architecture Patterns

The Industrial Internet of Things Reference Architecture technical report [9], produced and regularly updated by the Industrial Internet Consortium (IIC), covers the most commonly used IIoT framework design and development solutions.

Industrial Internet Consortium is an open membership organization, widely known for the development of various test platforms, demonstrating Industrial Internet real-world implementations, providing information for the secure and versatile IIoT ecosystem creation.

Modern IIoT system architecture can be viewed as an implementation of a certain acknowledged architectural
pattern. An architecture pattern is a simplified representation of the reference system or its part. There are three well-established architecture patterns [9, 12]:

- three-tier;
- gateway-mediated edge connectivity and management;
- layered databus.

3.1. Three-Tier Architecture Pattern

Three-tier architecture (Fig. 1) is composed of three logical layers of data and control flow processing:

- **Edge tier** collects data from the nodes inside the proximity network.
- **Platform tier** receives data from the edge tier, processes and analyzes it, performs management functions.
- **Enterprise tier** implements domain applications, provides end-user interfaces for control functions and interaction with processed data.

![Fig. 1 Three-tier architecture structure [9]](image)

3.2. Gateway-Mediated Edge Connectivity and Management Architecture Pattern

Gateway-mediated edge connectivity and management architecture (Fig. 2) primarily consists of a local area network (LAN) bridged to a wide area network (WAN) via edge gateway or hub. Devices inside LAN are isolated from WAN and are protected against unauthorized access.

![Fig. 2 Gateway-mediated edge connectivity and management architecture structure [9]](image)

The topology of the local area network may vary from bus to mesh (peer-to-peer), depending on the complexity and size of the system. The gateway has many capabilities, such as physical, networking and application layer bridging, data flow processing, management, and control functionality.

3.3. Layered Databus Architecture Pattern

Layered databus architecture comprises hierarchically connected layers of data buses (Fig. 3). A databus is a set of logically connected endpoints, representing one common data model.

Communication between machines, applications, and devices is usually performed inside a databus. Data transition between layers reduces the amount of information thanks to filtering on each level of the hierarchy. A larger percent of useful data in the overall data flow allows analyzing it on a larger scale.

The most common method of communication between layers is based on the subscribe-publish model. Subscribe-publish systems are proven to be effective at distributing large numbers of time-critical messages at high rates.
4. The Architecture of Railway Interlocking Systems

To determine if main principles of IIoT can be integrated into existing railway signalling environment, the architecture of a basic interlocking system should be observed. Unfortunately, implementations of interlocking systems are not standardized in every aspect across different countries, and manufacturers use different approaches to build their own systems, following only general standards in safety for railway applications.

Modern railway interlocking systems are based on the microprocessor technology thus are built using similar topologies as in computer networks. For example, EBI Lock 950 central interlocking system from Bombardier, has modular hierarchical topology (Fig. 4), consisting of three main subsystems: control and management layer, dependency handling layer, object controller layer. EBI Lock 950 is the most commonly used microprocessor interlocking system on Latvian railways.

Data flow organization between different subsystems of EBI Lock 950, as it can be seen from the given structure, resembles a layered databus architecture pattern widely used in IIoT systems. This fact gives an understanding, that integration of IIoT-enabled devices into a microprocessor interlocking system using a specialized layer in the subsystem tree is certainly possible from the technical point of view. The problem of this approach lies in the field of safety-related system certification.

5. IIoT as an Extension to Existing Signalling Systems

In Europe, requirements for the acceptance and approval of safety-related systems in the railway signalling field are defined by the set of European Standards issued by CENELEC (European Committee for Electrotechnical Standardization): EN 50126, EN 50129, and EN 50128 [2-4].
According to the “Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety” (EN 50126) standard [3], system lifecycle is resembled by the following diagram (Fig. 5):

Mentioned European standards apply to the following phases of complete signalling systems: design, specification, construction, installation, acceptance, maintenance, operation and, most importantly, modification or extension of individual subsystems.

Safety verification and validation should be repeated after any modification, resulting in a compliance check of Safety Integrity Level (SIL) and Software Safety Integrity Level (SSIL) of a complete system and its software. Therefore, upgrading existing signalling systems with new IIoT equipment, focusing on its full integration with already installed hardware and software, would generally be impractical. This concept might be feasible only for newly developed systems (built from the ground up) with IIoT architecture as a core component (Fig. 6).

Fig. 6 The example architecture of a signalling system with an integrated IIoT subsystem for data collection

Fig. 7 The example architecture of a signalling system with
Another approach is to make the IIoT system completely standalone and interface signalling equipment in a way SIL and SSIL are not affected so that the signalling system’s safety verification and risk re-evaluation procedures are unnecessary. An example of IIoT system with the one-way interface between outdoor railway equipment and IIoT data collection network is illustrated in Fig. 7. In practice, such system configuration can be used for the extensive collection of railway equipment parameters, selected data processing using machine learning and result analysis for the means of predictive maintenance.

Remote control of railway signalling equipment using IIoT system is another topic that raises a lot of questions. The reduction of probability of failure in microprocessor systems is usually achieved by increasing the redundancy of components, using hot reserve technology for the backup of critical elements, and utilizing benefits of real-time operating systems (RTOS). This means that IIoT devices intended for use in a remote control application should run RTOS and have safety-critical certification in SIL2/SIL3/SIL4, depending on the intended use case in the railway transport system. This also means that appropriate messaging protocols should be used for reliable information transfer without the introduction of delays or data loss and that the complete system should meet the requirements of the defined safety integrity level.

6. IIoT Security

The most important concerns of adapting IIoT systems, especially for the use in the transport industry, are security issues. The study of risks in industrial control and IIoT systems [5] performed by the cybersecurity company CyberX at the beginning of 2019 shows that 40% of the audited industrial sites have at least one direct connection to the Internet and 84% of sites have at least one remotely accessible device.

Any network connection that is open to the public poses a real threat to the security and reliability of a system which uses it. In railway transport, security and reliability of every system is critical and is directly linked to the safety of people, machines, and cargo. That’s why the existence of an external connection to the secured network of a signalling or interlocking system, as a rule, is strictly prohibited by the IT policies of the local railway duty holder.

Security concerns for IIoT systems raised in the CyberX’s report don’t mean that IIoT hardware and software, in general, can’t provide proper security options. Main reasons for poor security are human errors and misconfiguration of devices or networks they are part of. For example, the use of messaging protocols with encryption support, which are widely available (Table 2), in a combination with insecure authentication methods can result in a data breach.

The International Organization for Standardization (ISO) has developed and regularly updates ISO/TR 22100-4 technical standard which is aimed at IIoT system IT-security enhancement and defines basic principles of a secure industrial network. The fulfillment of the ISO/TR 22100-4 standard, as well as the security policy of a local railway duty holder, is generally enough to implement a secure railway IIoT system.

7. Examples of IIoT Systems for Railway Industry

Although IoT solutions are already implemented in many modern products and services for the railway segment of the transport industry, only a few of them are focused on signalling and interlocking systems and aren't widely available. The main field of interest for railway IoT product developers, determined by the trends in the industry, is maintenance tracking and location monitoring of locomotives [15], maintenance of way (MOW) equipment, wagons and cargo itself. For example, available solutions for railway transport IIoT from ZTR Control Systems include [16]:

- Equipment parameter monitoring;
- Asset location monitoring;
- Health diagnostics;
- Fuel management;
- Maintenance tracking and planning.

The illustration of IIoT practical application for railway signalling systems is provided by Efftronics company. Efftronics has the largest IoT network in India with more than 6 million interconnected railway signalling devices, consisting largely of equipment monitoring nodes. These nodes perform following functions [6]:

- Point machine monitoring (switching current, voltage, switching intervals);
- Data logging (voltage and current of various signalling equipment, relay status, digital and analog I/O status);
- Power supply monitoring;
- UPS battery monitoring;
- Earth leakage detection and measurement;
- Interlocking system integrity testing (data collection and analysis).

The extensive amount of collected information and parameters is used in diagnostics and predictive maintenance of signalling equipment.

8. Conclusions

This paper investigated the possibility of IIoT implementation in railway transport signalling systems. The observation of communication technologies and messaging protocols for the IoT shows, that despite the common
misconception about reliability and security of IIoT devices, they can perform fail-safe data handling when using appropriate connection media type and protocols with encryption and QoS options enabled [14]. Although the design principles of an IIoT architecture allow to completely integrate IIoT devices into a signalling or interlocking system, modern IIoT solutions for railways are built as standalone applications because of the safety-related requirements for the hardware and software (SIL, SSIL).

Reviewed examples of the IIoT application in railway signalling and interlocking device monitoring in the field of the predictive maintenance correspond to the demands of railway operators all over the world. Latvian Railway, the railway infrastructure manager in Latvia, has entered the era of a rapidly growing number of microprocessor-controlled systems and related components, but still has many older devices, incapable of providing sufficient diagnostic data natively. The introduction of modern diagnostic data collection and analysis system on Latvian railway for both older and newer signalling equipment would improve the maintenance planning, reduce the cost of maintenance, allow to perform predictive maintenance and increase the equipment availability rate.

References

Investigating of the Combustion Process in a Diesel Engine Fueled with Conventional and Alternative Fuels

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Abstract

Supplying diesel engines with vegetable oils is an important issue in the era of looking for alternative fuels. The first designs of this type of engines were supply with vegetable oil, only the refining of crude oil increased the popularity of diesel fuel. The main problem of vegetable oil is viscosity and freezing point. This significantly increases the pressure resistance in the fuel system. The study analyzed the combustion process on diesel fuel and canola oil. For this purpose, a "old type" diesel engine without supercharging as well as an engine brake and an original measured pressure measurement system were used. Differences were shown in the course of the analyzed pressures with the supply of both fuels, which increased as the load increased. The possibility of supplying this type of engine with vegetable oil has been confirmed.

KEY WORDS: mechanical engineering, combustion engines, fuel supply, alternative fuel, testing

1. Introduction

Alternative fuels and sources of propulsion in transport are still being sought [1]. The use of gaseous fuels like LPG [2] or CNG [3] has become widespread in spark-ignition engines. In the case of LPG vapor fuelling, fuel systems are universal [4], although sometimes there are problems with their adaptation [5]. With continuous exacerbation of the exhaust gas toxicity standards, the LPG phases are no longer efficient due to the dosage irregularity of the injectors [6] and their rapid consumption. Liquid phase LPG supply [7] is able to meet the current emission requirements, however, it causes maintenance problems. The current trend indicates the use of hydrogen as a fuel for transport applications [8]. Gaseous fuels are also used as an admixture in fuelling diesel engines [9]. The diesel engine can also be completely converted to spark ignition. There are still engines for non-road applications [10], which also have to meet the emission requirements [11] and are not subject to standardized tests on the dynamometer [12].

The first designs of diesel engines were fuelling with vegetable oil. Only the oil refining process popularized diesel oil. Currently, the aim is to decentralize the production of fuels for transport applications [13]. That is why the topic of plant-derived fuels is attractive. The possibility of producing oil by farmers and using it on your own farm eliminates transport costs. Many studies concern biodiesel [14-17], but this fuel requires the use of esters. Therefore, the production of cold pressed vegetable oil (cPVO) seems to be the most economical. Due to the higher viscosity of vegetable oil with respect to biodiesel, there are problems with the a problem with pumping capability in the fuel system [18, 19]. Vegetable oil can be a fuel for tractor diesel engines [20], even those that meet modern flue gas standards [21].

The evolution of diesel engines is not conducive to the use of vegetable oil due to the high degree of complexity and precision of implementation of executive elements. Common-rail injectors now use a piezoelectric drive [22-24] that allows a faster response to forcing impulses. However, there are precise pairs, whose cooperation and wear can be assessed experimentally [19], or modeled similarly as in the case of braking systems [25, 26]. Experimental research indicates significant pollution of the fuel system when fed with vegetable oil. On the basis of the operational assessment [20], however, it is suggested to modify the fuel system that adapts the engine to supply with vegetable oil. Perhaps a new organization of the combustion process, such as for example Reactivity Controlled Compression Ignition (RCCI) [27], will allow for a richer utilization of vegetable oil.

2. Subject of the Research

The object of research was the naturally aspirated diesel engine with parameters presented in Table 1. The XUD 9 (162) engine is a naturally aspirated diesel engine with a distributor injection pump. This type of fuelling system is devoid of temporary adaptation adjustments, as is the case with common-rail engines. The lack of corrections allows for a direct comparison of the tested fuels, where the regulation is mainly due to the setting of the motor power supply.
The tested engine technical data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>XUD 9 (162), naturally aspirated</td>
</tr>
<tr>
<td>Combustion chamber</td>
<td>Ricardo Comet Mark V</td>
</tr>
<tr>
<td>Number, configure of cylinders</td>
<td>4, in-line</td>
</tr>
<tr>
<td>Timing system</td>
<td>2 valves per cylinder</td>
</tr>
<tr>
<td>Displacement</td>
<td>1905 cm³</td>
</tr>
<tr>
<td>Bore / stroke / connecting rod length</td>
<td>83 mm / 88 mm / 142 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>23</td>
</tr>
<tr>
<td>Max. power at rotation speed</td>
<td>47 kW at 4600 rpm</td>
</tr>
<tr>
<td>Max. torque at rotation speed</td>
<td>118 N·m at 2000 rpm</td>
</tr>
<tr>
<td>Injectors</td>
<td>Bosch KCA 17542</td>
</tr>
</tbody>
</table>

3. The Test Stand

The tests were carried out on the Automex AMX100/10000 engine bench test (Fig. 1). External parameters were evaluated by determining the braking torque. On the dynamometer frame (Fig. 1), the engine was fitted with a special sub-frame. The motor is connected to a drive shaft and next with a eddy-current brake. Brake and motor cooling forces the pump. Heat transfer takes place in a special exchanger. The cooling liquid is collected in the tank. The rotational speed/supply stage is controlled by the servomotor and the rotational speed is read with the meter. Fuel from the tank flows to the gravimetric fuel meter and then to the engine injection pump. The exhaust gases leave the room in the extraction line, in which the measuring probe of the opacimeter is mounted. The whole is controlled by the monitoring and manual control system of the engine dynamometer.

4. The Measuring System

The AVL GM12D piezoelectric sensor from AVL was used to measure pressure (Fig. 2). It was placed in a special adapter in the place of a glow plug (pre-chamber). The electric charge signal from the sensor was processed and amplified using AVL FLEXIF PIEZO for a voltage signal. The measurement of the angle of the crankshaft position was carried out by an inductive sensor BOSCH 0261210030 located at the gear wheel of the flywheel. The obtained angular resolution of the shaft position measurement is 2.65 deg. Determination of the Top Dead Center (TDC) was done by means of the optical sensor TCST 1103 and a polycarbonate disc mounted on the camshaft. Voltage signals from angle and GMP sensors were amplified in transistor amplifiers. The waveforms were recorded using the NI DAQCard-6024E measurement card and special software in the LabVIEW environment.

The recorded curves required processing to determine the momentary angular positions of the crankshaft corresponding to the pressure measuring points. Original software was created in the Delphi 3 system (Fig. 3). It made it possible to read the time courses recorded and through mathematical operations to determine the angular positions. The result of this operation was the values necessary for further processing.
Determining the indicator diagram requires determining the instantaneous cylinder volume as a function of the crank angle $V(\alpha)$. The piston displacement $x$ in the function of angle of crankshaft rotation $\alpha$ was calculated:

$$x(\alpha) = R \left[ (1 - \cos \alpha) + \frac{\lambda}{4} (1 - \cos 2 \alpha) \right],$$

where $\alpha$ – the angle of crankshaft rotation; $\lambda$ – the connecting rod coefficient $L/R$; $L$ – the length of the connecting rod; $R$ – the crank radius.

The instantaneous displaced (swept) cylinder volume:

$$V_d(\alpha) = A_p R \left[ (1 - \cos \alpha) + \frac{\lambda}{4} (1 - \cos 2 \alpha) \right],$$

where $A_p$ – piston area.

The clearance volume:

$$V_c = \frac{\max V_d(\alpha)}{\varepsilon - 1},$$

where $\varepsilon$ - compression ratio.

The total volume of the cylinder:
The results of calculations using the software (Fig. 3) were saved to the .txt file and subjected to further analysis using their own Matlab software procedures.

5. Tested Fuels

The fuels used in the tests are diesel (D) and cold pressed canola oil (C). The basic fuel properties was presented in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Diesel fuel</th>
<th>Canola oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane number</td>
<td>56.00</td>
<td>42.00</td>
</tr>
<tr>
<td>Kinematic viscosity (mm²/sn) at 20 °C</td>
<td>3.80</td>
<td>67.30</td>
</tr>
<tr>
<td>Density (kg/m³) at 20 °C</td>
<td>825.00</td>
<td>915.00</td>
</tr>
<tr>
<td>Lower heating value (kJ/kg)</td>
<td>35.60</td>
<td>33.90</td>
</tr>
<tr>
<td>Condor point (°C)</td>
<td>–15</td>
<td>–3</td>
</tr>
</tbody>
</table>

6. Results and Discussion

Based on the recorded pressure curves in the engine pre-chamber, it was possible to evaluate the combustion process with two fuels. In the initial phase tests were carried out on the unloaded engine which did not show significant differences. Therefore, further tests were carried out under load. Each time in the tests, the rotational speed was maintained at 1000 rpm.

Fig. 4 Comparison of pressure curves in the cylinder of the Talbot XUD9 engine operating at 1000 rpm at various loads (Diesel fuel – black line, Canola oil – red line)

At a load of 20 N·m (Fig. 4 – 20 N·m), the differences in the curvature pressure are negligible, as was the case with no load. The maximum pressure value varies by around 5% in favor of diesel fuel. From the curves shown in
(Fig. 4d – 20 N·m) it can be seen that the beginning and the end of combustion occur at similar volumes (angular position of the crankshaft). Similarly, with a load of 40 N·m (Fig. 4 – 40 N·m). The peak pressure value varies by approx. 4.3% in favor of diesel fuel. Beginning and end of combustion with similar volumes. At a load of 60 N·m (Fig. 4 – 60 N·m) a slightly delayed canola oil self-ignition and longer burning time are visualized. The peak pressure value varies by around 5.2% in favor of diesel fuel. At a load of 80 N·m (Fig. 4 – 80 N·m), the self-ignition delay increases. The peak pressure value varies by around 3% in favor of diesel fuel.

**Comparison of differences in the maximum pressure values in the XUD 9 pre-chamber when fed with diesel fuel and canola oil presented in Table 3.**

<table>
<thead>
<tr>
<th>n, rpm</th>
<th>fuel / oil</th>
<th>$p_{\text{max}}$, bar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>load 20 N·m</td>
<td>load 40 N·m</td>
</tr>
<tr>
<td>1000</td>
<td>Diesel fuel</td>
<td>73.66</td>
</tr>
<tr>
<td></td>
<td>Canola oil</td>
<td>69.58</td>
</tr>
<tr>
<td></td>
<td>difference, %</td>
<td>5.54</td>
</tr>
</tbody>
</table>

As a result of the conducted measurements of the pressure indicated in the engine pre-chamber, it was found that the "older type" diesel engine can work without any modification on the canola oil. The tests were carried out in laboratory conditions, where the temperature often exceeded 20°C. Low ambient temperature, in turn, can cause problems with pumping capability, which was confirmed in the course of refilling a gravimetric fuel meter. Supplying with pure rapeseed oil entails a decrease in peak pressure values in the low speed range in the cases studied. On average, the maximum pressure in the tested range differed by approx. 4% in favor of diesel fuel. Small differences in the beginning and end of combustion were apparent, but they did not affect the functioning of the engine.

**7. Conclusions**

Vegetable oil can be used as an alternative fuel in a "old type" diesel engine without supercharging. As shown by the tests using the engine test bench and the indicated pressure measurement system, the external parameters on diesel fuel and canola oil are similar. The maximum pressure values different by 4%. The indicator diagrams selected with the help of the original software allowed for the evaluation of the combustion process. The ignition delay is prolonged when feeding with vegetable oil. The probable cause of this state of affairs may be a problem with pumping capability in the fuel system (higher canola oil viscosity). At higher fuel dosage required as the load increases, the fuel goes into the cylinder with a certain delay (canola oil). The solution to the problem with the higher viscosity of canola oil can be the heater, which will overcome this problem by increasing the temperature of the fuel. Further work is planned to focus on the assessment of external parameters within a wider range of rotational speeds. An important issue for further consideration is the exhaust gas rating - particulate matter emission.

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**References**


Possibilities of Quality and Degradation of Operating Fluids

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Abstract

The correct operation of the vehicle drive system is highly dependent on the quality of the fluids. They are degraded in vehicle operation. This is due, among other things, to the increase in the presence of contaminants and the decrease in the content of additives. Samples of selected operating fluids of different ages were evaluated. The results showed that with the use of emission spectrometry it is possible to monitor the course of degradation of operating fluids and subsequently to predict the optional interval of its replacement.

KEY WORDS: operating fluids of vehicles, degradation, replacement interval, emission spectrometry, Spectro Q100

1. Introduction

The main propulsion unit is a four-stroke gasoline or diesel engine. Especially in order to get rid of oil dependency, the effort is to replace the reciprocating combustion engines with another drive unit [1]. The electric motor appears to be the driving force of the future [2]. There is a number of problems to solve for its full use. Therefore, the great effort of designers is focused on hybrid technologies. It is a combination of a combustion engine with electric engine. It follows that the combustion engine is, and probably for a long time, the main driving force of the transport machinery and equipment.

The operation of the combustion engine is ensured by a wide range of operating fluids [3, 4]. Basic include liquid and gaseous fuels, lubricating oils and lubricants, coolants and antifreeze agents. These operating fluids must meet a wide range of technical requirements. These requirements are, by the European Union, given by European standards.

In the Czech Republic, technical requirements for gasoline fuel are given by the ČSN EN 228 Motor Fuels - Unleaded Car Gasoline standard [5]. These are octane, vapor pressure, density, distillation test (evaporated at 70°C, 100°C, 150°C and distillation end temperature), type analysis (content of pellets, aromatics and benzene), sulfur, oxygen and lead content.

The technical requirements for diesel fuel are given in ČSN EN 590 [6]. These include flash point, ash content, water content, total impurities, corrosive effect on copper, oxidative stability, sulfur content, lubricating at 60°C, cetane number, cetane index, density at 15°C, viscosity at 40°C, end of distillation temperature and the content of polycyclic aromatic hydrocarbons. Technical requirements and methods of testing for other automotive fuels are given by ČSN EN 589 (for liquefied petroleum gases), ČSN 65 6507 for FAME-based biofuels for diesel engines, ČSN 65 6508 (for mixed diesel fuels containing FAME) and ČSN 38 6110 (for CNG).

Engine oil requirements are mainly determined by SAE J 300, EN ISO [7, 8]. Physico-chemical parameters are prescribed for each oil, such as appearance, density, kinematic viscosity, viscosity index, freezing point, flash point, sulfate ash content, total base number (TBN), total acid number (TAN), CTC-ash , evaporation, oxidative stability, pumppability, phosphorus content, HTHS viscosity, shear stability and more.

There is a number of national and company specifications to describe the physico-chemical properties of coolants. The most important are ASTM D-3306 (USA), SAE J-1034 (USA), BS 6580 (1992 - UK), NF R 15-601 (France), CUNA NC 956-16 (Italy), ONORM V 5123 (Austria), JIS K 2224 (Japan), BMW 1701, VW 774 and others. A large proportion of European coolant manufacturers are based on the Volkswagen Group's corporate technical standard (VW 774) [9]. The 2005 standard (VW 774F) divides the coolants into four classes - C, F, G and H. The coolants designated by the manufacturers as Class B can be compared to the requirements of VW 774 of 1994. The following basic physico-chemical parameters are: water content, boiling point, free alkalinity, density at 20 °C, pH of aqueous solution in a ratio of 1:2 and especially freezing point [°C] of the mixture with water in the ratio 1:1 and 1:2.

In practical operation, when operating the combustion engine, operating fluids are degraded. This degradation, in the case of individual operating fluids, is dependent on the character of its conditioning to be used. In the case of so-called one-off operating fluids (for fuels), the change in its quality parameters depends mainly on the storage time (at the manufacturer, at the filling stations, or in the vehicle tank). For circulating fluids (lubricating oils and coolants), changing its quality parameters depends on a wide range of operating conditions. This issue is extensive, complicated and so far little developed.

But it turns out that some patterns are the same for all operating fluids. In particular, the quality indicators of
operating fluids vary with the decrease in additives and the presence of contaminants. It is this issue that deals with the presented article.

2. Methods and Means

A number of procedures is used to monitor operating fluids, ranging from a quick and indicative assessment of field quality (e.g., appearance, foaming, etc.), to monitoring of physico-chemical parameters according to CSN in certified laboratories, to evaluation through various instrumental techniques [4, 9, 11, 13]. To monitor the decrease in additive content and the presence of contaminants, the so-called trend analysis, the most commonly used methods are atomic emission spectrometry (AES), atomic absorption spectrometry (AAS) and polarography. These methods are implemented in practice using modern instrumental instruments.

The Spectro Q100 is at the researchers' workplace. It is an optical-emission spectrometer of the RDE series (Rotary Disk Electrode). A basic diagram of the operation of the apparatus is shown in Fig. 1. A rotating disc electrode 4, which is immersed in the oil sample 5, still feeds a fresh sample into the gap space. Between disc 2 and rod electrode 4 a high-voltage spark occurs, which atomizes the sample of the oil being examined. The light beam entering the optical system through the entry slot 6 impinges on the hollow diffraction grating 8, which distributes the radiation to individual spectral lines that correspond to the elements present. Behind the slots 9 are placed photomultipliers 7, sensing the intensity of the individual lines and converting the energy of the incident radiation into a proportional electric current. The evaluation device (voltage computer) 1 converts to the concentration of individual elements, displays the results on the screen or sends it to the printer or to the storage medium [12].

![Fig. 1 Scheme of atomic emission spectrometer in modification AES/RDE [12]. Description: 1 – PC, 2 – rod electrode, 3 – AC source, 4 – disc electrode, 5 – oil, 6 – input slit, 7 – photomultiplier, 8 – diffraction grating, 9 – output slits.](image)

The application of this device is intended for mineral and synthetic lubricants including turbines, distilled fuels, heavy fuel oils (HFO), petroleum, glycol fluids and turbine rinsing water [12]. The standard configuration of the Q100 is 22 elements. Generally, these elements can be divided into wear metals (15 elements such as aluminum, cadmium, chromium, copper, iron, lead, magnesium, manganese, molybdenum, nickel, silver, tin, titanium, vanadium, zinc), contaminants (5 elements such as boron, calcium, potassium, silicon, sodium) and additives (10 elements such as barium, boron, calcium, chromium, copper, magnesium, molybdenum, phosphorus, silicon, zinc) [12].

Identifying wear metals in the operating fluid may seem difficult. However, parts of each engine are mostly made of known construction materials. If the amount of a particular material/metal is detected in the operating fluid, the likely point of wear can be determined, thereby locating the possible fault location. For example, iron is the main structural material of the cylinders, crankshaft, piston-rods, camshaft, distribution system, aluminum is the main structural element of the piston and cylinder block, other materials such as copper, tin, nickel represent the structural elements of bearings, piston pin housings, groups of valve components, materials such as chrome and silver are elements of the piston ring, bearing. Materials such as silicon are an additive, but may also be an indicator of poor condition of the air cleaner supplied to the combustion engine [13].

The identification of additives in the operating fluid is very complex. This is because a so-called additive package is added to the base liquid, which contains more additive elements. In addition, the exact composition and content of the additive package in each operating fluid is the trade secret of the manufacturers. However, using modern methods, it is possible to identify the basic elements contained in the additive package. Knowledge the individual elements and especially the trends (increase or decrease) it is possible to determine whether it is an increase in the contaminant or a decrease in additives.

3. Results and Discussion

At the Department of Combat and Special Vehicles, University of Defence, Brno, several tens of samples of various operating fluids were analyzed. The analysis was performed with a Spectro Q100. A relatively large database
was created from analyzes of these samples. In this article selected results from the measurement of hydraulic oil, coolant and engine oil are presented. Before the measurement, the instrument was calibrated using the Standard oil (75 Base, 500 g) and the Calibration standard (22 elements, 100 ppm, 200 g). The evaluation of the measured value record was performed using the SpectrOil Software Windows program.

Three samples of the SHELL SPINAX S3 ATF hydraulic fluid were subjected to an elemental analysis, ie the measured abrasive metal, contaminant and additive content. The analysis was performed on the newly purchased liquid and then after 250 hours and 500 hours. The aggregate measurement results are shown in Table 1. The concentration is given in parts per million (ppm).

Table 1 shows that for elements B (boron), Ca (calcium), P (phosphorus) and Zn (zinc), the content of the measured elements decreases with increasing runs. These are probably elements that are added to the oil as an additive to improve the quality of the oil. However, it is also apparent from the table that for the elements Al, Cd, Cu, Fe, K, Mg, Mn, Na, Pb, Si the content of the measured elements increases with increasing runs. These are probably elements that come into the oil as wear products, e.g. Al, Fe, Cu and others, or as contaminants from the outside, e.g. Si.

<table>
<thead>
<tr>
<th>Runs [hours]</th>
<th>B</th>
<th>Ca</th>
<th>P</th>
<th>Zn</th>
<th>Al</th>
<th>Cd</th>
<th>Cu</th>
<th>Fe</th>
<th>K</th>
<th>Mg</th>
<th>Mn</th>
<th>Na</th>
<th>Pb</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>83,34</td>
<td>2531</td>
<td>1222</td>
<td>1438</td>
<td>0,39</td>
<td>1,81</td>
<td>0,29</td>
<td>0,00</td>
<td>0,57</td>
<td>11,30</td>
<td>2,80</td>
<td>1,55</td>
<td>0,00</td>
<td>4,44</td>
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<tr>
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<td>2196</td>
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<td>3,41</td>
<td>1,77</td>
<td>20,47</td>
<td>37,24</td>
<td>2,13</td>
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<td>4,17</td>
<td>8,74</td>
<td>3,17</td>
<td>12,60</td>
</tr>
<tr>
<td>500</td>
<td>63,00</td>
<td>2067</td>
<td>1153</td>
<td>1230</td>
<td>2,87</td>
<td>1,92</td>
<td>19,13</td>
<td>49,63</td>
<td>2,23</td>
<td>12,85</td>
<td>3,98</td>
<td>8,90</td>
<td>3,88</td>
<td>14,70</td>
</tr>
</tbody>
</table>

Table 2 shows the measurement results of the coolant FB 19400, specification: G12+ (type F), Ford: WSS-M97B44D, VW: TL 774 F (type F). Measurements were made for the newly purchased liquid and then every year for five years. It is apparent from the table that even with the evaluated coolant can be observed elements that have an upward trend of Al, Cu, Ca, Zn, (contaminants) and a tendency of decreasing Mg, Si, Mo, B, K, Na (additives). The elements that do not occur in the evaluated liquid, so its value is zero (Fe, Pb). However, the table also shows that, for example, silicon (Si), which is present as an air contaminant in most operating fluids, is added to the coolant as additives.

Table 3 shows the results of Ford Formula 5W/30, ACEA: A1/A5, API: SM/SL/CF, FORD: M2C-913-A/B engine oil measurements. Measurements were made on newly purchased liquid, then after 250 km and 14700 km. It can be seen from the table that there are also elements that have an upward trend in Cu, Fe, Al, Si, Mg, Mn, Ni (contaminants) and a tendency of decreasing B, Ca, Mo, P, Zn (additives).

Knowledge the time-dependence (increase or decrease) of the components contained in the operating fluids is only the first step in addressing the issue. In order to determine the condition or interval of replacement of the operating fluid, it is necessary to know the so-called limit concentration. This issue is relatively unfinished in the current operating fluids. There is some progress in engine oils. For example, according to publication [13], diesel engine limit values are above 75 ppm for iron, copper over 45 ppm, chromium over 20 ppm, nickel over 40 ppm, aluminum over 35
ppm, tin over 12 ppm, and silicon over 25 ppm. The limit values for gasoline engines are for iron above 150 ppm, copper over 35 ppm, chromium over 25 ppm, nickel over 40 ppm, aluminum over 50 ppm, tin over 12 ppm and silicon over 25 ppm.

4. Conclusion

Samples of hydraulic oil, coolant and engine oil of various ages and runs were evaluated. The results showed that for all operating fluids, some elements are increasing (contaminants) and some elements are decreasing (additives). Knowing the limit values, it is relatively easy to determine not only the condition of the operating fluid, but also to predict the optimal time for its replacement. Today, by creating such a database of infrared spectra, it leads to routine diagnostics of fluids in the operation of vehicles.

Acknowledgement

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References

Effect Analysis of Payload Variation on Energy Consumption of a Hydrogen Powered Light Urban Train

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Abstract

In this study a light hybrid rail train hydrogen powered is considered and the influence of the payload factor variation on traction energy consumption is investigated. For this purpose, a parametric software has been developed to simulate the rail train running over a railway path. As simulated system, an existing non-electrified single-track line has been taken into consideration and the traction energy requirement has been evaluated as function of the pay load factor. The specific fuel consumptions of a similar Diesel train have been compared under the same operating conditions. The results highlight that the hydrogen rail train allows a significant fuel saving to be achieved.

KEY WORDS: urban rail train, hybrid power unit, hydrogen fuel cell, flywheel, fuel consumption, payload variation

1. Introduction

More than 30% of total energy consumption in the European Union (EU-28) is due to transport requirements; the road modal transport produces 25% of the total amount global CO₂ emissions given that the road transport is mostly based on the use of internal combustion engines fed by carbon-based fuels. European cities are increasingly affected by problems caused by transport and traffic. Urban mobility accounts for 40 % of all CO₂ emissions of road transport and up to 70% of other pollutants from transport [1].

In order to contribute to a 60%, cut in transport emissions by the middle of the century, the European Commission adopted a strategy for a competitive transport system that includes the block of traffic for conventionally-fueled cars in cities [2].

As is evident, the issue of emission reduction in transportation field needs a systemic approach that, as well as the incentive to use public transport, also includes innovation actions for both new propulsion systems and eco-friendly fuels that can be produced by renewable energy sources.

In the rail transport sector, the traction vehicle is fed by electrical energy or by Diesel; the latter is used on secondary lines usually characterized by low service levels that often pass through urban areas causing local pollution, the former requires expensive electric infrastructures, that are economically justified only for high flows primary lines (passengers or goods).

A third way, based on hybrid energy sources for the railway traction, is currently developed and used mainly for urban passenger transport applications. This technological solution allows internal combustion engines to be substituted by new propulsion systems capable of achieving zero local emissions even on non-electrified railway lines.

In particular, we refer to electrical motorized vehicles fed by a hybrid power unit (HPU) consisting of hydrogen Fuel Cell (FC) and Energy Storage System (ESS).

Several hybrid power solutions for rail trains have been studied, realized and tested; most of the implemented technical solutions are based on HPUs consisting of FC as energy source and electrochemical batteries as ESS [3-8]. A first hydrogen powered three cars tram is already operative in Qingdao city (China) since 2016 [9]. Two hydrogen FC trains by Alstom in Germany will be operative by late 2019 for extra-urban applications [10].

All the above-mentioned systems use FCs hybridized with electrochemical batteries that cause chemical pollution when considering their whole life time, from the extraction of chemical elements to the recycling processes.

As innovation, authors proposed to use an eco-friendly HPU consisting of hydrogen FC and Flywheel Energy Storage Systems (FESSs) as hybrid source for electric traction urban vehicles [11-13]. Moreover, the use of this innovative HPU was also proposed and studied in order to realize a Light Hydrogen Electric (LHE) urban rail train able to operate with no emissions on non-electrified lines [14].

This paper analyses the fuel consumption of a LHE rail train operating in an urban line by varying the pay load factor. The analysis results are presented and discussed in terms of specific energy consumption (kWh/passenger/km).
2. Rail train overview

The scheme of the LHE train proposed architecture consists of two end side trolleys and a passenger wagon between the two motorized cars (Fig. 1).

A traction motor and a FESS are placed on each side motorized car; the hydrogen tanks and the FC system are distributed on the roofs. The power train includes two traction electric motors (EM) fed by a HPU consisting of FCs and FESSs. The FC system is composed by $n$ FC stacks and the FESS consists of $n_F$ single units. The devices of the two rail cars share the communication bus and the DC power bus. FC system and FESS are connected to the DC power bus (red line) by means of converters (CM and CFESS) that manage the power flows required by the master control system (CS) by means of a communication bus (green line).

3. Models

The system is simulated by means of a mechanical-dynamic model, used for analysis and investigation. The parametric simulation software has been developed using open source software Scilab; it allows the rail vehicle to be simulated on a defined path by varying system parameters. It also allows the HPU power flows and the performance of the whole system to be analyzed.

The whole model consists of the LHE rail vehicle model and HPU sub-models, described as follows.

3.1. Rail Vehicle Model

The rail vehicle running is simulated by using the motion equation (1):

$$T(s) = \sum R(s) + m \cdot \alpha \cdot \frac{d^2 s}{dt^2},$$

where $s = s(t)$ – the train position; $T(s)$ – the tractive effort; $m$ – the gross mass (vehicle mass and passenger mass); $\alpha$ – the rotational inertia coefficient.

The motion resistances $R(s)$ are defined from relation (2):

$$\sum R(s) = R_w(s) + R_a(s) \pm R_s(s).$$

The rolling resistance $R_w(s)$, the air resistance $R_a(s)$ and the railway longitudinal slope resistance $R_s(s)$ are evaluated as follows:

$$R_w = \left[ 0.7 + \frac{130}{m_{ax} \cdot g} + 0.009 \cdot v \right] \cdot m \cdot g \cdot \cos \beta,$$

$$R_s = m \cdot g \cdot \sin \beta,$$

$$R_a = 0.0473 \cdot C_{d} \cdot S \cdot v^2 + (n-1) \left( 0.0716 \cdot v^2 \right),$$

where $m$ – the gross mass (vehicle mass plus mass of passengers); $m_{ax}$ – the mass on axle; $v$ – the train speed; $g$ – the acceleration of gravity; $\beta$ – the angle of the track slope, $C_d$ is the drag coefficient, $S$ is the vehicle frontal area, $n$ is the wagons number, $\alpha$ is the rotational mass inertial coefficient; and $a(t)$ – the acceleration of the train.

As relations (3) and (5) are empirical formulations, speed is in km/h, mass in ton and resistance in newton.

The electrical power for traction $P_{el}(s)$ is calculated as follows:
\[
\begin{align*}
    P_M(s) &= \frac{1}{\eta_d \eta_t} \left( \sum R(s) + \alpha \cdot m(s) \cdot \frac{d^2 s}{dt^2} \right) ds \\
    &\quad \text{if } P_M(s) > 0, \\
    P_M(s) &= \eta_d \eta_t \left( \sum R(s) + \alpha \cdot m(s) \cdot \frac{d^2 s}{dt^2} \right) ds \\
    &\quad \text{if } P_M(s) < 0,
\end{align*}
\]

where \( \eta \) – the transmission efficiency; \( \eta_d \) – the electrical drive (electrical machine and converter) efficiency.

### 3.2. HPU Model

The HPU of the train is modeled considering separately the FC model and the FESS model; the FC system operates accordingly to the average traction power requirement \( P_{M,A} \) and the FESS manages the dynamic power \( P_{dyn}(t) \).

Concerning the FESS, its stored energy \( E(t) \) is calculated by relation (7):

\[
E(t) = \frac{1}{2} J_f \omega^2(t),
\]

where \( \omega(t) \) – the angular speed; \( J_f \) – the rotor moment of inertia.

The useful amount of energy \( \Delta E_{max} \) is:

\[
\Delta E_{max} = \frac{1}{2} J_f \left( \omega^2_{max} - \omega^2_{min} \right),
\]

where \( \omega_{min} \) – the minimum rotor angular speeds; \( \omega_{max} \) – the maximum rotor angular speeds.

Defining the dynamic power as:

\[
P_{dyn}(t) = P_{FC}(t) - P_M(t) = P_{M,A} - P_M(t)
\]

and assuming that the FESS angular speed \( \omega(t) \) is always in the range \((\omega_{min}, \omega_{max})\) it is possible to compute the FESS electric power as:

\[
P_{FESS}(t) = P_{dyn}(t)
\]

with \( P_{FESS}(t) > 0 \) when power is stored in the system.

Then the FESS mechanical power is computed as:

\[
\begin{align*}
    P_{FESS,M}(t) &= \eta_{FESS} P_{FESS}(t) \quad \text{if } P_{FESS}(t) > 0, \\
    P_{FESS,M}(t) &= \frac{1}{\eta_{FESS}} P_{FESS}(t) \quad \text{if } P_{FESS}(t) < 0
\end{align*}
\]

The FC is modeled using the electrical work of a FC, considered as a reversible system. Since the FC operates at constant power, the maximum output power is chosen as operating point with the aim to minimize the rating of the whole FC stack; this choice has been possible because the value of efficiency in this point does not differ much from the maximum efficiency one. Therefore, a FC constant efficiency (\( \eta_{FC} \)) is assumed in the model.

### 4. Simulation

An existing non-electrified single-track rail line (23.6 km long), crossing the sub-urban area of L’Aquila city (Italy) and currently served by diesel trains, has been chosen for simulation. The rail line consists of 12 stations of which 8 (red dots) were designed in addition to the 4 (green dots) already existing (Fig. Fig. 2). The rail train speed profile has been computed and plotted in Fig. Fig. 3.

A bidirectional light hybrid electric (LHE) rail train configuration with 3 cars, two of which are motorized was selected in accordance with the rail train scheme of Fig. 1. The characteristics of the considered LHE rail train and HUP are listed in Table 1.
The simulation has been performed by assuming i) no longitudinal rail track slope, ii) full payload condition and iii) initial speed for FESS ($\omega_0$) of 50,000 rpm.

Fig. 4 shows the traction electric power $P_M(t)$, the FC system power $P_{FC}(t)$ and the FESS electric power $P_{FESS}(t)$ profiles; the corresponding energies are showed in Fig. 5.
It can be noted that the electric energy required ($E_e$) to the FC system is 258 MJ per journey. Without braking energy recovery, the traction electric energy would be 422 MJ; given that the recovered electric energy is 225 MJ the actual electric energy needed for the traction is 198 MJ, such a value is lower than $E_e$ because of the devices efficiency.

5. Energy Consumption Analysis

A traction energy consumption comparison was performed by simulating the LHE train and a similar (three passenger coaches) diesel train running over the selected rail path in the same operating conditions. To this aim, the “Minuetto” diesel train (110 t of mass, 322 passengers of carrying capacity) has been considered as benchmark [15]. Table 2 lists, for the two rail train types, the specific traction energy need.

The calculation results show that the LHE train specific traction energy requirement is 56% lower than the diesel train one. The difference of the traction energy need is mainly due to the LHE train lower mass and to its recovery energy capability.

Fig. 6 illustrates, for the LHE and Diesel rail trains, the traction energy need vs the passengers load factor. A variation of the load factor from 10% to 100% causes a moderate increase of the whole train energy consumption, of about 15%, and a specific energy consumption variation from 439.9 kJ/km/pass to 50.5 kJ/km/pass.

Table 2

<table>
<thead>
<tr>
<th>Rail train type</th>
<th>Carrying capacity Passengers</th>
<th>Mass @ full load ton</th>
<th>Traction energy MJ</th>
<th>Specific traction energy $\frac{kJ}{\text{pass} \cdot \text{km}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen LHE</td>
<td>215</td>
<td>73.05</td>
<td>198</td>
<td>50.5</td>
</tr>
<tr>
<td>Minuetto (Diesel)</td>
<td>322</td>
<td>122.5</td>
<td>672</td>
<td>87.9</td>
</tr>
</tbody>
</table>

Fig. 6 LHE train specific consumption vs load factor
6. Conclusions

A light hybrid electric urban rail train fed by a hybrid power unit consisting of hydrogen fuel cells and a set of high-speed flywheel energy storage systems has been considered. Both the hydrogen train and current diesel train with similar carrying capacity have been simulated for running over a redesigned existing railway. The results of the comparative traction energy consumption analysis show that the hydrogen rail train allows a traction energy saving of 56% at full load with respect to a Diesel train.

In conclusion, the simulation results demonstrate a significant energy saving when the LHE train is utilised instead of diesel trains along a non-electrified suburban line where the stops are close to each other and the intervals at constant speed are very short.

References

Sustainable Development of Transport and Logistics in Slovakia

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Abstract

Sustainable development of society is a development that keeps current and future geo-generators in a position to satisfy their basic living needs, while not reducing the diversity of nature and preserving the natural functions of ecosystems. The basic concept of sustainable development is based on the assumption that the limits of the development of society in the present way are limited. Globalization and the growing need for environmental protection and material resources require a significant improvement in the coordination of the various forms of transport; the goal of sustainable logistics is to focus on the environmental impacts of business activities, that is, to examine the relationship between the different modes of transport and the level of environmental pollution and to reduce the material and energy intensity of logistics activities. Care and protection of the environment is an important part of the company's strategic goals of long-term growth in its value. The paper deals with the analysis of the fulfilment of the state policy objectives in the field of transport and logistics and proposes recommendations for more efficient corporate management in order to promote sustainable development.

KEY WORDS: sustainable development, transport, logistics, green logistics

1. Introduction

In recent decades, humanity has slowly begun to realize that the unregulated development or growth that has taken place in the environment of our planet's limited resources has been unsustainable for a long time. It is necessary to replace it with something more sustainable in the interest of both humanity and the biosphere. In 1987, the UN General Assembly adopted the report "Our Common Future", in which sustainable development was defined as a development that is capable of meeting the needs of current generations without jeopardizing future generations' ability to meet their own needs. In particular, this definition contains the basic principle of sustainability, an ethical leitmotif, the principle of accountability to future generations. We always talk about sustainable development when we realize the link between human needs and natural resources. Sustainable development is the way to find and find solutions that benefit people, the economy and the environment in the long term. Thus, sustainable development is, rather than a scientific solution, a moral challenge for society. It responds to the current and important need for future development, based on a new relationship between people and their relationship to the environment in which they live. She refuses to overcome the idea that economic, technical and environmental goals are against each other. In this context, transport and logistics in Slovakia have a difficult position given the nature of transport infrastructure, which is a long-term, financially demanding physical capital, often in public ownership, which in many cases still works, but no longer meets new conditions. On the other hand, it is difficult, often impossible, to apply knowledge management to transport and logistics markets working on poorly configured transport infrastructure, but which cannot be changed so quickly.

2. Sustainable Development

The definition of sustainability first appeared in 1972 as part of the Rome Club's "Growth Boundary", defining itself as "a state of global equilibrium in which the Earth's population and capital are more or less constant and the growth or decline of these variables must be under close scrutiny". As stated in the National Sustainable Development Strategy of 2001, terms such as sustainability and sustainable development began to be used in the early 1970s, in particular to recognize that uncontrollable growth (population, production, consumption, pollution, etc.) is unsustainable in an environment of limited resources. Several conferences followed, and the definitions of sustainable development include the definitions given in the World Commission on Environment and Development report "Our Common Future", which was drafted in 1987. Sustainable development means targeted, long-term (continuous), comprehensive and synergistic a process influencing the conditions and all aspects of life (cultural, social, economic, environmental and institutional), at all levels (local, regional, global) and towards a functional model of a particular community (local and regional community, country, international community) which satisfies the biological, material, spiritual and social needs and interests of the people, eliminating or significantly reducing the threats, detrimental or destructive conditions and forms of life, does not burden the country beyond the acceptable level, uses its resources sensibly and cultural and natural heritage [1].

The most important social elements that can be formulated from each definition include:

- Sustainable development is a targeted process of change in the behaviour of human society;
- Development is understood as achieving the highest sustainable quality of life;
- Development should ensure not only intra-generational but also inter-generational equality in meeting people's needs;
- Development is to promote harmony between humanity and nature, to ensure a sustainable intra-species equality as well as inter-species equality.

Sustainable development is a development that keeps current and future generations from meeting their living, spiritual, social and economic needs. At the same time, it maintains a quality environment and high diversity of nature. Sustainable development can be defined as Sustainable development of society is a development that retains the ability of present and future generations to satisfy their living needs, while not reducing the diversity of nature and preserving ecosystem functions naturally. [2]

2.1. Objectives and Principles of Sustainable Development (SD)

The basic long-term priorities and objectives of sustainable development include:
- Consolidating Slovakia's position among developed democratic countries within the world community;
- Building and long-term functioning of the modern state and public administration system;
- Achieving balanced territorial and regional development;
- Achieving a long-term high quality of human and social resources;
- Building and long-term functioning of the new economy model;
- Achieving and maintaining high quality environment, protecting and rationalizing the use of natural resources.

The challenge for Slovakia is to translate the principles of sustainable development into everyday behaviour, to assess all planned and implemented activities through sustainable development criteria and to evaluate the direction to sustainability through a set of SD indicators. [3] A set of 132 SD indicators (of which 125 relevant for SR - 38 social, 23 economic, 49 environmental and 15 institutional) discussed and adopted at its 4th session April 18 to May 3, 1996 in New York the UN Commission on Sustainable Development (CSD), of which the Slovak Republic was a member in 1996-2000. The TUR indicators are linked to 40 chapters of AGENDA 21. In the SR, ensuring the SD is only in the beginning, the MoE SR plays an important role in supporting the principles of SD through various conceptual and legislative measures, projects and programs. Furthermore, they are environmentally oriented non-profit organizations and initiatives. Indicators are the most effective tool for assessing the environment and sustainable development.

2.2. Indicators of Sustainable Development

Indicators are measurable quantities that provide us with information about the state, development and processes in their quantitative and qualitative terms. Their role is to comprehensively and objectively reflect the state of the strategic objectives set. They should meet the criteria of measurability, scientific justification and political relevance. The need for indicator environmental assessment from the perspective of sustainable development emerged from the Government Resolution No. 211/2005 on the bases of the Action Plan for Sustainable Development. The Action Plan for Sustainable Development in the Slovak Republic for 2005 - 2010, which was approved by the Government Resolution no. 574/2005, identifies specific indicators for individual areas that need to be evaluated and, by means of them, deducted the fulfilment of the objectives of SD. [4]

Distribution of TUR indicators: Environmental pillar, Economic pillar, Social pillar, Institutional pillar

We can define indicators of sustainable development at two levels:
- Global - here we are talking about indicators that are set for the relevant areas within the country, territory, economic cluster;
- Business level - These are indicators that are based on global indicators, but each enterprise applies them as their own conditions, taking into account the impact of business activity on each of the areas (environmental, social, economic).

Business indicators for sustainable development should be implemented within:
- individually adapted to the company's internal conditions;
- precisely defined and limited to be measurable and evaluable communicated to all stakeholders;
- permanently maintained, modified and refined;
- take into account timing and external local conditions [1].

3. Sustainable Transport

Mobility of people, products, and goods is a fundamental condition for economic development and growth. At the turn of the 20th and 21st centuries, mobility in economic life played a crucial role. Passenger and freight transport increased. It was the golden age of mobility. The development of mobility in the world was not even, there were disproportions that affected the growth of the country's economy. Expansion of mobility has not been uniform across the world. Inequalities have emerged, making growth processes more difficult while integrating transport. There are no barriers to development in developed economies, on the contrary, in developing countries, these processes are slow. The
benefits of mobility are economic growth and living standards. Negative manifestations are chemical, physical environmental factors, various negative phenomena resulting from transport technology, clumps, congestion, regulatory impacts, transport safety and others. [5]

A typical example is the growth of passenger and freight transport in Europe at the end of the 20th century. The biggest increase was recorded by road transport, e.g. automotive traffic grew by 75%, its volume in tonne-kilometers doubled in 1970-80. Rail traffic has increased by 25%, air traffic by 8% a year in Europe. (Group Transport 2000). In addition to transport systems in large cities, investment in new infrastructure has maintained its usual pace with growth in traffic. The total length of motorways in Western Europe increased by 150% from 1970 to 1992 from 15,000 km to about 38,500 km (Union Rutiere de France, 1992). The study of the European Conference of Ministers of Transportation - CEMT between 1975 and 1985 found that land transport (cost-effective, costly) increased by 25% and infrastructure investment fell by 25%. Studies say that in 1980 there were at least 6,000 km of international roads overloaded, of which 1,600 km in the former West Germany and 500 km in the Netherlands. In the next decade, the situation continued to deteriorate, with the number of particularly congested points increasing. At present, this divergence is spreading between the volume of land transport and investment in infrastructure, causing global problems. In developed countries (where motorization has taken place earlier), mobility has increased from 60 to 70-75%, rail from 20% to 10%. In developing countries, rail transport has dropped from 50% to 10% by the end of the last decade of the 20th century. Pedestrian traffic belongs to mobility. In the OECD Member States, walking traffic is about 5 to 6% of the total, 0.5% to the US, 60 to 90% to developing countries. [6]

The growing integration of the European economy and the creation of a single market have a decisive impact on the future development of transport. Traffic intensity is increasing; there is room for intermodal transport with the intention of transporting cargo over longer distances. Road and automotive managers need to address this relevant issue in view of the expected competitiveness within Europe. Industry growth is driven by transport and logistics requirements. Supply Chain Management focuses on optimization processes, especially on information, financial and material markets from sources to the customer. The aim is to balance the external flows of different actors (suppliers, manufacturers, distributors) in order to reduce costs, create maximum value for customers and create favourable conditions for competitiveness. Road transport, by creating negative externalities, is one of the biggest intruders of sustainable development. If we define externalities, they are a source of market failure that occurs when economic operators transfer costs or benefits beyond the market mechanism to other entities. We divide them into: positive externalities of transport (benefits) and negative externalities of transport (costs), which according to [7] can be divided into social (congestion, traffic accidents, land grabbing, loss reducing locality) or environmental (air pollution, global climate changes, noise, vibration, barrier effects). [2,7]

3.1. Coordination of the Different Forms of Transport

Logistics is an important support function of supply chain management. Its main objective is, among other things, to reduce stocks as much as possible. Transport, including intermodal transport, is an important component of logistics. Logistics expenditures are 1/3 to 1/4 of the expenditure incurred by each logistics company. Effective transport intermodality reduces transport costs and also has an impact on stock reduction. This will free up working capital for productive investment. International transport is geared towards better integration of modes of transport, the aim being to increase the quality and reliability of door - to - door services. Intermodality is one of the key incentives for sustainable mobility. It enables better use of infrastructure and services, is more environmentally friendly and socio-social than 'clean' road transport. The EU has issued a report on "Interoperability and Integral Freight Transport in the European Union" COM / 997/243, which notes that some disproportions (disadvantages) in relation to in-service infrastructure and services remain. Against this background, the EU has adopted an Action Program recommending the following initiatives:

- Developing ITS intelligent transport systems application;
- Creation of electronic commercial application, IMD intermodal transport;
- Continue to manage the supply chain in logistics and intermodality;
- Demonstrate potential transport intermodalism for supply chains [8].

We have to say very critically in Slovakia about the activities of the administration, especially about our combined transport, which is the basis of intermodality. It is important to mention the various misconceptions in the creation of combined transport in recent years. So far, there is no acceptable concept of combined transport. Combined transport costs are not proportionate to today's situation. Investments in combined transport are passive. Without solving these problems, we will hardly catch up with European intermodal transport. Despite these shortcomings, logistics in terms of Sustainable Development - Transport (TUR-D) and Mobility has a significant place in our economy.

The White Paper is a comprehensive project for European transport policy by 2010. It was developed by the EC on 12 September 2001 and presented for public debate. The White Paper (WB) is of great importance for the Slovak Republic and for all states that have joined the EU. The aim of the project is to manage and control traffic developments across Europe. Responds to extremes in particular:

- increased intensity of all types of transport;
- the growing movement of people and goods.
The predecessor of the current WB (2001) is WB 1992/93, which was focused exclusively on "The development of a common transport policy for the future". It was published on the basis of the Treaty on European Union in Maastricht. Based on this, access documents of the Slovak Republic to the EU were drawn up. The White Paper responds to increasing mobility and has set four main objectives by 2010:

- moving the balance between modes of transport;
- elimination of bottlenecks;
- placing the user in the heart of the transport policy, which also deals with the infrastructure burden;
- managing globalization in transport.

4. Sustainable Logistics

The term green logistics can be explained as studying the impacts of logistics as such on the environment. Green logistics determines the impact of transport, as an article in the logistics chain, on the territory under review, trying to reduce the material and energy intensity of individual logistics activities. The aim of green logistics is also to minimize these wastes, while reverse logistics deals mainly with movement.

Benefits of Green Logistics. [9]

- compliance with applicable legislation and all applicable environmental requirements;
- reduction of operating costs;
- savings on fines and other sanctions;
- limiting the costs associated with an unclear organizational structure and a clearer definition of investment intentions;
- improving relations with the public, public authorities and other environmental organizations;
- increasing entrepreneurial credibility for investors, banks and insurance companies (lower interest rates, premiums).

There are activities that have reverse and green logistics in common. For example, reworking a used product for reuse is the subject of both of these logistics. Conversely, some activities are always typical for one, e.g. reducing energy consumption or designing disposable packaging with reduced material consumption are typical of green logistics. "Green logistics" means its sustainable ecological orientation. The requirement of sustainability is to satisfy the needs of today's generation, without the possibility of future generations being strike. Sustainable concepts for green logistics focus on environmental, economic and social aspect. [1, 9]

According to the German study "Trends and Strategies in Logistics - Global Network in Conversion", the environment and logistics are not fashionable, but lead to long-term changes in logistical value creation. Energy and resource costs are rising. Optimizing the use of energy and resources in logistics is therefore a serious challenge for the future. At present, the implementation of environmental measures at the Board of German Enterprises is at an early stage. Many times there is no basis for strategically dimensioned concepts - economic efficiency calculations, integration concepts and deployment that would allow for economical implementation. In addition, green logistics is often limited to transport logistics. Fraunhofer Institute for Material Flow and Logistics has recalculated that on average about 40% of total costs are spent on energy in in-house logistics systems. He estimated that, by using green logistics approaches, up to a third of these costs could be saved. For example, solar modules on the roofs of the halls and the optimization of not only heating and cooling cost, but also packaging, processes and in-house transports. According to the study, logistics can implement environmental and resource conservation measures in five areas:

- market and product;
- structures and planning;
- processes, control and measurement;
- technologies and resources;
- workers, customers, suppliers and service providers.

The study shows, in a simple example, how the decision on the dimensions of the packaging of the product has an impact on the CO2 emissions related to the net transported unit of quantity. The bindings range from volume and weight through the number of pieces in the storage means to the vehicle load and the number of journeys. As a factor of optimization with regard to green logistics, storage and handling technology as well as appropriate information technology are involved through all stages.

Warehouse management systems are increasingly contributing to green logistics today; they work ecologically and at the same time cost-effectively and efficiently. In warehouses, modern software solutions provide energy-efficient control, transparent product flows, and resource and capacity optimization. From the supervisory point of view, the optimization of loading order or the creation of multimodal processes and transports are applied. The simulations detect the best possible degree of utilization of the storage space as well as the amount of packaging material needed. Route planning and route optimization enable optimum use of loading space and reduce energy and transport costs. When planning and designing concepts, green logistics aspects need to be taken into account - for example, using high-quality materials in roof and wall structures in distribution centres and freezers to reduce energy consumption. The problem of waste disposal arises at the end of the supply chain. Ecologically sound solutions are needed: from belt conveyors to waste, for example, to unpacking stations, to comprehensive recycling concepts for raw materials and returnable packaging [10].
With regard to the social component of sustainable concepts, it is also a working environment - for example, noise-reduced technology and, above all, ergonomic workplace design. Reducing physical exertion as well as movements that do not contribute to their own logistical role, but it motivates workers and reduces morbidity. In addition, the performance and quality of operative processes are increased. Information technology applications are user-friendly menu menus on the screens with the ease of incorporating staff with improved visibility into operational processes. Productivity is also affected by reduced error rates. Of course, sustained efforts to protect the environment and resources will require costs. Investments in both process planning and new processes and technologies are associated with short to medium-term higher costs for logistics. However, economies of scale and competitive advantage arise. This applies in particular to sections with a high degree of automation. Marches improved from a sustainability perspective provide not only optimized use and savings; it is also possible to acquaint customers and the public with them, thus improving the image of the business. The challenges of sustainable, ecological logistics should not be seen as a burden but as an obligation. Their consistent involvement in innovative solution concepts provides process optimization capabilities and increased competitive advantage [4, 11].

4.1. Reducing the Energy Intensity of Logistics Activities

While the need for the logistics sector to respond to the challenge of climate change is clear, low-carbon logistics solutions and flexible transport modes are not yet available. The option of switching the transport of goods from a more carbon intensive transport mode to rail, for instance, depends on the railway infrastructure being in place. Improving efficiency of transport modes also presents and challenge. There are only a few market-ready technologies and solutions today that can meet the specific needs of the transport and logistics sector. This is especially true for air freight and long-distance road transport, where there are currently alternative technologies and fuels. Finally, sustainability is also a cultural issue: today, many contradictions between economic growth and environmental protection, rather than realizing how they might go hand-in-hand. Companies or individuals who already act in an environmentally aware or sustainable way are still considered to be “tree huggers.” At the same time, although combating climate change has become a key topic of public discourse and media coverage, Hard time reaching global political agreements on reducing greenhouse gas emissions. As already demonstrated by many companies and organizations today, sustainability can be a trend-setting business model, opening up new market opportunities and preparing for future scenarios. It can also help cut costs by introducing more efficient processes and reduced inputs of natural resources. No single company can come up with all the answers by itself. That's why it is important for the World Business Council for Sustainable Development (WBCSD) or the UN Global Compact to bring together companies from all regions and industries to do business in a more sustainable way. In fact, the first indices that rank companies based on sustainability-related criteria, such as the Dow Jones Sustainability Index, are already being used by investors. These indices and rankings not only encourage companies to change their approach to business, but they also provide a level of transparency that was previously missing [5, 12].

Transport is the third largest air polluter after industry and energy. Thus, in terms of anthropogenic, that is, human activities that have a significantly less negative impact on the climate than nature itself. Approximately ninety percent of air pollution is caused by natural resources, such as fires, volcanoes or soil erosion. Anthropogenic activities account for the remaining ten percent, with transport being third, mainly due to the world's largest ships and air transport. A summary of greenhouse gas emissions that affect global warming is known as the carbon footprint. According to the International Maritime Organization, maritime transport accounts for three percent of global carbon dioxide (CO2) emissions and one tenth of the world's transport emissions. In road transport, several "greening" measures have been taken. Truck and bus manufacturers have to comply with the strict EURO VI ecological standard with a minimum of permitted harmful particles, while LPG and CNG drive make the difference even bigger and electric cars are no longer a rarity. Most Slovak transport companies use the latest modern vehicles with technologies that not only adhere to strict European standards for engines, but further add to fuel consumption and engine emissions.

5. Analysis of the Fulfillment of the State Policy Objectives in the Field of Transport and Logistics in Slovakia

Transport policy in Slovakia takes into account the EU's Lisbon Strategy, whose strategic goal for the next decade is to build the most dynamic and competitive economy. This transport objective will be mainly ensured by the development of transport infrastructure, the promotion of transport services liberalization and the development of information and communication technologies. The analysis of transport and logistics in Slovakia is the basis for assessing the current strengths and weaknesses and opportunities and threats to be taken into account when formulating global and specific transport policy objectives, priorities and measures [13]:

Strengths:
- the strategic geographical position of the SR in the west-east, north-south, - transport infrastructure of the Slovak Republic as part of the European transport networks (TEN-T);
- density of existing transport infrastructure, - relatively high proportion of rail transport performance compared to EU15;
- social interest in reducing traffic accidents and its consequences;
- low externalities of rail transport, in particular low accident rates;
- the ongoing modernization of the railway corridors, - the Government's efforts to speed up the construction
of motorways and expressways;
- preparing for the introduction of road infrastructure charging;
- decentralization in the field of road transport infrastructure;
- direct access to the European Transport Corridor VII (Danube - Main - Rhine);
- a developed public transport system in terms of area coverage.

Weaknesses:
- the inability of transport infrastructure included in the TEN-T network;
- insufficient financial resources for the development of transport infrastructure;
- low level of information and communication technologies in transport;
- inadequate technical condition of railway infrastructure and high charges for its use;
- impaired access by regions to superior TEN-T infrastructure (expressways);
- inadequate technical and qualitative status of other transport infrastructure (at state, regional and municipal level);
- exceeded traffic performance (especially Class I roads) and missing road bypasses;
- Inadequate technical and technological level of intermodal terminals (with the exception of the Good terminal);
- under-utilization of aviation and waterway potential;
- undeveloped liberalization of rail freight services;
- poor quality of transport services (public transport, integrated transport systems) and their lagging behind advanced EU countries;
- a low level of renewal of the fleet of vehicles and limited possibilities to support the renewal of public passenger transport means (suburban, urban).

Opportunities:
- ensuring sustainable mobility by promoting environmentally friendly modes of transport; - Improving the quality, safety and reliability of transport based on intelligent transport systems;
- traffic management and reduction (infrastructure charging);
- proportional development of the different types of transport infrastructure
- improving the accessibility of Slovakia and regions to TEN-T networks and to superior transport infrastructure;
- reducing externalities by developing multimodal transport systems;
- increasing the allocation of resources for transport infrastructure by means of multi-source financing of transport infrastructure (infrastructure charging, private partnership projects - PPP, EU funds);
- reducing the number of victims and consequences of road accidents;
- increasing the use of aviation and waterway potential;
- regulated competition in public passenger transport to achieve more efficient and attractive passenger services.

Threats:
- reduction of transport accessibility and related reduction of attractiveness of the territory of Slovakia and individual regions for investors;
- increasing the environmental impact of transport;
- deterioration in the quality of transport infrastructure caused by a lack of funding for its development, maintenance and operation;
- the increasing trend of shifting freight transport from rail to road (decline in national and transit traffic) and the sharp increase in individual motoring;
- congestion causing an increase in energy, time and economic losses, reducing the competitiveness of the Slovak economy;
- increasing the environmental impact of transport caused by a lack of funding for the renewal of public passenger transport means [13,14].

5.1. Strategic Objectives of Transport and Logistics Development in the Context of Environmental Protection

Global strategic objectives were set in analogy to the vision of the Slovak transport sector. They reflect the trends and needs that are set in the European and national strategic or analytical documents. Below are the basic starting points for the development of transport in the Slovak Republic from the perspective of the European Union:
- Achieving sustainable mobility is a global goal. Delayed or limited introduction of new technologies could condemn the EU transport sector to irreversible decline. The EU transport sector is facing increasing competition in the rapidly developing world transport markets;
- The importance of the quality, accessibility and reliability of transport services has increased further in the coming years, inter alia due to the aging of the population and the need to promote public transport. Sufficient frequency, convenience, easy access, service reliability and intermodal integration are key features of service quality. The availability of travel time information and track alternatives is equally important for both passengers and cargo to
ensure smooth direct mobility;
- Europe needs a network of corridors that transport large and consolidated cargo and passenger volumes, with transport being highly efficient and low-emission, thanks to the widespread use of more efficient modes of transport used in multimodal combinations and the use of advanced clean fuel technologies and infrastructure;
- Despite the enlargement of the EU, there are major differences between the eastern and western parts of the transport infrastructure that will need to be tackled. The European continent must also be united in infrastructure;
- IT tools should be put in place to facilitate administrative procedures, to enable cargo tracking and tracing and to optimize travel plans and traffic flows (e.g. ITS, SESAR, ERTMS, SafeSeaNet, RIS). Their deployment should also be promoted through their use in the TEN-T infrastructure and the gradual integration of modal systems;
- The core network must ensure an effective multimodal link between EU capitals and other major cities, ports, airports and key land border crossings, as well as other major economic centres. It should focus on completing missing links, especially in cross-border sections and bottlenecks, on modernizing existing infrastructure and developing multimodal terminals in river ports and on urban logistics consolidation centres. Long-distance transport requires a better connection between rail and airports;
- Traffic congestion is a major problem, especially in road transport and threatens accessibility. Public sources of infrastructure financing are under increasing pressure and a new approach to financing and pricing needs to be taken;
- With regard to urban transport, a combined strategy including spatial planning, pricing regimes, efficient public transport services and non-motorized transport infrastructures and clean vehicle charging/refuelling are needed to reduce congestion and emissions. Cities in excess of size should be encouraged to develop urban mobility plans that combine all these elements. Urban mobility plans should be fully in line with integrated urban development plans. An EU-level framework will be needed to ensure that road-charging schemes for inter-urban and urban use are interoperable [15];
- A single European transport area should simplify the movement of citizens and freight, reduce costs and enhance the sustainability of European transport. The area where deficiencies are most obvious is the internal market for rail services, the completion of which is a priority for the creation of a single European railway area. This includes the removal of technical, administrative and legal barriers that still hinder entry to national rail markets. Further integration of the road freight market will make road transport more efficient and competitive. It is also necessary to create an appropriate framework for addressing European tasks in the field of inland waterway transport. Market access to ports must be further improved;
- Market opening must be better adapted to job quality and working conditions, as human resources are an essential element of any high-quality transport system. It is also well known that the shortage of skilled labour will pose a serious problem in transport in the future. It will be important to unify competitiveness and the social agenda in the wake of social dialogue, in order to avoid social conflicts that are known to cause significant economic losses in several sectors, particularly aviation;
- Choosing projects suitable for EU funding must reflect this vision and must emphasize European added value. Co-financed projects should also reflect the need for infrastructure that minimizes environmental impact, is resistant to the potential impact of climate change and improves the safety and protection of users [16];
- Diversified sources of public and private funding are needed. It is also necessary to better coordinate the Cohesion Fund and the Structural Funds with transport policy objectives, and Member States must ensure that sufficient national funding is available when planning their budgets, as well as sufficient capacity to plan and implement projects. Other sources of funding to be considered include schemes for the internalisation of external costs and charges for the use of infrastructure that could generate additional sources of income;
- To fully apply the "user pays" and "polluter pays" principles, and more to involve the private sector in eliminating inconsistencies, including harmful subsidies, in generating profits and securing funding for future transport investments;
- Transport protection is an EU priority. The EU’s comprehensive approach to policy-making, legislation and monitoring of aviation and maritime security should be further consolidated and strengthened through cooperation with major international partners. For passenger safety purposes, detection methods need to be improved to ensure a high level of protection with minimal difficulty. A risk-based approach should be considered for the protection of non-EU cargo. There is also a need for an appropriate European approach to land transport protection in areas where EU intervention has added value;
- The establishment of a framework for safe transport is essential for European citizens. A European strategy on civil aviation safety will be developed, including adaptation to new technologies and, of course, including international cooperation with key partners. In rail transport, harmonization of the issuing of safety certificates and subsequent surveillance is essential in the Single European Railway Area. In these transport sectors, the European Aviation and Railway Safety Agencies play an indispensable role;
- Although the number of fatalities in the EU has almost halved, initiatives (in technology, enforcement, education and, in particular, focusing on vulnerable road users) need to be developed to further reduce these losses even further;
- Experience with extreme weather conditions in recent years makes it clear that there will be a need for sustainable mobility plans to be maintained in order to maintain the mobility of passengers and goods and the throughput of emergency services during emergency situations. These emergencies have also demonstrated the need to
increase the resilience of the transport system by developing scenarios and planning progress during events associated with extreme weather conditions;

- Given the obligations arising for the Slovak Republic from international treaties in the field of civil emergency planning, it is necessary to ensure the accessibility of the designated transport corridors for the military equipment of the Alliance troops, respectively building new corridors and their diversification. When building a new civilian infrastructure, it is also necessary to take into account the specific requirements of military equipment (e.g. higher road load, bridge and underpass passage) for transport infrastructure. This should be taken into account for all available transport infrastructure types (ship, rail, air, and road);

- At the same time, the European Union has called for a drastic reduction in global greenhouse gas emissions, with the agreement of the international community, to reduce climate change below 2°C. In order to achieve this, the EU generally needs to reduce emissions by 80-95% below 1990 levels by 2050, in the context of the necessary reductions in developed countries as a group. The European Commission's analysis shows that while in other sectors of the economy a significant reduction can be achieved; greenhouse gas emissions need to be reduced by at least 60% by 2050, compared to an important and growing source of greenhouse gases. By the year 2030, the goal of the transport sector will be to reduce greenhouse gas emissions by around 20% below the 2008 level. Given the significant increase in transport emissions over the past two decades, this would still mean that emissions would still exceed 1990 levels by 8%;

- If we apply the approach so far, the dependence of transport on oil could still be almost 90%, and renewable energy sources would be just over 10%, the 2020 target. 1990 by a third higher. The cost of congestion will increase by about 50% by 2050. The difference in accessibility between central and peripheral areas will increase. The social costs of accidents and noise would continue to grow [17, 18].

5.2. Proposals for Corporate Governance Recommendations for Sustainable Development

Corporate Social Responsibility is comprised of three core areas:

- environmental area - deals with the environmental impact of the company;
- economic area - is focused on the economic situation in the company, how the company has values and it also concerns the management of the company;
- social area - this area contains the social policy of the company, how the company manages its employees, deals with various social benefits and what the society has to do with the environment.

The proposal for applying sustainable transport and logistics in the context of a corporate social responsibility strategy is based on the following recommendations:

- define a new business strategy, taking into account sustainable aspects of each area (social, environmental, economic);
- change internal corporate culture and communication;
- respect people and develop them, take into account the individualities and personal interests of people;
- define ethical principles and set professional behaviours;
- promote the individual approach of each employee to his / her duties;
- find ways to continuously improve processes, technologies and reduce the negative impact on the business environment;
- to train and train staff;
- communicate effectively with suppliers and contractors;
- raise awareness of environmental, safety, occupational health and energy management in logistics processes, and create room for implementing sustainable green logistics principles;
- Ensure the availability of the necessary funds to buy safe, environmentally friendly and energy efficient input materials, new technologies, manufacturing facilities and the necessary services.

6. Conclusion

The state of the art says that the activities of society change living conditions in local areas and even disrupt the great ecosystems and climate of the planet. It is necessary to reflect on the future of development. One of the tools could be sustainable development. The intention is to move forward so that future generations will not be affected by the satisfaction of society's needs. It is important to think about what needs to really satisfy through exhaustible resources. This brings us to the concept of rationalization and its necessary introduction in the use of natural resources, whether by society or by enterprises. Environmental protection has become a major issue. The transformation of environmental protection into business goals is now a necessary step, not just a sign of good business name. Different solutions are already available in the world enough to make the business willing to change its situation and invest its time and money. One of the biggest polluters is transport, which is part of logistics. The gradual transition to green logistics is a successful foundation where a business can profit from cost reductions, improved competitiveness, enhanced market image, possible tax breaks or other state bonuses. Green Logistics is a subsystem of eco-logistics, as an application area of logistics, with its main focus being monitoring, evaluating, and reducing the negative impacts of various industrial activities on the environment and individual environmental components. In addition to legislation, the interests of
consumers are affected by products and services that show the least impact on the environment, both during production, consumption and after the end of their life cycle, when they become waste. Green logistics presents an active approach to environmental protection, but in comparison with standard logistics properties, resp. logistics systems are characterized by several paradoxes that can be followed in the field of mitigating externalities.

References

Abstract

The present state of the management of the rolling stock repair and maintenance quality in the projects of development and support of transport infrastructure has been analyzed. The concept of quality model has been considered in different aspects. The process of quality management in projects of repair and maintenance of rolling stock, as well as its features, has been investigated. The information model of management is proposed, and the methodology of transport infrastructure projects planning is presented for ensuring the quality of design work during operation. According to the demands of the modern market, there is an increased interest in the issue of quality, which is a major factor in improving living standards, economic, social and environmental security. It is impossible to solve it only by controlling the quality of finished products, that is, by traditional methods. There should be an integrated, systematic approach, the realization of which is possible only within the framework of the quality management system, which is based on project management. Repair and maintenance projects for rolling stock are not typical and are implemented according to a specified procedure. Quality parameters and the process of its provision need to be developed for each project separately. The task of ensuring the quality of the project at an appropriate level is relevant at all stages of its life cycle and is implemented by different interrelated procedures. The process of quality planning is decisive in terms of management at the planning stage, the main results of which are the basic plan for project requirements, as well as a quality management plan with a detailed description of the processes of provision and control.

KEY WORDS: model of management, quality, project, rolling stock, standard ISO 9000, information model, infrastructure, methodology, modeling, system analysis

1. Introduction

The increased interest to managing the quality of repair and maintenance of rolling stock in transport infrastructure development and support projects is an important factor in improving living standards, economic, social and environmental safety. The solution to the problem of ensuring the required quality by traditional methods is practically impossible. There should be an integrated, systematic approach, implementation of which is possible only within the framework of quality management system using modern methods of project activity. Quality is a complex concept that characterizes the effectiveness of all aspects of activity: strategy development, organization of production, marketing, etc. [1].

As project activity is one of the key issues in the development of quality management of repair and maintenance of rolling stock in the projects of development and support of Ukraine's transport infrastructure, there grows the relevance of the study of integration issues in the management of quality parameters as well as the methodology of organization, planning, management, coordination of human, financial and material and technical resources during the life cycle that is aimed at the effective achievement of the project goal and the determined results by composition and work volume, their value, time, quality through the application of modern methods of management technology [2].

The most important parameter of the project, that is possible and necessary to manage, is its quality, and quality management involves the processes necessary to meet the needs for which it is developed, as well as the quality of the project and project output [3]. While studying the project quality management system and the planning methodology, there is still the problem of integrating the quality management principles and their adaptation to transport infrastructure projects with the management of the quality of repair and maintenance of rolling stock, which requires further systematic research. Thus, we can say that the purpose of the work is to form a management model to ensure the quality of design works on repair and maintenance of rolling stock of transport.
2. Research Materials and Results

Recently, quality management has been perceived as a finished product in the finished form. However, the problem of improving the quality of products and services is so complex and varied that its successful solution is possible only if all participants in the production and technological process of repair and maintenance of rolling stock not only take on the pragmatic side of this business, but will also form a modern system of views, improve the system and quality management, develop the methodology of planning in infrastructure projects [4].

Quality in modern economic conditions is an integral target characteristic of each project product. Without observing the planned parameters and quality standards of the project object, it is impossible to achieve the objective set before the project.

In this paper, management project is seen as a set of interrelated organizational and technological tasks and measures aimed at restoring normative transport and operational parameters of repair and maintenance of rolling stock and are carried out in the conditions of financial and other resource constraints within certain time limits. The main reason for the development and implementation of repair and maintenance projects for rolling stock is non-compliance with normative indicators.

Within the project management, there are two types of processes, the first of which are the project management processes that are general regardless of the type of project aimed at achieving a single goal and include the following groups of processes: initiation, planning, execution, monitoring, management and completion project. The second type of process is the process-oriented product that defines the main properties, characteristics and product designation, with the subsequent realization of this complex, in line with the interests of all interested parties in the creation of the product of the project. Quality project management focused on both groups of processes is not enough to succeed. The key to the project success is the detailed elaboration of concrete, measurable criteria for the quality management of all types of project processes [5]. Therefore, there is a need to integrate quality management in the management of all types of project processes, which will ensure satisfaction of customer requirements not only in the quality of the final product of the project, but also in its qualitative functional system.

The main quality parameter of the project is the quality of the product, namely the transportation of passengers, cargo, which is the result of the project. The quality of products or services is most often viewed as the set of its properties, which determine the level of ability to meet certain needs of consumers in accordance with their purpose.

In the management of the quality of repair and maintenance of rolling stock in transport infrastructure projects, the concept of "quality" is most often viewed in four aspects [6]:

1. The product quality of the project as meeting the market needs and expectations of consumers, which is achieved through accurate and effective identification of customers' needs and expectations in order to meet them.

2. The quality of project development and planning, which is achieved through detailed and thorough development of the project itself and of its product.

3. The quality of work on the project in accordance with the planned documentation, which is ensured by compliance with the project implementation of its plan, as well as ensuring the developed characteristics of the project and the project itself.

4. The quality of the resources involved in the implementation of the project, which is achieved through the quality logistical support of the project throughout its life cycle.

The process of quality assurance of the project at the level of quality management in transport infrastructure projects consists of the adoption of planned systematic measures that ensure the fulfillment of all the foreseen processes necessary for the project to meet the quality requirements.

The planning methodology is the most important factor affecting the quality of the project and includes the following stages:

1. Defining the objectives of the project and their description. Quite often, projects start without a clear goal.

2. Definition of technological stages. For the project, the implementation technology that defines the stages of the project development should be chosen. One of the typical planning errors is the mismatch of the technological cycle plan.

3. For technological steps, you need to define a list of tasks, specify their interconnection, sequence and predicted duration.

4. Need to agree on the resources allocated to the project. It should be noted that all resources of the organization should be distributed centrally. Quite often there is a planning error, due to the fact that some scarce resources are used simultaneously in two different projects.

5. Risk analysis and assessment lead to new challenges and to attracting additional resources.

6. Determining the price of resources determines the budget. One of the typical mistakes is that the budget is allocated without paying attention to the projected cost of the project. The formation of a quality assurance plan should be based on a systematic approach. The quality management process in the project is part of the planning of any project.

ISO 10006: 2005 Standard "Quality Management Systems - Quality Management Instructions" defines a management project as a single process consisting of a combination of coordinated and controlled operations with start and end dates performed to meet a specific requirement, and contains limitations on time, cost, and resources [7].

Quality assurance involves defining a standard, appropriate methods and quality requirements. Integration of ISO standards [7] and RMVOK [8] provides an opportunity to formulate a logical set of quality assurance measures that can be presented as a quality assurance plan. Thus, influence on the quality of the final result can be done by the method
of forming its processes. All processes are elements of the system in which they operate. The quality of the construction of this system and the mechanism of its functioning is reflected in the quality of its constituent processes.

Transport infrastructure projects for the repair and maintenance of rolling stock are not typical and are implemented in accordance with the established procedure. The quality parameters and the process of its provision need to be developed for each project separately. The task of ensuring the quality of the project at an appropriate level is relevant at all stages of its life cycle and implemented by various procedures that are interrelated [9].

In order to ensure that the achieved results of the project are consistent with previously established indicators, project quality management is required through the implementation of the following processes: planning, assurance and quality control of the project [10].

Quality planning is carried out as part of the planning of the project, which must include the work, which ensures the quality of the project results. The quality plan should determine how the project will ensure the quality of the work from the position of the organisational structure, resources, technological support. An important element, at the stage of quality planning, is the development of documents regulating activities on project quality control (project reporting form) and quality management procedures. Quality planning begins with defining project quality objectives, policies and standards that are relevant to the content of the project. Then, the actions and responsibilities of team members that are required to achieve goals and standards are determined. The result of quality planning is presented in the form of quality assurance plans and management processes that ensure the implementation of these plans, and is achieved by synchronizing with the main planning (content planning, timetable, cost) and auxiliary (risk planning, team) planning processes [11].

Quality assurance is provided through the process of implementing planned systematic quality management operations that ensure the fulfillment of all the foreseen processes necessary for the project to meet the established quality requirements. To monitor project quality, it is necessary to define benchmarks and criteria to determine the quality of the project to the standards established in the quality assurance plan. Knowledge and experience in quality assurance accumulated in the current project should be used when drawing up plans for quality assurance of the following projects.

Thanks to the system model of criteria, it is possible to determine the system effectiveness of designing and implementing relevant transport infrastructure projects to improve the management of the quality of repair and maintenance of rolling stock. The quality of project work is determined by the expression:

$$e_f = \left[ \frac{\int_{0}^{\infty} \phi_t(i, W_i, W_i^*) \left| W_i(i) - W_i^*(i) \right| di}{\int_{0}^{\infty} W_i(i) di} \right]^a; \quad W_i = W_i^*, \quad i = 1, 2, \ldots, N,$$

where $W_i$ - the variable characterizing the production-technological potential in transport infrastructure projects for a period of time; $W_i^*$ - useful work performed by transport infrastructure subdivisions for repair and maintenance of rolling stock at a time interval.

$$W_i = \left( \sum_{j=1}^{M} \sum_{k=1}^{N} h_{jk} L_{jk} \right) (1 + r_j) + \left( \sum_{k=1}^{K} a_k c_i q_i \right) (1 + r_j) + \left( \sum_{j=1}^{M} b_j c_i q_i \right) (1 + r_j) + \left( \sum_{p=1}^{P} c_{ip} Q_{ip} \right) (1 + r_j) =$$

$$= (1 + r_j) \left( \sum_{j=1}^{M} \sum_{k=1}^{N} h_{jk} L_{jk} + \sum_{k=1}^{K} a_k c_i q_i + \sum_{j=1}^{M} b_j c_i q_i + \sum_{p=1}^{P} c_{ip} Q_{ip} \right); \quad j = 1, 2, \ldots, M; \quad i = 1, 2, \ldots, N; \quad k = 1, 2, \ldots, K; \quad p = 1, 2, \ldots, P,$$

where $r_j$ - the given level of profitability of functioning of production processes of repair and current maintenance of rolling stock during $i$ time period; $0 < r_j < 1$; $c_{ip}$ - price of services provided on $p$ item during $i$ time period; $Q_{ip}$ - number of rendered services and performance of work in the environment of operation of production processes for repair and rolling stock retention during $i$ time period.

$$h_{jk} = h_{ij} k_{ji} + h_{ik} k_{ki} + h_{ij} h_{iij},$$

where $h_{ij}$, $h_{ik}$, $h_{iij}$ - accordingly, norms of expenses for wages, materials, spare parts for mechanisms of $j$ items during base period; $k_{ji}$, $k_{ki}$, $k_{iij}$ - accordingly the index of growth of expenses for wages, materials, spare parts during $i$ time period; $h_{ij}$, $h_{iij}$, $h_{iij}$ - accordingly, norms of costs for electric, thermal energy and compressed air in the
base period; $k_{e}$, $k_{T}$, $k_{CT}$ - respectively, growth indices of standard costs for electric, thermal energy and compressed air during $i$ time period.

$$E_{pi} = \left| \sum_{i=1}^{T} (W_{pi} - \bar{W}_{pi}) \right|$$

$$E_{pi} = \int_{0}^{T} \varphi_{pi}(i,W_{pi},\bar{W}_{pi}) W_{pi}(i) - \bar{W}_{pi}(i) \, di,$$

where $\varphi_{pi}(i,W_{pi},\bar{W}_{pi})$ - weight function, which shows that the same deviations at different times are different.

The criteria for system efficiency of work and the implementation of relevant transport infrastructure projects are determined by expression:

$$E_{r} = \max \{ \Phi_{r}, \Pi_{p}, \Pi_{BC}, \Pi_{PP}, T, E, B_{m}, B_{e}, C, P_{CM} \},$$

where $\Phi_{r}$ - return on capital; $\Pi_{p}$ - productivity; $\Phi_{o}$ - capital stock; $M_{o}$ - mechanic equipment; $K_{e}$ - load factor of equipment; $\Pi_{BC}$ - suitability of rolling stock; $\Pi_{PP}$ - productivity of the production process; $T$ - the complexity of the production process; $E$ - energy intensity of the production process; $B_{m}$ - cost of materials; $B_{e}$ - cost of equipment; $C$ - cost of production processes functioning; $P_{CM}$ - level of work places specialization.

To achieve the planned project quality indicators in the process of providing it, the project quality control is a mandatory element. Which, based on interim observations of project results, enables us to determine compliance with normative indicators and standards and to develop action to eliminate deviations [12-15].

Taking into account the process approach, an information model for managing the quality of repair and maintenance of rolling stock in transport infrastructure projects has been developed (Fig. 1).

![Fig. 1 Information model for quality management of repair and maintenance of rolling stock in transport infrastructure projects](image-url)

This model reflects the entire life cycle of quality management of repair and maintenance of rolling stock, allows
us to conclude that each process is responsible for obtaining input resources and generating output results. Project quality management is cyclical and should consist of processes focused on quality policy. An important aspect of quality management in transport infrastructure projects is the consideration of normative and technical documentation, as without complying with regulatory parameters and technologies, quality standards of a project object, it is impossible to achieve the objectives set for the project.

Therefore, it is the methodology of quality planning that is decisive in terms of project quality management at the planning stage. The main results of the quality planning process are: a quality baseline, which contains the content of the project quality requirements, as well as a quality management plan with a detailed description of the project's quality assurance and quality assurance processes.

3. Conclusions

Integration of quality management into the overall system for managing repair projects and the ongoing maintenance of rolling stock will improve the quality of the final product of the project, improve the key indicators of the project stages by tracking their control values; create a logically constructed chain of project processes and minimize the cost of their implementation. The quality should be laid down for each project, for each technological process, for each worker, engineer, and manager, and cannot be obtained with only one control.

It has been investigated that quantitative and qualitative composition of technological equipment influences the level of use of production and technological potential of repair and maintenance of rolling stock, and a complex of measures for optimization of technological processes leads to a reduction of labor intensity, increase of labor productivity and quality of performed works. Due to the systematization of the main criteria of efficiency and quality of use of the production-technological potential of transport infrastructure enterprises’ departments, which allows us to manage the quality of repair and maintenance of rolling stock, we can proceed to implement a system model of operation of units in modern conditions, which will ensure the safety of transportation both for cargo and passengers.

References


Container Shipping Safety: Young Seafarers Viewpoint

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Abstract

The article presents the results of a research conducted among young seafarers on the safety of container shipping. The hazards affecting the navigation security have been identified and analyzed. Using the surveys, the opinion of seafarers with the up to 5 years' experience of sailing at sea on the factors influencing the hazards occurrence in the maritime transport of containers was examined. As a result of the research, it can be concluded that the young container ships crew is convinced that hazards caused by the influence of the human factor are most common in container shipping, including the routine and carelessness of seafarers that have the greatest impact on safety loss.

KEY WORDS: maritime transport, hazard, safety, container shipping

1. Introduction

The observed dynamic development of maritime container shipping is related to the development of international trade, including import and export of goods. Cargo flow between various regions of the world is carried out using a specialized fleet, including container ships.

Container shipping in the continental and intercontinental relations is strongly influenced by economical and financial factors, techniques and technologies used in cargo handling, maritime policy, as well as requirements related to environmental protection, etc. Moreover, the high safety level should be provided during each carriage.

Despite the developed regulations, procedures and international conventions implemented in the container shipping, various extraordinary situations may occur. In such situations, the ship crew should be aware about the possible hazards and their impact on shipping safety to find the solutions and minimize possible adverse consequences. It should be emphasized that ship’s crew besides the experienced seafarers is regularly accompanied by young staff who, through gaining experience, develop their opinion on possible hazards and possible behavior in situations that may occur while working at sea.

The aim of the article is to examine the opinion of young seafarers, who have working experience up to 5 years, on the subject of container shipping safety, including factors affecting the occurrence of hazards during maritime transport of containers. For this purpose the factors causing hazards had been identified and the survey among the Polish seafarers was conducted.

2. Hazards in Maritime Shipping

In the process of effective setting of container shipping safety, the risk analysis plays a leading role. The methods used in risk analysis of technical systems are usually divided into two groups: qualitative and quantitative. The methods from the first group are applicable in case the purpose of risk analysis is to seek for the ways to reduce risk without using its quantitative description. Their common feature is that the risk level is determined separately for each of the hazards specified during the identification process. For this reason, qualitative methods are not suitable for determining and assessing the overall risk. They may be used to assess the so-called partial risk, i.e. related to a specific hazard. A typical approach to formulating qualitative risk analyzes for the purpose of assessing the safety of navigation is presented in the guidelines of the International Maritime Organization (IMO) [6-11].

The basic objective of risk analysis is to answer some key questions related to the type of hazards that may accompany the ship's operation, factors that may initiate the process of hazards release, changes and effects accompanying the released hazards, estimating the probability of adverse events (e.g. marine accidents) or potential ways to reduce possible damage [1, 14, 23].

In this paper, we are looking for answers to the first of the questions formulated above related to the container ships safety. The concept of the hazard connected with navigation safety is formulated in [6]: "hazard - a potential to threaten human life, health, property or the environment". On the basis of the guidelines for formal safety assessment (FSA), it is referred, among others, to the hazard "size", as well as types and "causes" of hazards. Similarly, with regard to the safety of machines, the hazard is defined as "potential source of harm" [15].

In the case of cargo ships operation, the source of hazards may deal with their construction and equipment, crew,
cargo and the environment in which they operate [4, 2]. Correct identification of such hazards is important to ensure the proper level of navigation safety. For this reason, it is important to conduct the hazards analysis orderly [12, 14, 23, 24]. Hazards can be classified considering, among others, their origin or nature of potential damages [15]. In the first case, there are mechanical, electrical, thermal, ergonomic, material risks (related to the properties of materials and substances), noise, vibration, radiation and hazards generated by the environment in which the machine is operated. In the second case, for example, toxic, fire, electric shock and cutting hazards are distinguished [19, 22]. The standard regarding risk analysis in technical systems [17] (document was withdrawn in 2015) presented the proposal to group hazards into four categories. These are natural hazards (floods, earthquakes, tornadoes, etc.), technical hazards (industrial devices, transport systems, etc.), social hazards and hazards resulting from lifestyle. Considering shipping, the hazards may be classified, for example, due to factors causing them. These include, for example: human error, navigational, thermal, operational, technical, technological [7, 24]. In this context, it is worth to emphasis the research results presented in publication [16]. Although this document does not explicitly refer to the definition of a hazard, but its scope is determined. It distinguishes, for example, "hazards from excessive pressure".

In the paper devoted to selected issues related to the safety operation of sea-going vessels, events that threaten the ship are discussed [2]. These include, among others, the damage to main engines. In this context, the "serious hazard to the safety of the ship" or "situation threatening the safety of the ship" are highlighted. At the same time, the postulates of appropriate reactions to hazards, accidents and emergency situations occurred with ships are identified.

In each of the above mentioned approaches, the hazard is associated with the concept of potential damage, which may occur as a result of the specific hazard "release". Therefore, it can be assumed that regardless of minor differences in the definitions of hazards themselves, the scope of possible damage caused by its influence makes the significant difference. Bearing this in mind, this paper proposes, the systematization of hazards occurred in container shipping considering their sources. These sources were related to four groups of factors: human, technical and technological, environmental and climatic and systemic.

A. Hazards caused by the influence of the human factor

Analyzes carried out show that human errors accounted for ca. 80% of marine accidents [10, 16]. These errors may have their source in the process of construction, manufacturing or - most often – during unit's operation. The safety of shipping depends, among others, on their experience, knowledge, skills and conclusions drawn from the analysis of earlier mistakes made at various stages of design, construction or operation on ships [3, 5].

B. Hazards caused by the influence of the technical and technological factors

Hazards caused by the influence of the technical and technological factor may be associated primarily with the unreliability of the structure and technical equipment of the unit (energy, loading, propulsive, etc.). Each ship is an element of the technological process ensuring the movement of cargo in the water environment. It follows that the individual's safety as an engineering system is also directly affected by physical and chemical properties. Hazards referring to technical and technological factors group are classified according to the cause of their occurrence into [15, 22]:

- structural, created as a result of making design and construction errors;
- productional, arising as a result of violations of manufacturing technology, the use of poor quality materials and inadequate quality of installed equipment;
- operational, resulting from violations and incorrect operating conditions of the equipment, which may result in excessive load on the equipment.

Other known classifications of these factors are related to the dynamics of their development, the type of possible effects, predictability of occurrence (predictable and unpredictable hazards are distinguished) etc.

C. Hazards caused by the influence of the environmental and climatic factors

These hazards form a group on which the human influence is rather low [21]. It turns out that man is not able to predict exactly the unfavorable weather conditions development on sea. These hazards include sea currents, waves, strong winds, freezing etc. Therefore, information messages about prevailing conditions should be monitored regularly, and above all, they should not be underestimated in order to adapt the vessels movement to the changing situation on sea [20, 22].

D. Hazards caused by the influence of the systemic factors

Hazards caused by the influence of the systemic factors are closely related to the human factor group. The systemic factors apply to [25]:

- management methods and tools in maritime transport;
- ways of integrating functions and activities;
- coordination with various non-transport activities (economy, education, health or environment protection) under the human-machine-environment system.

Hazards caused by the influence of the systemic factor also depend on [2, 18]:

- employment policies of land management staff and crews of vessels;
- the security philosophy of the company managing the given unit;
- crews trust to management employees on land;
- management policy;
- proper communication rules between the shipping company and the ship, ensuring cooperation of the ship
with pilots, continuous contact with the ship owner, traffic control systems, etc.

Nowadays, crew reduction is observed as very popular procedure used by shipowners, which is associated with the introduction of intelligent systems that can replace the mariners. However, it should be noted that these devices also require maintenance. As a result, the crew is overworked and overloaded with duties, as well as cannot meet all expectations of the ship managers and follow the regulations.

To sum up, regardless of the type of hazards caused by the impact of human, technical and technological, environmental and climatic, or systemic factors, extraordinary situations take place and can result not only in financial losses, but also the losses to the environment or crew health and life. Moreover, it should be emphasized that the factors that cause dangerous extraordinary situations are interrelated and usually do not occur individually.

3. Research Methodology

In order to conduct risk analysis, including hazards identification, expert groups are usually created. Undoubtedly, the observations and remarks of young seafarers may be interesting in this regard.

The assessments of qualified, young maritime personnel on container shipping safety was obtained using surveys. To this end, a questionnaire was developed that aimed at obtaining the opinion of young seafarers working at sea for no more than 5 years regarding factors that threaten the safety of maritime containers transportation and the potential consequences of their release.

The opinion of qualified young seafarers regarding safety of container shipping was examined using the surveys. To conduct the study the hazards occurring during container shipping were identified and the questionnaire was developed. The aim of the survey was to investigate the view of young seafarers working at sea no longer than 5 years on the factors influencing the safety of maritime containers transport and potential consequences of that impact.

The survey was placed on the website http://www.portalmorski.pl with the consent of its administrator on 19.09.2017 and lasted until 31.12.2017. The respondents answered the proposed questions. 93 respondents from Poland took part in the survey, performing different positions on ships.

4. Results

Young seafarers who took part in the survey sailed or sail on different vessel types (Fig. 1). The largest group of surveyed seamen (24% of respondents) worked or work on feeder ships with a capacity of 1000 – 2500 TEU. A similar percentage share belongs to panamax container ships (2500 – 4000 TEU). In turn, 13% of the examined seafarers gained experience on suezmax ships (8000 – 12000 TEU). Post-suezmax vessels (12000 – 14000 TEU) chose only 4 respondents in their answers. From the group of 93 respondents there was no person working on vessels with a capacity above 18000 TEU. The analysis of the data presented in Figure 1 shows that young staff gets experience on smaller container vessels.

![Fig. 1 The type of container ships on which the respondents gained their experience](image)

![Fig. 2 Type of functions performed by respondents on the container ships](image)
The respondents were asked to give the type of function performed on the ship. Fig. 2 shows that 49% of the respondents performed the operational function (they are officers with a degree II/III and mechanics with a grade III/IV). 37% of the respondents performed the auxiliary function, they are ratings, motorists, etc. In turn the management function was performed by 14% of respondents. This result shows that the respondents performed different functions on ship gaining the experience and the vast majority of them were not involved in management activity.

The essence of the study was to identify the factors that have the greatest impact on the safety loss at sea according to the young staff of ships (Fig. 3). The respondents assessed individual groups of factors on a scale from 1 to 5, where 1 – group of factors having the smallest impact, 5 – the largest. The analysis of the results shown on Figure 3 reveals that the greatest impact according to the young staff is the group of hazards caused by the human factor impact (61% of the respondents rated this group of factors at 5 points). The analyzes show that 47% of respondents rated the environmental and climatic factors on the average safety level (giving it 3 points). The assessment of the technical and technological factors is very similar. In turn, the impact of the systemic factor by the respondents was assessed ambiguously. The highest number of ratings for this factor was at the level of 2 points, representing 34% of respondents answers. This may indicate that according to the young staff there is a small impact of this factor on the shipping safety, or this staff to a lesser extent dealt with the occurrence of this factor while performing their work due to the too little professional experience.

Next questions aimed at examining the impact of selected hazards related to specific groups of factors on the safety of container shipping. The respondents were asked to evaluate particular identified hazards within the groups on a scale from 1 to 6 points, where 1 – the smallest impact, 6 – the largest. Each factor within the groups was assessed separately.

The study results referring to the impact of the human factor are shown in Fig. 4. Among the selected hazards, the respondents gave the highest values (5 and 6 points) to the possible routine and inattention (59% of answers). This indicates that this hazards type, in the opinion of the respondents, most often affects the occurrence of situations threatening the shipping safety. According to respondents, terrorism and other possible human behaviors threaten the safety rarely. 27% of respondents answered that excessive use of alcohol does not significantly affect the extraordinary situations occurrence, however a similar number of seafarers rated them at 5 and 6 points. Failure to comply with applicable regulations according to respondents was largely recorded at the level of 5 points – 22% of responses. The abandonment of official duties was indicated at a similar level. Although the assessment rates for this hazards were very diverse, 16 people rated it at 6 points, and 23 respondents stated its influence at the level of 5 and 4 points. It should be noted that the young staff of container ships considers this factor to be significant.

Analyzing the survey results presented in Fig. 5, it can be concluded that the majority of respondents thinks that within the group of technical and technological factors, the loss of nominal properties due to aging of materials used to
build the ship is the most frequently appeared hazard. In total, 35% of respondents rated this hazard at 6, 5 and 4 points. Another factor that is considered to be affecting the occurrence of the hazard is the insufficient reliability of ship's equipment, 22% of respondents rated it at 5 points. However, a slightly larger number – 29% of seafarers – believe that this factor does not affect too much the extraordinary situation appearance and rated it at 3 points. Production defects in construction materials are also considered by the majority of respondents as less important.

Within the group of environmental and climatic factors, according to the respondents the occurrence of extreme wind conditions is a very common (Fig. 6). 26% of seafarers rated this phenomenon for 6 points. Also excessive waving, loss of visibility through rain and fog had been quite highly rated – at 5 points (15% and 18% respectively). According to the young staff, strong and unfavorable currents have a smaller impact on the occurrence of ship safety loss, because the majority of responses assessed it at levels 1, 2 and 3 points on the rating scale. It should be noted that none of the respondents evaluated this phenomenon for 6 points. The occurrence of ice phenomena or very high air and water temperatures has been assessed in various ways. The majority of seafareres thinks that it has an average impact on the safety loss (55% of respondents rated it at 2 and 3 points).

From the detailed analysis of the data contained in Fig. 7 it could be noted that the main hazards related to systemic factors group, that were assessed at 6 points, are: additional overloads (44% of respondents consider this), crew reduction by shipowners – 40% of answers, and fatigue in the length of contracts – 25% responses. Young staff also thinks that training deficiencies cause the occurrence of ship safety loss to a lesser extent. Only 15 respondents out of 93 rated this factor for 6 points. Paying attention to systemic factors, the young staff of the cintainer ship stated that imprecise regulations are one of the least affecting hazards. It should be noted, however, that the systemic factors (Fig. 7) are very much related to the human factor.
The article presents the survey results of young seafarers’ opinion on the safety of container shipping. The selected groups of hazards were identified and analyzed in detail. On the basis of the conducted research, it can be stated that the young ship staff (that have work experience on ship up to 5 years) is aware of the hazards occurring in container shipping The most significant factors group influencing the container shipping safety is human factor. In turn, the systemic factors group is considered to have the least significant impact on shipping safety.

However, to analyze the seafarers’ opinion on the safety of container shipping in more details, the results of surveys filled by stuff should be compared to the opinion of the experienced crew, as well as referred to the statistical data obtained from the ship accidents reports. This will form the direction of our further scientific research.

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Modelling of Distribution Systems Using Cargo Bikes in City Logistic

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Abstract

Implementation of cargo bikes into city logistic systems in European countries has been growing in recent years. Cargo bikes are environmentally friendly transport means, relatively easy to use. The last mile delivery of small shipments is their main application. Experience with the use of cargo bikes in city logistic systems shows that such systems can be reliable and cost-effective respecting local conditions and appropriate planning. Suitable location of distribution centers and optimization of distribution routes are of great importance in planning. This work defines distribution models using cargo bikes, compares their advantages and weaknesses and suggests possible optimization strategies.

KEY WORDS: cargo bikes, city logistics, distribution models

1. Introduction

Cargo bikes are one of the unconventional ways of distributing goods within the city logistics. Bikes are powered by electricity or using physical human power. In most systems, the cargo bikes were supplemented with electric mini-vans for faster distribution of goods and for shipments with higher weight. According to the European Cyclelogistics project [4], more than half of the motorized routes for the distribution of goods in European cities could be transferred to bicycles or cargo bikes. However, it can be quite different locally in every city.

The purchase of bicycles and vehicles discourages most corporate delivery companies. However, noise reduction, congestion reduction, substitution of motor vehicles by cargo bikes, time savings for merchants, good company image and more are the main goals in all systems.

2. City Logistic Distribution Models Using Cargo Bikes

In Europe, bicycles are already implemented in the city logistics systems, eg in the Netherlands, France, Belgium, Denmark, Great Britain, Germany, Ireland and the Czech Republic.

In Paris, several depots located direct in the city are used to consolidate and distribute shipments. Mainly large logistic companies are the clients of this system. Distribution is planned by an application that optimizes the route by minimizing route lengths, the specifics of the means of transport, minimizing time per trip, minimizing stops within a single path [2, 5].

In Toulouse, Paris, Bordeaux and Lyon, there operates a company, which targets primarily on green logistics. It has a fleet of eco-vehicles from electric cargo bikes to electro and NGV vans with high capacity. They use their own distribution centers at outskirts such as in the city centers [14].

In Spain (eg Barcelona, Madrid, Zaragoza, Valencia) cargo bikes are used to deliver packets from several e-shops with a guarantee of delivery within 60 min [2].

In Copenhagen, there is an express company that focuses on delivering parcels of up to 80 kg, mail pick and delivery, flowers and lunch delivery for business and private clients. Shipments are delivered on the same or next day [3].

In San Sebastian, Spain, a consolidation center was created from an unused warehouse in the city center. The cargo bike system is mainly used by shipping and business companies. The system is operated with the support of local authorities [2, 12].

The London cargo bike system uses electric vans and tricycles to deliver shipments from a small consolidation center to central London [2, 10].

UPS uses cargo bikes in Germany. In Hamburg, the concept is built on 4 main points where the containers (microdepots) are located, from which the workers sort the shipments for the next day [13].

In the Czech Republic, bicycles are used to deliver small shipments in the wider center of Prague. The courier delivers small shipments in the backpack on the back with standard bike or the cargo bike is used for larger shipments. [9]. DHL operates a cargo bike with a lockable cargo space in the center of České Budějovice. This concept is already used in the Netherlands [6].

In these systems, the bikes are generally used as a transport mean for last mile delivery [1, 8, 10]. Systems are always linked to one or more distribution centers. It is important that distribution centers are within reach of the optimum range for couriers regarding customers. This usually involves location of the depot in the wide city center.
Usually, this is a multi-stage system with at least one distribution center on the outskirts of town and other depots in the city center. Transport to distribution centers is most often realized by road vehicles, but also other types of transport can be used in suitable conditions.

Distribution models using cargo bikes must respect the specific characteristics of cycling. These characteristics may in some cases favor bicycles against other modes of transport (eg easy availability of targets) or may be a disadvantage (eg lower speed and less driving distance). Table lists the strengths, weaknesses, opportunities, and threads for the cargo bike system in general.

### Table

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
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<tr>
<td>environmentally friendly</td>
<td>limited driving distance</td>
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<tr>
<td>small space requirements for loading / unloading and driving on narrow streets</td>
<td>low speed</td>
</tr>
<tr>
<td>low operating costs</td>
<td>the need to locate a depot in the city center</td>
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<tr>
<td>legislative definition of a bicycle (not a motor vehicle)</td>
<td>dependence on weather</td>
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<td></td>
<td>the need for an initial investment</td>
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<tr>
<th>Opportunities</th>
<th>Threads</th>
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<tr>
<td>freight traffic limitations</td>
<td>insufficient circle of end customers</td>
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<tr>
<td>high emissions and noise levels in the city centers</td>
<td>the risk of congestion in common traffic with other vehicles</td>
</tr>
<tr>
<td>existing unused commercial spaces in the urban area</td>
<td>no interest in cooperation from business companies</td>
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<tr>
<td>increasing the image of the participating companies</td>
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<tr>
<td>a growing offer of different types of cargo bikes</td>
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The basic strategies for implementing and developing systems with cargo bikes can be identified from Table 1. These systems are characterized by almost no direct emissions and very low noise levels, which, when deployed, can help reduce the emissions and noise levels in city centers. This is in the interest of the local authorities, which may be motivated to participate in the system. For example, they may offer free commercial spaces in their ownership (eg unused warehouse) to set up a depot. Environmentally friendly, this system can be a positive advertisement for the city and the participating companies and can help to attract new business partners.

If organizational measures are introduced on the roads in the city to limit the freight transport by motor vehicles, the bike gains an operative advantage of better customer access (it can use cycling paths, streets with no entry of motor vehicles, etc.). This way the bike can also avoid congestion on roads with higher traffic and less capacity. Small space requirements improve customer availability, especially in historic city centers. This opens the opportunities to attract a wider range of customers.

The limited driving distance must be solved by locating depots with the appropriate distribution area. This can be done by using existing unused spaces or areas where a container can be placed (eg UPS in Hamburg). The driving distance can be increased by selecting the appropriate bike type. The wide range of bike types also makes it possible to partially eliminate the influence of the weather (eg bike with rain cover). Higher initial investment in the purchase of bicycles and the possible establishment of a depot can be particularly balanced by increasing the company image as an environmentally friendly company, especially for larger international companies.

Due to relatively low bike speeds and the risk of congestion in common traffic, it is necessary to plane the routes with maximal use of cycle paths and road with lower traffic. In many cases, this allows to achieve a significantly shorter route and a shorter delivery time at a lower speed than a truck.

The business concept of cargo bikes distribution systems can be in form of:

- **an independent company**

  In this case, the system is operated by an independent company operating as a carrier. The company can focus on both business and private clients. It can also focus on a defined range of shipments (e.g. meals, blood conserves). If such a company enters the market as a new one, the disadvantage is that it must acquire a sufficiently large range of customers. The advantage can therefore be if the company establishes cooperation with large logistics or trading companies, for which it realizes the last mile delivery from their distribution centers. In this case, a range of regular customers is given in advance. This concept is suitable for larger urban agglomerations where demand is high enough.

- **own cargo bikes of delivery / logistics companies**

  In this model, large companies with large clientele use their own bikes for their customer service. The advantage of the system is a steady range of customers. The required number of bicycles can be effectively adapted to a given number of customers, so it is possible to use it even in smaller towns. Large companies also have enough resources for their initial investment, and the environmentally friendly image could be also important for them. From the point of view of the local government, the disadvantage may be the focus of the system only on the customers of the given company and thus also the more difficult expansion of the range of customers.

Business concepts of companies operating cargo bikes and their position on the market are mentioned in e.g. [8].
3. Optimization Strategies

Several decision problems are solved when setting up a suitable distribution system using cargo bikes:

1) strategic decisions with a long-term horizon - the design of the distribution system structure, the number and location of distribution centres;
2) tactical decisions with a medium-term horizon - assigning permanent customers to distribution centres, choosing the way to trace and deciding;
3) operational decisions - the determination of daily bike routes.

When we choose a suitable optimizing method for the location of distribution centres, it is necessary to determine the appropriate criterion for optimization. [7] It is important to realize whether the distribution centres will be limited in capacity, whether any dependencies will be formulated between the distribution centres, etc. It is also important to note whether we choose locations for distribution centres from a set of predetermined locations or whether the location of a distribution centre could be anywhere in the defined area.

In the case of cargo bikes distribution centres, which are usually located within the urban area, the choice of predetermined locations is more likely. Determining the set of these locations is based on the available free space, their transport availability and possible customer preferences.

At the time of the distribution system design, only regular customers are likely to be known. This is the case with the application of a distribution model where the cargo bike system is introduced by an existing company (eg delivery, logistics) with a given range of customer.

If cargo bikes are introduced by a new company and bicycles are used, for example, to delivery small consignments to households, individual customers are not known at the time of designing the distribution system. In this case it is possible to divide the area into small homogeneous units and then work with the centroids of these units.

When we choose distribution centres from a set of possible locations, we need to select an optimization criterion. The form of the optimization function will depend on whether it is a median or p-median location problem, covering problem, or cost-oriented task.

P-median location is a cost-oriented task with minimizing total transport performance. The goal is to find a set of distribution centres for which the aggregate weighted distance will reach the minimum (1):

\[
f(D) = \sum_{v \in V} w(v) \cdot d(v, D),
\]

where \( w(v) \) -weight rating of vertex (or customers); \( d(v, D) \) - the v-vertex distance from the set of distribution centres (the cost aspect can be partially considered here).

If we solve the covering problem, it is possible to consider the maximum distance from the distribution centre to the individual customers (see Spanish model). In this case, it is necessary to cover the area with several distribution centres so that the cargo bike could be in time to the customer.

If we solve a cost-oriented task, it is possible to define an optimization function that minimize the cost of the distribution system. In a cost function, fixed costs (especially the construction and operating costs of distribution centres) and variable costs (service costs for individual customers) can be considered. Within the setting of the solution conditions it is possible to set individual properties of the distribution system, for example, whether individual distribution centres will be limited in capacity or whether it is necessary to serve each customer form distribution centres or to serve the customer directly from the source.

A model, in which the capacity of individual distribution centres is limited, and customers need to be served only from distribution centres, is mentioned as an example below. If we know:
- primary source location;
- a set of possible distribution centers locations;
- a set of customers (or centroids of homogeneous areas);
- distance between all objects;
- the volume of requirements of all customers;
- estimation of costs to satisfy the requirements of individual customers from the primary source through individual distribution centres (depots);
- the construction and operating costs of distribution centres;
- capacity limitations of the distribution centre;
we can obtain this model outputs:
- decision on whether a distribution centre (depot) should be built and operated in given location;
- decision on whether the customer should be supplied from given distribution centre (depot).

The advantage of this model is that we get not only the solution of the location problem but also the solution of the allocation problem, i.e. we also know the assignment of customers (or homogeneous units of the given area) to distribution centres.

This model can be adapted to specific conditions by setting inputs and conditions. Mostly it can be solved using the available tools, eg Solver in MS Excel or special

It is also possible to solve locational problems by other methods, eg by means of genetic algorithm etc.

Once the distribution system has been set up, the tasks of an operative character are also being solved. This is the
daily service of individual customers. We can use Capacitated Vehicle Routing Problem algorithms. The task is solved for each distribution centre separately. The aim of the task is to design such a set of cargo bike routes so that the total length of routes for all customers is minimized.

Input data for the solution are:
- matrix of distances between all objects (i.e. between all customers and distribution centre);
- daily customer requirements;
- a set of different types of bikes with a given capacity.

Input conditions are:
- each bike leaves the centre and returns to it;
- each type of bike can only be used once;
- every customer must be satisfied with only one attempt.

Furthermore, the task types can also be different whether the customer needs to be served at a given time, in a time window, or whether the customer's service time is arbitrary.

Heuristic methods based on Cluster First - Route Second, Route First - Cluster Second, Savings - Insertion, Improvement Exchange, mathematical programming methods, etc. can be used for solving this problem. Possible methods for solution are given eg in [1, 11].

4. Conclusions

The general problem of introducing new city logistics systems lies in the high initial costs. Market research in the city can help to identify suppliers and customers who would be connected to the system and the position of the logistics center. Cargo bikes systems are relatively easy to apply and profitable especially in larger cities. Their optimization is possible using standard procedures/softwares and considering local conditions (eg weather, traffic, terrain, customer preferences, size of the urban area).

References

The Impact of Psychographic Segmentation on Marketing Communication in Transport Company

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Abstract

Based on the segmentation process, the market is divided into several segments representing customer groups with similar requirements for quality, price, technical parameters and other product characteristics. Psychographic segmentation is focused on definition a market segment according to people’s lifestyle, personality character and hierarchy of values. It also takes the psychological aspects of consumer buying behaviour into account. These psychological aspects include consumer’s lifestyle, his social standing as well as his activities, interests and opinions. Mentioned factors are obvious in services sector such as transport companies. The aim of this article is to define the theoretical basis of the impact of psychographic segmentation on marketing communication from the viewpoint of domestic (Slovak) and foreign authors. This includes an analysis of the marketing communication in the case of transport company, in relation to psychographic characteristics of its consumers. The secondary data for the analysis was obtained from annual company reports, statistical tables and published professional publications. General scientific methods were applied for the processing of the data e.g. description, comparison, analysis, synthesis, deduction and induction. Based on this, benefits of marketing communication taking into account psychographic characteristics of consumers are highlighted and proposals are put forward for its effective implementation within the transport companies.

KEY WORDS: marketing communication, psychographic segmentation, transport company, consumer, buying behaviour

1. Introduction

Due to growing the competitive environment in the transport market, transport companies can no longer enough with current marketing methods that ensured their success with customers. Recently, the efforts of carmakers to promote individual passenger transport have intensified and negative impacts on the use of public passenger transport have been recorded [12]. For that reason, transport companies have to strengthen its competitiveness and increase efforts to attract and retain customers.

In order to succeed in a competitive battle, transport companies need to focus on requirements that the customer considers to be a priority in meeting their needs. Above all, it means qualitative factors, namely reliability and regularity, speed and readiness to meet customer requirements, and last but not least, safety. The lifestyle of customer target groups, as well as their attitude towards environmental protection and level of social responsibility, also have a major impact on the perception of transport services [16].

An important and effective factor in every sector of the economy including the transport is the appropriately chosen marketing communication with regard to the specifics of the target segments. In recent years, market signals have been clear - traditional forms of marketing communication, focusing primarily on one-way information flow, are no longer sufficient for customers. The market is becoming more demanding and requires dialogue. It does not have to be a personal contact, but modern forms of dialogue through progressive forms of communication that enable not only fast ordering of products on-line but above all permanent and flexible informing customers. The triumph for the company is the ability to quickly record and react to these changes. By using modern marketing methods in the field of marketing communication, the company will increase its competitiveness and attractiveness in the eyes of the traveling public.

2. Literature Review

The issue of marketing and marketing communication in transport company has been researched and analysed by many foreign as well as domestic authors, and remains actual.

According to several authors, transport company starts to seriously consider its marketing concept mostly in the case of a decline in transport services, changes in customer behavior, increasing competition, slow growth in transport services [3, 6, 10].

As a result of marketing efforts of car industry, car is now considered o be one of the most comfortable and fast
means of transport and is always associated with notions like “freedom” or “control”, even though these notions do not necessarily reflect the mode of car use in a congested city. Taking this into consideration, it seems important to develop marketing of public transport in order to improve the overall image associated to it, restrain current users from switching to the use of private vehicles and attract new users [21]. There has been a number of initiatives in this area which prove that marketing of public transport can be indeed a way of fostering its use. Public transport information provision is another important factor that can favor people to use public transportation modes [7].

Transport marketing is a specific area of service marketing applied in the conditions of transport services. The main factor affecting transport marketing and marketing communication is the customer and his transport needs, which are specified in the transport requirement [18].

Furthermore, Reznicek states that the application of marketing in transport services varies according to the mode of transport as well as the country where the service is provided [18].

According to Jakubikova, the goal of transport marketing is above all to maximize customer satisfaction, optimize the choice of transport service provider and its services, and maximize quality of life [8].

Marketing communication in transport companies includes advertising, sales promotion, personal sales and public relations. The company uses these communication tools to communicate with customers and to achieve its marketing goals [13].

Currently, in time of massive development of communication and information technologies, it is no longer enough for companies to use only mentioned traditional communication tools. These tools should be complemented by new progressive forms. Such forms include: an internet marketing, mobile marketing, guerilla marketing, event marketing, product placement and others.

Over the past 20 years, the Internet has become a very important competitive marketing tool, even in transport companies [19]. It allows stakeholders to communicate not only easier, but also allows them to communicate with a huge number of people at the same time. Nowadays, the most used form of internet marketing is social networks.

Social networks we can see as a universal communication platform. They are relatively new and currently the most popular type of web applications. The content of social networking is all that is published on the web application. These are the texts, comments, ratings, link to websites, photos, videos and applications [2].

Social networks are places where people gather, to create the circle of friends or to join a particular community with common interests [9]. Unlike other media that companies can use in their marketing communication, for social networking there is typical constant contact with customers. Companies can respond to questions, comments, complaints and promote customer's reaction. Due to a large number of customer's reviews, company can best assess the perception of its products and appropriately adjust its offer [14].

The trend, however, become mobile applications. The dynamic advent and development of mobile devices are visible all around us. The company is moving from classic computers to smartphones and tablets. With regard to the number and pace of application growth, the marketing of mobile applications is becoming more and more common today [4].

Another progressive form of marketing communication is guerilla marketing. It is an unconventional marketing campaign whose purpose is to achieve maximum effect from a minimum of resources.

Event marketing is also often included as a public-relations tool, as it is a form that serves to promote corporate value, branding a business by staging emotional experiences with consumers. The event's success lies in the perfectly timed organization of the event in terms of time and space, in the creative idea, the right choice of performers, quality refreshments and service, graphically matched invitations and ultimately public awareness [20].

Product placement is defined as the use of a real branded product or service generally in the audiovisual work (film, TV series, computer games), live broadcasts or performances or books that are not of an advertising nature in clear, generally contracted terms conditions. It is a non-violent and non-intrusive form of advertising that has the customer's desire to own a product as the main character of the film or computer game.

Over the years, several authors have dealt with the impact of psychographic segmentation on marketing communication.

Angelidou et al. examined how globally observed market and societal trends (such as the shared economy, the emergence of sustainable lifestyles, technological ubiquity and individual empowerment) will affect the demand for public transport services over the next 10 years in European cities [1].

Gajanova focused on identifying the existence of statistical dependence between online content marketing tools and demographic and also psychographic segmentation variables [5].

Moravcikova focused on the importance of Y generation as a market segment, to identify online marketing communication tools that are preferred by the analyzed generation and have an impact on brand loyalty. Part of her research was to determine gender-based psychographic segments of generation Y within the VALS method that can help an entrepreneur determine which communication tool to use effectively in an appropriate manner for the selected segment in the Slovak Republic [15].

3. Methods

The aim of this article includes a literature review on the issue from the perspective of both domestic (Slovak) and foreign authors. By using methods of description, comparison, deduction, induction, it discusses the essence of marketing communication in transport company as well as the impact of psychographic segmentation on marketing communication.
communication and also analyses the marketing communication in the case of transport company, in relation to psychographic characteristics of its consumers. Based on this, the benefits of marketing communication taking into account psychographic characteristics of consumers are highlighted, and proposals are put forward for its effective implementation within the transport companies.

The secondary data for the analysis were obtained from annual company reports, statistical tables and published professional publications – both in print and electronic media. General scientific methods were applied for the processing of the data. When examining and identifying the impact of psychographic segmentation on marketing communication, the definitions of the approaches and concepts that are mentioned above were maintained.

4. Results and Discussion

Market segmentation is underused in the transport services sector. Most small companies are only marginally involved. Transport services are often offered without focusing on specific needs or segments. Most transport service providers mistakenly think that every customer in the transport market wants to buy their service. However, there are always customers who are not interested in buying a transport service from other carriers. Therefore, market segmentation in transport services is particularly important in today's competitive environment, which will intensify due to integration processes in Europe.

In Central and Eastern Europe, public transport had a dominant position on the transport market in the 1990s. Market share is currently declining, especially in bus transport [11, 17]. However, there is a way that could help stop the negative development of public passenger transport, namely thoughtful marketing strategy with marketing communication of transport companies focused on specific characteristics of target segments including psychographic aspects.

The essence of such a strategy is to build a company's reputation and sympathy with it. It is a long-term process, but with a very effective result. It includes an effort to persuade customers in the long term and get into their subconscious. In practice, such a strategy uses an emotional impact on existing and potential passengers in all ages, with different lifestyle and social standing, presenting humorous or sensitive stories, for example, on posters, in newspapers, on the Internet to reach the largest possible population of the city in terms of age and their technical skills. Marketing material should highlight some of the generally accepted disadvantages of car travel, but also highlight some recent improvements in local bus traffic.

We examine the marketing communication in the case of transport company, in relation to psychographic characteristics of its consumers. Slovak Bus Service Zilina (SAD Zilina – Slovak abbreviation) is a service company oriented exclusively on bus transport.

Specifically, it is a company providing transport services in connection with regular and occasional services. At present it is one of the largest carriers in suburban transport in Slovakia. Despite the dominant market position of the company in general, the public passenger transport situation is largely determined by various socio-economic impacts. For this reason, it is important to look at the sustainability of competitiveness, which means finding solutions that make transport services more attractive to passengers.

The company strategic goal is focused on attractiveness of public passenger transport, the increase of the number of passengers and, in particular, the satisfaction of general public. This is all about improving quality and safety in the use of bus services. On the basis of monitoring the development of the previous period, the company assessed that marketing has become an important element that points to his direction. The company has also adopted a marketing approach as a basis for developing a positive perception by the traveling public. In addition to classical methods and approaches, they focus mainly on leaving a favorable impression through event marketing, social networks or mobile applications, following results from requirements of target groups including psychographic aspects.

Advertising is particularly important for the intangibility of the transport service. The company is aware that a large number of people can reach appropriate advertising with regard to the specific characteristics of consumers. The company has decided to raise awareness in an innovative way by working with a local agency to create a video clip capturing the work of bus drivers who try to harmonize the timetable with the weather. As it has been written in print media and even in television news programs, up to 4.2 million people have hit the video. In addition to a number of positive responses, the company could also enjoy new jobseekers. Another manifestation of unconventional advertising activity last year also became a regular TV show Busmania. It was an entertaining concept of a travel quiz for mainly bus passengers.

As mentioned above, thanks to the development of information technology, the internet and social networks are becoming an essential part of life for most consumers. For young consumers it represents lifestyle, from a certain perspective. Therefore, the company decided to support its advertising activity by creating its own Facebook page and YouTube channel. There were several reasons for this, one of which is the possibility to reach a specific target group, offer interesting, valuable information to people and encourage them to contact the organization through sharing online content. Thus, company timely and real-time manner informs about the introduction of new connections, about possible changes in timetables, but also about the events it is preparing. The fact that the site enjoys popularity and people are interested in it, expresses the number of fans, which is almost 4,500.

In addition to the social network, the company also has an official website with information on news, events and the like. It also allows searching for a connection, the option to recharge credit on transport card or to purchase a
transport card online via e-shop.

The company regularly offers a number of brochures and catalogs in client centers. Through these brochures, passengers can learn about the news, the possibility of purchasing a transport card, the benefits of travelling comfortably, in fun, socially, ecologically and conveniently.

Other promotional materials include the publication of a corporate magazine. The magazine captures the most significant changes, news or events among employees.

As part of the promotion, the company regularly participates in trade shows and exhibitions focusing on transport and tourism, eg. Czechbus Praha, which is an interactive, specialized fair focused on the issues of Czech and Central European public transport. The company is represented at the fair every year and by its participation it not only presents its name but also deepens its current business relations and also acquires new business partners, who are on the transport market.

Within the event marketing activities, every year, the company organizes the Open Door Day entitled "Get to Know Your Bus". As part of the activity, public transport within the region is presented pleasantly and informally, through all activities related to the performance of the transport process. This successful event is focused on all ages and target segments.

The company also specializes in occasional events that are associated with events from the calendar. In particular, it is Valentine's Day, International Children's Day, St. Nicholas and the like. Events enjoy great popularity from the public.

As a part of PR activities, the company prepares the necessary documents every year, but does not publish them on its website, so there is space for improvement. On a regular basis, however, we can find in the local periodical and in the regional press the contributions that inform about ongoing events, the possibility to compete, the opening of busses or, for example, about the restrictions on timetables during the holidays. The company is of the opinion that newspapers are a tradition and there are still customers who prefer the method of promotion.

SAD Zilina is favorable to sponsorship, such as support for sports in the city (a basketball team, a male volleyball team, a youth ice hockey team in Martin).

Mobile phones and smartphones are an integral part of our lifestyles, so the company has reacted flexibly to this by introducing mobile apps to its customers.

The MyBus application offers detailed information about connections, departures, stops and the exact location of SAD Zilina buses or information about the time of delay. Because it is a web service, Internet access is required to find links. It is also possible to use the free wifi in SAD buses. The UBIAN app is an alternative service that passengers can use comfortably in their mobile devices. Its advantage is also working during the offline mode, when it can search for destination stops and propose the best routes. In the case of the online mode, the application has additional expanding features, such as determining the exact position of the bus on the map along with stops or providing information about the time of the connection and replacement solutions.

It is obvious, that in designing and subsequently implementing marketing communication tools, the company was influenced, among other things, by the psychographic aspects of segmentation, such as consumer’s lifestyle, his social standing as well as his activities, interests and opinions.

Given the growing trend and interest in online products, we propose to continue marketing activities to support the e-shop product through print, social networks and video sharing about purchasing and recharging the transport card on YouTube channel or social networks.

Due to the growing interest in the Instagram social network, especially by the younger generation of consumers, it would be advisable to set up an account on that social network and communicate with it through target segments.

5. Conclusions

The presented activities are assessed from the economic point of view, especially by the passenger, eg. from the point of view of the development of the number of transported persons, where the basic motive of all marketing activities is the reduction or stopping the loss of passengers. The impact of well-targeted marketing communication is one of the key aspects when deciding on the use of public passenger transport by passengers and therefore it is important to pay close attention to it. It means, that marketing communication taking into account psychographic characteristics such as the lifestyle, personality character and hierarchy of values of customer target groups including their attitude towards environmental protection, also have a major impact on the perception of transport services.

Only attractive public transport using modern marketing activities focused on high quality and safety can reduce the number of cars and parking spaces, making it easier to use the public space for residents in the regions and improve their quality of life.

Acknowledgements

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References

Ammonium Sulphate Preparation for Shipping: Process Optimization

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Abstract

The process for the preparation of the fertilizer for shipping includes the supply and granulation of raw materials, packaging of raw materials into bulk bags and their transportation to the place of loading for shipment. The main problem with this process is the consumption of time. The research object is a technological process for the preparation of ammonium sulphate for shipping. The research aims at offering optimization possibilities for the ammonium sulphate preparation process in the case of activities of Granmax, JSC activity. The main methods of research are chronometric observation and technological operation analysis. The technological situation of activities of Granmax, JSC is analyzed. This company is located close to the stevedoring companies, which carry out most of the fertilizer transshipments in the Port of Klaipeda, in the reserve area, next to the railway infrastructure and the largest container terminal in the Port of Klaipeda. The total time of ammonium sulphate preparation can be shortened by ensuring the quality of raw materials, purchasing an additional bucket loader, using a wider elevator and automatic equipment for tying up bulk bags.

KEY WORDS: ammonium sulphate, fertilizer, preparation, granulation, packaging, transportation

1. Introduction

The research object is a technological process for the preparation of ammonium sulphate for shipping. The technological situation of activities of Granmax, JSC is analyzed as a case of this study. This company is located close to the stevedoring companies, which carry out most of the fertilizer transshipments in the Port of Klaipeda, in the reserve area of the Port of Klaipeda, next to the railway infrastructure and the largest container terminal in the Port of Klaipeda. The main company’s activity is the production of granulated fertilizer (ammonium sulphate). The company has more than 40 employees and an annual production of 250,000 tons of granulated fertilizer [14].

The process for the preparation of the fertilizer includes the supply and granulation of raw materials, packaging of raw materials into bulk bags (500 kg) and their transportation to the place of loading for shipment. Technological problems regarding the fertilizer preparation process are investigated worldwide [1-11]. The main problem with this process is the consumption of time. Therefore, the research aims at offering optimization possibilities for the ammonium sulphate preparation process in the case of activities of Granmax, JSC activity. The main methods of research are chronometric observation and technological operation analysis. The research was conducted on 18-22 March 2019. This article presents an overview of the study results.

2. Ammonium Sulphate Preparation Process and its Optimization

The ammonium sulphate preparation process and its optimization is analyzed on the basis of chronometric observation of operations, raw materials and their shortage, granules packaging and storage operations.

2.1. Chronometric Observation of Operations

The technological process for the preparation of ammonium sulphate for shipping is analyzed. The start and end time of operations is observed. The technological process for the preparation of ammonium sulphate consists of the following operations: raw materials are transported to the factory, poured into a pit, put on the production line and granulated; the granules are poured into the packaging machine; bulk bags are attached and inflated; the granules are weighed and poured out; the bulk bags are brought to the ramp, tied up and transported to the place of loading for shipment. Ammonium sulphate bulk bags (Fig. 1) and their loading for shipment (Fig. 2) is shown.

Fig. 1 Ammonium sulphate bulk bags [13]  Fig. 2 Loading of bulk bags for shipment [12]
In other words, raw materials for fertilizer are delivered by semi-wagons or by ships to the territory of the factory. Then, raw materials are taken to a 3-metre deep pit. The raw materials for fertilizer are lifted from the pit and distributed on the production line. The fertilizer is granulated. The granules are poured into the packaging machine where they are packed into 500 kg bulk bags. A bulk bag is placed in the discharge chute. 500 kg of granules falls into the bulk bag. The truck operator takes the bulk bag to the ramp where an employee ties it up. Depending on the situation, bulk bags are transported to the place of loading for shipment or to the warehouse.

The technological process for the preparation of ammonium sulphate for shipping is assessed by applying the method of chronometric observation of operations. The 30-ton fertilizer granulation process is observed, and the technological activities of one shift in granulating 360 tons of fertilizer are evaluated. Time data is presented in Table 1.

<table>
<thead>
<tr>
<th>Event</th>
<th>Operations</th>
<th>18 03 2019</th>
<th>19 03 2019</th>
<th>20 03 2019</th>
<th>21 03 2019</th>
<th>22 03 2019</th>
<th>Average duration (min)</th>
<th>Average duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Supply of raw materials</td>
<td>11</td>
<td>13</td>
<td>12</td>
<td>14</td>
<td>10</td>
<td>30 t of fertilizer</td>
<td>360 t of fertilizer</td>
</tr>
<tr>
<td>2</td>
<td>Transportation of raw materials and pouring them into a pit</td>
<td>20</td>
<td>16</td>
<td>14</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>192</td>
</tr>
<tr>
<td>3</td>
<td>Transportation of raw materials on the production line</td>
<td>30</td>
<td>35</td>
<td>26</td>
<td>34</td>
<td>35</td>
<td>32</td>
<td>384</td>
</tr>
<tr>
<td>4</td>
<td>Granulation of raw materials and pouring them into the packaging machine</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The time of supply of raw materials is not evaluated because it depends on the suppliers of the raw materials. It was found that 30 tons of ammonium sulphate fertilizer is granulated in 60 min. 360 tons of fertilizer is granulated during the shift (12 h). Granmax, JSC is able to granulate 450 tons taking into account the set capacity. This difference depends on the long duration of the operations performed. In order to granulate 450 tons of fertilizer, 37.5 tons of raw materials must be granulated per hour. 30 tons should be granulated in 48 min.

The duration of granulated fertilizer packaging operations is given in Table 2.

<table>
<thead>
<tr>
<th>Event</th>
<th>Operations</th>
<th>18 03 2019</th>
<th>19 03 2019</th>
<th>20 03 2019</th>
<th>21 03 2019</th>
<th>22 03 2019</th>
<th>Average duration (s)</th>
<th>Average duration (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Attachment of the bulk bag</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>7,200</td>
</tr>
<tr>
<td>2</td>
<td>Inflation of the bulk bag</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>720</td>
</tr>
<tr>
<td>3</td>
<td>Weighing of granules</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>5,760</td>
</tr>
<tr>
<td>4</td>
<td>Pouring of granules</td>
<td>6</td>
<td>9</td>
<td>7</td>
<td>8</td>
<td>5</td>
<td>7</td>
<td>5,040</td>
</tr>
<tr>
<td>5</td>
<td>Transportation of the bulk bag to the ramp</td>
<td>7</td>
<td>10</td>
<td>8</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>6,480</td>
</tr>
<tr>
<td>6</td>
<td>Tying up of the bulk bag</td>
<td>30</td>
<td>33</td>
<td>21</td>
<td>24</td>
<td>17</td>
<td>25</td>
<td>18,000</td>
</tr>
</tbody>
</table>

Total duration: 60 43,200
360 tons of fertilizer are granulated daily. 720 bulk bags are packed. One bulk bag is packaged and tied up in 60 s. 720 bulk bags are packaged and tied up in 43,200 s (12 h or 720 min). In order to produce 900 bulk bags in 12 h, 720 bulk bags should be packaged and tied up in 34,560 s (9.6 h or 576 min). One bulk bag should be prepared in 48 s.

If the duration of granulation and packing is reduced, this would result in 90 tons more of fertilizer during the shift and 5,580 tons more of fertilizer per month. 66,960 tons more of fertilizer would be granulated and produced for shipping per year. It is possible to reduce the duration of transportation of raw materials, pouring them into the pit, bringing them on the production line, packing them and tying up bulk bags. This can be done by analyzing separate operations and optimizing them, for example, the average duration of supply of raw materials to the territory, their transportation and pouring into the pit is 12 min. This duration can be shortened by delivering raw materials to the factory near the pit. As a result, the duration of transportation would be reduced.

When raw materials are delivered by semi-wagons, they are transported to the factory with a bucket loader. Thus, one of the solutions is to purchase an additional bucket loader in order to take the raw materials alternately and transport them to the pit. In this case, the transportation of raw materials would be reduced twice up to 6 min. An additional bucket loader could produce 5,580 tons more of granulated fertilizer per month.

Raw materials are brought on the production line on average in 16 min. Raw materials are lifted from the pit and onto the production line using an elevator. This duration could be shortened by using an elevator with a wider band, which would increase the amount of the raw materials lifted during the same time period. In this case, the duration of bringing 30 tons of raw materials on the production line could be shortened by approximately from 16 to 10 min.

Granulation of ammonium sulphate and pouring of the granules into the packaging machine depends mostly on the quality of raw materials. If raw materials have a high content of moisture, granulation takes longer than usual. In such a case, an additional granulation cycle is required. Granulation of raw materials takes 30, 35, 26, 34 and 35 min. If only the capacity of the production line is estimated, 30 tons of raw materials can be granulated in 26 min. Thus, a longer or shorter duration depends on the quality of raw materials.

One bulk bag is packaged and tied up in 60 s. It is possible to shorten this duration up to 48 s in order to pack 900 bulk bags per shift. The tying up of a bulk bag takes the longest compared with such operations as attachment and inflation of the bulk bag, weighing and pouring of granules, transportation of the bulk bag to the ramp and tying it up. The last operation takes on average 25 s. This duration can be shortened optimally by using automatic equipment for tying up bulk bags instead of tying up them by hand, as it is done now.

### 2.2. Raw Materials and Their Shortage

The first stage of the granules producing process is the supply of raw materials. This stage was chosen to be discussed in more detail in this section of the article as it was more convenient in terms of its content. The supply of raw materials is related to the determination of the required quantity, delivery, and achievement of proper storage conditions. The stocks of raw materials are very important in the production chain because they increase demand, which can be satisfied with the products that are produced in advance. Increase in the level of the stocks leads to lower costs of production and transportation because of a scale effect.

There are cases when suppliers are late in delivering raw materials. Sometimes they deliver less raw materials than expected. This leads to stoppage of the factory activities. Each case of stoppage and launch of the factory activities means extra costs. The factory administration makes efforts to avoid stopping the factory activities if there is no special need. Shortage of raw materials leads not only to a forced shutdown of the factory but also to a shortage of finished products. Usually raw materials are delivered in semi-wagons, properly isolated, dry and of high quality. However, there are cases when raw materials are not properly packaged. As a result, they become moist, and the production process suffers damage. Such raw materials can still be used but their processing requires more time. Furthermore, raw materials can be of poor quality, and such materials are difficult to be processed. Poor quality raw materials are often characterized by a high level of dustiness, which makes it difficult to granulate them.

Raw materials are brought to the territory of the factory by the suppliers’ means of transport. However, they are transported further to the production site by the company’s means of transport, i.e. a front loader. The method of transport has an effect on the solutions related to the location of the infrastructure and the levels of stocks. It is necessary to ensure the quality of raw materials and their fast and cost-effective transportation when they are brought to the territory of the factory. Sometimes undesirable impurities, for example, metal cuttings, mix with raw materials during their transportation using a front loader. If the metal cuttings enter the production line, the equipment is damaged, and it might be necessary to stop the factory activities. It is important to choose high quality ammonium sulphate raw materials for the production process because it is easier to compress them and they are less dusty. As a result, equipment is covered in less dust, and the amount of the fertilizer produced daily is increased because of a lower likelihood that production would have to be stopped due to mechanical problems of the equipment. It is also necessary to avoid wet and viscous raw materials. In addition, appropriate conditions of transportation and storage at the territory of the factory have to be ensured. As it was mentioned, it is recommended to order more raw materials because this allows for better delivery conditions. When a larger quantity of raw materials is ordered, the company always has the necessary stocks taking into account the fact that ammonium sulphate fertilizer does not have an expiration date.

It would be meaningful to purchase a larger quantity of raw materials when market conditions are favorable. The warehouses almost always have some free space. A larger quantity of the produced fertilizer stored in the designated areas in the company would always be at hand.
2.3. Granules Packing and Storage Operations

The logistics situation of the company as well as its organization has an impact on the results of its activities. Therefore, it is important to consider each step. The study revealed that the area related to the transportation and warehousing of bulk bags (500 kg) packed with ammonium sulphate granules needs to be improved within the company. The packaged bulk bags are transported using a forklift with a 3.5-ton lifting capacity and warehoused in the company’s territory or brought to the place of loading for shipment. As it was mentioned, there is almost always some free space left in the company’s warehouse. The warehouse space is not used efficiently. Although there is a warehouse for packaged bulk bags in the territory of the company, all orders are executed after their receipt. If more raw materials were ordered, more products could be packaged, and the warehouse space would be used more efficiently. The production would be ready for future demand, and a new order could be executed immediately.

The analysis of packaging and warehousing operations revealed that more effective operation could be achieved if bulk bags were carried using a more powerful forklift truck. As it was mentioned, the company currently uses a forklift with a 3.5-ton lifting capacity when performing outdoor storage operations. The forklift truck can carry 4 bulk bags of 500 kg at one time. It would be meaningful to replace the forklift truck with a more powerful one that could carry up to 6 bulk bags at the same time. These changes could save time when bulk bags are transported or loaded on truck-trailers.

3. Conclusions

Since the main issue with the process for the preparation of ammonium sulphate for shipping is the consumption of time, the article presents time optimization possibilities in terms of the process for the preparation of ammonium sulphate in the case of activities of Granmax, JSC. The total time of ammonium sulphate preparation can be shortened by ensuring the quality of raw materials, purchasing an additional bucket loader, using a wider elevator and automatic equipment for tying up bulk bags, i.e. an additional bucket loader and an elevator which is twice as wide as the one used currently would possibly help to shorten the time of preparation of raw materials by 12 min. During the shift, 450 tons of granulated ammonium sulphate fertilizer could be produced instead of 360 tons as it is now. The duration of packaging and tying-up operations can be shortened by using automatic equipment in order to pack up to 900 bulk bags per shift. If a larger quantity of raw materials was ordered, more products could be packaged, and the area of the warehouse could be used more effectively. It is important to replace a forklift with a more powerful one, which could carry up to 6 bulk bags at the same time. These changes would improve the process for the preparation of ammonium sulphate for shipping in terms of the time consumed and increase the quantity of granulated and packaged ammonium sulphate fertilizer produced per year by 66,960 tons.

References

Perspectives and Challenges for Development of Intermodal Transport in Poland

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Abstract

The development of intermodal transport is the greatest opportunity to improve the situation of railway transport in Poland. This is evidenced by the volume of intermodal transport carried out in other countries of the European Union. However, the dynamic development of intermodal transport is conditioned by the necessary actions that need to be taken in order to create competitive conditions for the Polish railway sector in relation to other modes of transport. The paper discusses the issues constituting barriers to the development of the intermodal railway transport. The proposed changes indicate the savings that will be achieved through the pursuit of sustainable development of transport. The removal of barriers indicated by authors will result in developing of the railway transport as an environmentally friendly alternative to other modes of transport, e.g. by reducing exhaust emissions as well as by reducing the energy consumption of transport and therefore environmental pollution.

KEY WORDS: intermodal transport, railway sector development, transport chains, intermodal services

1. Introduction

The main objective of the European Union's transport policy is to strive for sustainable development of transport [2, 14, 15]. The tasks of this policy include, among others: limiting the transport of goods by road and encouraging to move them from road to more environment friendly modes as railway transport [10]. The need to develop railway transport, optimise the use of railway infrastructure and integrate various transport modes, including the promotion of intermodal transport, is also pointed out in this policy [7]. Despite the fact that the market in Poland is still based on mass transport, a systematic downward trend is observed. This is a great opportunity for the development of intermodal railway transport, by taking over a significant part of goods from other branches of transport. The aim of the paper is to present the determinants for the intermodal transport development, including the challenges faced by railway transport.

2. Analysis of Railway Intermodal Transport in Poland

Intermodal transport is a prospective segment of transport in Poland [1]. According to data published by the Office of Rail Transport, the weight of cargo in intermodal transport in 2018 increased by 2.3 million tons compared to the previous year. In 2018, 17 million tonnes of intermodal cargo were transported by rail, i.e. that is almost 16% more than in 2017 (Fig. 1).

Fig. 1 Total gross weight of goods in intermodal transport in Poland (in million tons) [own study based on 5]
This should be considered as a very good result, because the total weight of goods transported by rail in 2018 increased only by 4%.

The total transport performance amounted to 6.2 billion tonne-km and increased by about 0.7 billion tonne-km, i.e. by almost 16% compared to the previous year (Fig. 2).

![Fig. 2 Transport performance in intermodal transport (in billion tonne-km) [own study based on 5]](image)

The number of transport units also increased significantly, respectively: Intermodal Transport Units (ITU) by 178 thousand units (increase by ca. 15%) to 1,259 thousand units and Twenty-foot Equivalent Units (TEU) by 226 thousand units (increase by ca. 14%) to 1,893.5 thousand units (Figs. 3 and 4). In the structure of transported units in 2018, as in the previous years, the major part (95%) of all transported units were 20- and 40-foot containers.

![Fig. 3 Number of Intermodal Transport Units (in thousands of units) [own elaboration based on 5]](image)

![Fig. 4 Number of Twenty-foot Equivalent Unit (in thousands of TEU) [own elaboration based on 5]](image)

The development of intermodal transport is also confirmed by the increase in number of operators providing such services. In 2016, 13 companies were involved in intermodal transport, while a year later it was 18 and in 2018 it
was 25 companies. In Poland in 2018 intermodal transport on the largest scale in terms of gross weight of transported goods and transport performance was made by the PKP Cargo (46.46% and 52.27% market share respectively) (Figs. 5 and 6).

Fig. 5 The share of operators in intermodal transport in Poland according to gross weight of transported goods [own work based on 5]

Fig. 6 The share of operators in intermodal transport in Poland according to transport performance [own work based on 5]

In addition to PKP Cargo, in 2018 the following companies had a significant market position (in terms of intermodal transport volumes): Captrain Poland, PCC Intermodal and DB Cargo Poland. Their market share, taking into account the gross weight of transported goods, was respectively 13.73%, 10% and 7.54%. In terms of transport performance, the share of these companies was respectively 12.52%, 8.03% and 10.18%. Despite the dominant position of PKP Cargo, the intermodal transport market is open and offers great development opportunities. This fact is confirmed by the growing position of Captrain Poland, which at the end of 2018 achieved an increase in the market share of 5.01% in the gross weight of transported goods and 5.26% in the transport performance, respectively, as compared to 2017.

3. Conditions for the Development Of Rail Intermodal Transport

The rail cargo market in Poland is the second largest market in the EU, and the share of rail in the overall transport performance in Poland is quite high in comparison to other European countries. In 2018, the largest increase in transit transport occurred on the route Terespol (Terespol-Brest border crossing) to Kunowice (Kunowice-Frankfurt border crossing). In comparison to 2017, the number of connections in this relation more than doubled to 360 routes launched monthly on average. There is also growing importance in international transit of seaports in Gdansk and Gdynia. In 2018, more than 2.7 million TEU were transhipped in these ports, compared to 2.3 million TEU in 2017. The development of intermodal transport, among others, is an opportunity to increase the market share of railways.

The goal of intermodal transport is to optimally link the various modes of transport in the transport chain in accordance with their predispositions and to fast, cheap and reliable deliveries in accordance with customer expectations and in accordance with the principles of sustainable development [6, 11-13].

Moving transports from roads to rail has a number of advantages [8]:
- mandatory charges for lorries on certain routes can be avoided;
traffic bans on certain days of the week or at certain times of the day can be avoided;  
the driver can spend the obligatory rest time in the sleeping car;  
on long transport distances, time savings are achieved and the wear and tear on the fleet is lower.

The increase in the share of rail in the market is also supported by: high transport potential, speed of rail transport in relation to other modes of transport, lower energy consumption, including the possibility of using electricity, relatively low environmental pollution and greater safety in relation to other transport modes [3, 4]. The above conditions in the development of the European transport system point to the need for better use the potential of rail transport. Despite the above mentioned advantages of rail transport in relation to other modes of transport, so far the chances of railways have not been fully used yet [9]. This is due to a number of barriers which are a threat to the development of intermodal transport market (Table).

<table>
<thead>
<tr>
<th>The barrier</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of legal regulations enabling the moving of certain controls, e.g. veterinary ones, to terminals located within the country.</td>
<td>Aggregation of multiple checks into 'one place' or their execution at 'one time', which will reduce the queue of trains at the border.</td>
</tr>
<tr>
<td>Poor condition of the railway infrastructure manifested by too long transport time and affecting the low commercial speed.</td>
<td>First of all, the removal of “bottlenecks”.</td>
</tr>
<tr>
<td>Poor organisation of track closures causing delays in delivery of shipments.</td>
<td>Closer cooperation between the infrastructure managers and railway operators in the field of maintenance and modernization of the railway network.</td>
</tr>
<tr>
<td>Uneven distribution of terminals on the railway network, including significant deficiencies on the Eastern Polish border.</td>
<td>Consultation and analysis of the need for terminals.</td>
</tr>
<tr>
<td>The lack of systems to online track shipments.</td>
<td>Implementation of ICT systems for shipments tracking.</td>
</tr>
<tr>
<td>Insufficient number of transhipment facilities, including limited length and number of tracks located in terminals.</td>
<td>Adjustment number of transhipment facilities to market demand.</td>
</tr>
<tr>
<td>High track access charges, complicated procedures for obtaining a discount for intermodal transport.</td>
<td>The long-term commercial policy based on discounts encouraging the increase number of network operations.</td>
</tr>
<tr>
<td>Lack of instruments to promote intermodal transport.</td>
<td>Large-scale actions to raise awareness of the benefits of intermodal transport.</td>
</tr>
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<td>High costs of terminal and container investments.</td>
<td>Tax relief, low-interest loans.</td>
</tr>
<tr>
<td>The lack of clear and consistent rules regulating the separateness of the intermodal industry, taking into account its specificities.</td>
<td>Codification of the rules in a way that enable uniform interpretation by the all involved authorities.</td>
</tr>
<tr>
<td>Lack of regulation to allow healthy, cross-industry market competition.</td>
<td>Sustainable transport policy.</td>
</tr>
<tr>
<td>Lack of conditions enabling long-term investments.</td>
<td>State and European Union aid.</td>
</tr>
<tr>
<td>Uneven financing of different modes of transport.</td>
<td>State financial policy based on the models of the most developed EU countries (in intermodal transport), co-financing taking into account the external transport costs.</td>
</tr>
</tbody>
</table>

The solution to these problems should be closely linked to the provision of adequate financial support from the state and the introduction of comprehensive actions to promote the intermodal transport sector. Only the governmental commitment can ensure the development of this segment and the delivery of measurable benefits.

4. Conclusions

The development of intermodal transport is one of the priorities of the European Union, influencing sustainable solutions in economic development, with a simultaneous increase in the share of alternative transport to road transport. Intermodal transport, in accordance with the policy of the European Union, is also part of a green transport mode. Poland, due to its geographical location, has a large untapped potential in the intermodal transport sector. Although the
data for this segment of the market indicate its continuous development, it is important to implement a strategic programme to increase the importance of this mode of transport. Investment in infrastructure modernisation, the upgrading and construction of new transhipment terminals and the establishment of regional logistics centres in the vicinity of large urban agglomerations are also important to support the development of intermodal transport. The share of transport in the standard containers by different modes of transport should be also increased, with the growing role of rail transport. A well-functioning railway service involving the transfer of the significant part of transported goods from road to rail should also be considered in terms of reducing external costs for the state budget. Reducing road congestion would undoubtedly lead to a reduction in the number of accidents and what is associated decrease the potential compensatory claims to injured people or victims. The implementation of this goal will require the development of railway infrastructure. Therefore, it is extremely important that the result of modernization is not only to increase the speed, but also to significantly improve the capacity. The need to build new railway lines that would enable the development of intermodal rail transport in Poland should be also considered.

References
Risk Response in the Logistics Projects in the Czech Republic

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Abstract

The paper aims to identify the possibilities of risk response in logistics projects. The research was carried out in two stages in the Czech Republic. The first stage took place from January to March 2019, and the second stage took place in April 2019. The questionnaire survey was done to collect data. The paper identifies the ways that are preferred of companies in the Czech Republic to deal with the risks involved in logistics projects. Furthermore, the financial amounts that companies are willing to release to address these risks are discussed. At the end of the paper, recommendations are made on how companies in the Czech Republic should address current and future risks.

KEY WORDS: risk, risk management, logistics, logistics projects

1. Introduction

A typical logistics project consists of many diverse articles, ranging from material suppliers, through manufacturers, distributors, wholesalers to retailers. It is quite natural that in most cases the logistics project only works properly when all project stakeholders are working properly. In other words, if a project article fails, the logistics project will easily collapse and fail to achieve its goals [1]. The more interested parties are involved in the logistics project, the more likely the project is to fail. A well-managed logistics project can provide the organization with a sustainable competitive advantage. Efficient logistics management helps increase customer satisfaction while maintaining delivery quality and reducing costs [2, 3].

The logistics project can be characterized by many features, but one of the important characteristics of the logistics project is its high level of risk. Logistics projects involve a degree of uncertainty too. This uncertainty is different for each project and depends on the type of project, its scope, the behavior of the stakeholders, but also at what stage the project is located. In the first phase, when project implementation is planned, uncertainty is high, but uncertainty is reduced to zero in the final phase of the project [4, 5]. However, we find risks at all stages of the project life cycle. The project team should continually monitor the development of the project, evaluate possible situations and monitor possible adverse effects that could cause the project to be threatened and thus increase the likelihood of the project being unsuccessful [6].

Therefore, project risk management is explained as a proactive approach, working consciously with uncertainties so that uncertainties with negative consequences are recognized and treated in a timely manner [7].

While most organizations only manage risks to a certain level, International Standard ISO 31000 sets out a number of principles that need to be met in order for risk management to be effective. This International Standard encourages organizations to develop, implement and continually improve a framework to integrate the risk management process into their overall leadership, strategy, and planning, management, reporting, policy, value and culture processes [8]. Risk management is a continuous process taking place at all stages of the project life cycle, ie. from the initial idea to the end [6]. Risks in logistics projects are first identified, then analyzed and subsequently evaluated. The purpose of risk evaluation is to decide which risks will be treated, which will be neglected and which cannot be accepted. Following is the phase of treated, when you need to choose a strategy to respond to a possible risk. The aim of risk management is to reduce the value of risk to such a level that the project is successfully implemented and completed [6]. This part, from the entire risk management process, covers the full spectrum of methods, techniques, approaches, and tools, whether at the operational or tactical level [9].

There are five ways to manage risks: reduce risk, avoid risk, transfer risk, share the risk, maintain risk [6, 10].

• Reduce risk - This means either reducing the likelihood of risk or reducing the impact of a risk. It is more likely it will be to reduce the likelihood of a risk.
• Avoid Risk - This is a drastic way to manage risks. Choosing this risk treatment option changes the entire project plan to avoid a specific risk. However, with the change in the plan, other risks arise.
• Transfer risk - This option does not eliminate the risk, it merely moves on to the other subject. Outsourcing or insurance contracts is a very common approach. However, not every risk can be covered by insurance contracts. This type of treatment is used for risks with low probability but high impact.
• Share risk - The strategy is based on risk-sharing by multiple entities. This approach is frequent for logistics.
• Accept the risk - The company decides for this option if the probability of occurrence of the risk is very low.
and its impact is very low too. In this case, you need to have a contingency plan that provides guidance on what to do to activate the risk. If the company did not have this plan and acted under the pressure of the situation, all decisions could be bad and potentially dangerous and costly [10].

The paper aims to identify the possibilities of risk response in logistics projects.

2. Research design and Methodology

A questionnaire survey was made with representatives of Czech companies for the purposes of this article. Companies were selected deliberately from the transport and storage sectors. The aim of the research was to find out how companies from transport and storage sectors approach risk management. The questionnaire was sent electronically, specifically by email. The number of questionnaires sent was 238 and the number of questionnaires processed was 54. The return rate was less than 22.7%. The questionnaire was divided into three blocks. The first block is focused on the employee himself, who was asked about the job position and the time he works in the company. The second block of questions was directed at the company. For enterprises, it was monitored whether it was a micro enterprise, a small enterprise, a medium-sized enterprise and a large enterprise, based on the number of employees. Furthermore, according to the scope of the company, enterprises were categorized as a regional enterprise, a national enterprise or a multinational enterprise. The last block of questions focused on the company's risk management process. It was examined what specific risks appear in companies in the transport and storage sector and what treatment they prefer most. The last question asked how much cost the companies are willing to release to eliminate emerging or future risks.

3. Results

A questionnaire survey was conducted to collect data. The survey was carried out on the territory of the Czech Republic and comprised the companies in the transport and storage sector. Of the companies surveyed, regional and multinational companies accounted for 37.04%. Companies in the category of national enterprises accounted for 25.93%. The following figure shows the risk groups and their percentages in businesses (Fig. 1).

![Figure 1 Risk areas in the enterprises](image)

The risk factor associated with the human factor has the highest percentage. These risks result from the level of experience and competence of the individual in the business. The second, very risky group are the economic risks. There are mainly cost risks that are caused by price increases. The risks from these two areas occur in most of the companies surveyed. Other risk areas affecting enterprises in the sector of the transport and storage are market risks, legislative risks, and financial risks. However, these risk groups do not occur either in half of the companies surveyed. A technical-technological risk can be considered a negligible group of risks, which occurs only in 3.7% of enterprises.
and results from the application of scientific and technological development. Another question was about the financial amount that companies are willing to release to eliminate risks per year.

![Fig. 2 Amount spent to eliminate risks per year](image)

It is clear from the picture that Czech companies operating in the transport and storage sector spend the most amount of CZK 10,000 - CZK 50,000 to reduce the risks associated with their business (Fig. 2). The following Table 1 depicts specific companies broken down by their scope and the amount of the cost they release to eliminate risks.

<table>
<thead>
<tr>
<th></th>
<th>Up to 10,000 CZK</th>
<th>10,000 CZK – 50,000 CZK</th>
<th>50,000 CZK – 100,000 CZK</th>
<th>100,000 CZK and more</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regional enterprise</strong></td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>National enterprise</strong></td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Multinational enterprise</strong></td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

It is clear from the table that companies that are only regional or national are capable of releasing less money to deal with risks and only a smaller number of companies of the same size are spending more of money. However, in the case of multinational companies, the amounts used to eliminate risks are relatively balanced, we find companies that spend large amounts of money, but also companies which spend only CZK 50,000 to eliminate risks.

The last question from the questionnaire survey was, what kind of treatment, companies prefer. There are five options: accept the risk, reduce risk, avoid risk, transfer risk and share risk.

![Fig. 3 Kind of treatment](image)
The most preferred way to treat risk is to reduce it. 72.22% of Czech companies prefer this type of treatment. The second most common way to treat risk is to avoid it. As already mentioned, this is a very drastic way, which is preferred by more than half of the Czech companies from the sector of transport and storage. The least popular option with the smallest percentage of how the risks are treated is sharing. Although according to literature this method of treatment is most used by logistics companies, Czech companies do not use this type of treatment much.

4. Conclusion

Data was collected from companies operating in the transport and storage sectors. The range of these companies ranges from regional to national to supranational. The questionnaire survey showed that the riskiest group are the risks associated with people and with their level of experience and competence. The second most risky group are economic risks. A negligible part of the risks is created by risks arising from scientific and technological development. Another question asked in the questionnaire survey was concerned with the financial amounts spent on risk reduction. Czech companies the most often spend from CZK 10,000 to CZK 50,000 for the treatment risks. This amount is popular with both SMEs and large businesses too. However, smaller companies are generally willing to release smaller amounts of money, while larger companies invest both small amounts and large amounts to eliminate risks. The risk reduction method is the most preferred method for Czech businesses from all methods. The least popular method is the method of share risk, where risk is shared between more subjects.

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References

The Study of Safety Factor Against Derailment of Vehicles on the Track Switch

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Abstract

The track switch is the most difficult part of the railway track, a section of increased danger of movement of rail vehicles. The wheeling of the wheel-flange on the rail is one of the factors of increased danger when rolling stock moves along the side track of the switch. The conditions under which combination is real derailment of the rolling stock are analyzed. These conditions are as follows: type of movement (e.g., facing movement); track switch settings; dangerous form of the wheel flange, when the wheel flange has a large undercut (thin flange), that is, when its inner edge is almost vertical. In the article, the movement of the wheel set in the switch in the facing movement direction is presented in three phases. Each of the phases is determined by the type of contact of the wheel with the elements of track switch. The first phase is hitting the flange on the point rail, when there is a gap between the tongue and the flange. The second phase – hitting the flange on the tongue. In this phase, the flange has a two-point contact: with the point rail and with the tongue. The third phase - the movement of the wheel-flange on the tongue. Examined track switches with nominal parameters, as well as faults of its elements: point rail, tongue, wing rail. Dependencies of the safety factor against the derailment on the profile parameters of the wheel and the track switch elements are given. The article contains recommendations on the parameters of the wheel flange profile and the elements of the track switch, for safe movement.

KEY WORDS: railway vehicles, derailment, track switch, flange reactions

1. Introduction

Derailing of wheel sets is the most common cause of accidents in rail transport [1]. The mechanism of railway vehicles derailing is a complex process that has been the subject of intense researches worldwide [2-4]. Safety factor against derailment is the main safety criterion of locomotives and cars on the railway. It was first determined by Nadal. Safety factor against derailment is equal to the ratio of the transverse force in contact of the wheel-flange with the rail to the vertical load of the wheel on the rail [5].

The article [6] considers the issue of the influence of the friction coefficient between the wheel-flange and the rail on the resistance to movement of the rail vehicle. It is noted that the friction coefficient greatly depends on different factors such as the state of the wheel and rail surfaces, atmospheric conditions and wheel motion speed. The design solutions for wheels, which reduce the resistance to movement and increase safety factor against derailment of vehicles, are given. The authors of [7] proposed a method of protection against derailment based on ratio of the wheel sets breakdown and ratio of the wheels unloading. Safety of derailment can be evaluated by assessing the margin safety limit.

The dynamic readings for three different types of carriages were compared in the article [8]. The main dynamic indicators of the car were investigated, namely, vertical and horizontal dynamic coefficients and the safety factor against derailment.

In the study [9], the process of derailment of a railway vehicle from rails was considered for low speeds with curved and twisted rails. The flange lifting mechanism was studied to perform quantitative assessment of the factors causing the derailment of rail vehicles.

The study [10] described the mechanism of derailment and the method of continuous control of the force between the wheel and the rail. New criteria for assessing the risk of derailment were offered.

A three-dimensional non-linear dynamic model of a wheel set and suspension system was developed in a study [11]. The effects of friction coefficient and speed of motion on the derailment were investigated. In addition, various ways of lubricating rails and their impact on the derailment danger were studied. The features of the two-point wheel-rail contact were also considered. Recommendations for improving the safety of derailment were given.
The mechanism of derailing for the track switches has its own peculiarities [12]. Cases of wheel sets derailment in track switches known from operation experience are mostly related to their defects.

Defects of the track switches are classified as follows:
- disconnect of switch rail and traction;
- lag of the switch rail from the point rail by more than 4 mm;
- switch rail shelling during which danger of a wheel-flange striking against the switch rail is occurred: 200 mm and more on backbone railway network; 300 mm and more on the receiving and departure track; 400 mm and more on the other rails;
- lowering of the switch rail against the point rail by 2 mm or more;
- breakdown of a switch rail or a point rail.

Diagrams of flange striking against switch rail of track switch in the case of defects in the switch rail are shown in Fig. 1.

The chance of a wheel-flange striking on a switch rail depends both on the angle of inclination of the flange profile and on the parameters characterizing the defects of the switch rail. When determining the allowable parameters of flanges wear, which affect the angle of flange inclination, the tolerances for the parameters of the track switches maintenance shall be taken into account.

![Fig. 1 Diagrams of flange striking against switch rail of track switch in the case of defects in the switch rail: a - gap between point rail and switch rail ($\sigma$); b - vertical deformation of switch rail ($h$); c - separation of switch rail ($s$)](image)

The study is devoted to clarifying the influence of the geometrical parameters of the flange and the track switch elements on the stability factor against derailment of the wheel set.

2. Methods and Course of the Study

Fig. 2 shows a diagram of the wheel facing movement on the track switch. A diagram of the flange reactions in the contacts of the wheel with point-rail and the switch rail is represented in Fig. 3.

Depending on the picture of the flange contact, it is possible to determine three phases of the wheel striking on the switch rail.

The first phase (striking of the wheel-flange on the point rail) exists in the area from point I to point II. At this phase, the wheel-flange is in contact with the point rail at point $K_2$, and there is a gap $\tau_1$ between a switch rail and a flange, which decreases during approaching to the point II. At the same time, the vertical and horizontal components of a normal flange reaction depend on the contact angle $\mu$ as per following ratios:

$$
P_2 = N_2 \cdot \sin \mu
$$
$$
H_2 = N_2 \cdot \cos \mu
$$

where angle of contact is $\mu = 90 - \gamma_2$.

The second phase (striking of the wheel-flange against the switch rail) continues from the point II to points III. In this phase, the wheel-flange is in contact with the point rail at point $K_2$ and there is a gap $\tau_1$ between a switch rail and a flange, which changes during approaching to the point II. At the same time, the vertical and horizontal components of a normal flange reaction depend on the contact angle $\mu$ as per following ratios:

$$
N_2 = \tilde{N}_2 + \tilde{N}_3
$$

and is determined by the following formula:

$$
N_2 = \sqrt{N_2^2 + N_3^2 + 2 \cdot N_2 \cdot \sin (\gamma_2 + \eta)}
$$

Contact angle $\mu$ can be described by the formula below:
\[
\mu = \arctg \frac{N_2 \cdot \sin \eta + N_3 \cdot \cos \gamma_2}{N_2 \cdot \cos \eta + N_3 \cdot \sin \gamma_2}.
\] (4)

The third phase is the movement of the wheel along switch rail after point III. At this phase, a gap \( \tau_2 \) occurs between the point rail and the flange and guiding force is transferred to the flange through the point \( K_3 \).

Components of the normal load at the point \( K_3 \) are as follows:

\[
P_3 = N_3 \cdot \sin \gamma \\
H_3 = N_3 \cdot \cos \gamma
\] (5)

Fig. 4 shows a diagram of the flange-switch rail contact on the third phase of the contact. Safety factor against wheel derailment depends on the angle of inclination of the profile \( \gamma_3 \) at point \( K_3 \). Angle \( \gamma_3 \) is called safety angle. Angle \( \gamma_3 \) is determined by location of point \( K_3 \) on the flange profile. Location of point \( K_3 \) depends on three main parameters of profile:
- parameter of flange slope \( qR \);
- radius of flange top \( r \);
- gap between point rail and switch rail \( \sigma \);
- lowering of switch rail top relatively to point rail \( h \);
- angle of inclination of switch rail \( \alpha \).
The objectives of the study are as follows:
1) to determine the effect of the parameters \( \sigma, h, \eta, r \) and \( qR \) on the safety factor against derailment of the wheel set;
2) to determine the minimum allowable value of the flange slope parameter \( qR_{min} \) based on the meeting of the safety conditions for the derailment of wheel set.

3. The Study of the Influence of the Parameters of the Wheel-Flange and of the Track Switch on the Safety Factor Against Derailment

In the study, it is assumed that the slope parameter \( qR \) has the least allowable value \( qR_{min} \) at maximum flange worn sharp. In this case, flange angle of inclination is equal to \( \beta = 90^\circ \).

Fig. 5 shows the chart for determining the minimum value of the slope parameter \( qR_{min} \).

As per Fig. 5 minimum value of flange slope parameter \( qR_{min} \) and current value \( qR \) are determined with the help of the following formulas:

\[
qR_{min} = r - 2\sqrt{r - 1}; \tag{6}
\]

\[
qR = AA' + r - 2\sqrt{r - 1}, \tag{7}
\]

where \( AA' = (h_f + \delta - 13) \tan \beta \) and

\[
qR = (h_f + \delta - r - 13) \tan \beta + r - 2\sqrt{r - 1}. \tag{8}
\]

Based on the contact scheme (Figs. 4, 5), it is possible to determine the dependence of the contact angle \( \gamma_s \) in flange contact on the parameters of the track switch by using following ratios:

\[
\gamma_s = \varphi - \varepsilon; \tag{9}
\]

\[
\varphi = \arcsin \frac{h}{\sqrt{h^2 + (K_s \zeta)^2}}; \tag{10}
\]
As a result, dependence of contact angle (\( \gamma_3 \)) on profile radius when flange top (\( r \)) and parameters of track switch (\( \alpha, \sigma, h \)) is as follows:

\[
\gamma_3 = \arcsin \frac{h \cdot \cos \alpha}{\sqrt{h^2 + \sigma^2 - 2 \cdot h \cdot \sigma \cdot \sin \alpha}} - \arcsin \frac{\sqrt{h^2 + \sigma^2 - 2 \cdot h \cdot \sigma \cdot \sin \alpha}}{2 \cdot r \cdot \cos \alpha}.
\]

The below indicated condition can be accepted as a criterion for safe passage through a track switch:

\[
\gamma_3 \geq \left[ \gamma_3 \right].
\]

From the formulas (13)-(14), we obtain ratio \( \sigma = \sigma(h, r, \gamma_3) : \)

\[
\sigma = \left( \sqrt{4 \cdot r^2 \cdot \sin^2 (B) - h^2} + h \cdot \tan \alpha \right) \cdot \cos \alpha,
\]

where

\[
B = \arccos \left( \frac{2 \cdot r \cdot \cos \gamma_3 - h}{2 \cdot r} \right) - \gamma_3.
\]

4. Research Results

Ratios (14) and (16) allow us to assess the safety factor against derailment of vehicles on the track switch depending on the parameters of the track switch and the shape of the flange. Fig. 6 shows the dependences of the safety angle (angle of inclination of the flange profile at the point of contact with the switch rail) on the gap between the switch rail and the point rail for different values of the radius of the flange top: \( h = 0, 5, 10, 15 \) mm.

![Fig. 6 Dependences of the angle of inclination of the flange profile at the point of contact with the switch rail on the gap between the switch rail and the point rail and lowering of the switch rail top with respect to the point rail when different values of flange top radius: a \( r = 15 \) mm; b \( r = 20 \) mm](image)

The tangential inclination angle at the point of flange and switch rail contact to the horizon is proposed to use as safety factor against derailment of vehicles on the track switch. Fig. 6 represents Danger Zone and Safe Zone. The dangerous
contacts of the gap between switch rail and the point rail and the lowering of the switch rail top with respect to the point rail and the radii of the flange top were determined.

Fig. 7 shows the results of calculating the dangerous ratios of the flange and track switch parameters. Danger and Safe zones are defined for different values of the flange top radius.

![Fig. 7 Dependences of switch rail top lowering on point rail and the gap between switch rail and point rail for safety angles: a - 60 grad; b - 50 grad](image)

5. Conclusions

The mechanism of the locomotive wheel passage through the track switch was clarified. The tangential inclination angle at the point of flange and switch rail contact to the horizon was proposed to use as safety factor against derailment of vehicles on the track switch. The results obtained allow clarifying the dangerous parameters of the track switch and wheel-flange. In particular, it has been concluded that the minimum radius of the flange top shall be limited.

References

The New Applications for Operational Planning and Evaluation of Train Routes with the Support of Information Systems in Slovak Conditions

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Abstract

The article focuses on the operational planning and evaluation traffic management with the support of information systems. The sectoral and specific information systems present the major support for management decisions. Timeliness, accuracy and validity of the information has a significant share in decisions particularly in stochastic process that is transport. In field of Slovak Railways, the Infrastructure Manager has built up a whole range of interconnected information systems, which helps manage and evaluations those decisions. A separate part of this operational information system consists A Shift plan, which is the basic document for the operational management and subsequent evaluation of traffic on the Slovak railways. It is important to note that the information systems decide on a particular real situation. Our paper deals the process for planning, managing and evaluation the railway running with these information systems.

KEY WORDS: the train position, dispatcher apparatus, operational management, operational information systems

1. Introduction

The basic task of information systems in transport companies is to record operational situations operatively. These situations can cause problematic operational situations in the next event sequence. The information systems can support the efficient management of all recorded traffic events and provide information support to transport service providers with their customers.

Management and operation of infrastructure are providing by the Infrastructure Manager (IM). It generally owned by the state. This body is responsible for non-discriminatory access by railway undertakings (RU) providing transport of trains in passenger transport and freight transport. The access of RU to railway infrastructure is a complex process, which defined by precise legal conditions and procedures. In addition, it provides the infrastructure manager space for business and marketing behavior [1].

The RUs as customers purchase from the infrastructure manager the railway infrastructure capacity in the form of train paths. Allocation of railway infrastructure and its assessment presupposes knowledge of technology traffic control, track line technology, and economic implications of these processes. This complex question has closely related to the determination of railway infrastructure capacity, which represents the maximum potential offer of infrastructure manager. The compiled timetable is operating plan and offer to potential customers [2].

The basic precondition in managing the issue is a defined process management of railway infrastructure capacity. It is determining in the particularly procedure for identifying the model railway infrastructure’s capacity [3, 4]. This process depends on the definition of optimal performance permeable elements of railway infrastructure and is an important basis for decision making on investments for its development.

In the conditions of a liberalized transport market, it is necessary to select the information’s according to the new criteria. They result from the different actors in the transport market, whose existence is the result of the transformation process.

When evaluating the tasks of information system is necessary to know the relationships and technological processes in the processes of railway traffic and transport operation, as well as economic relations.

2. The Operational Management of Train Traffic

The basic document for the train’s management is the train traffic graph. However, the train traffic graph is a long-term plan. This plan is changed (by various influences) on a daily, even up to hourly basis according to operational conditions. This includes the calendar restriction of trains, special carrier requests, cancellation or changes of train paths, technical and technological impacts of both the carrier and the infrastructure manager [5]. Significant operational constraints are train delays; reconstruction works on infrastructure, weather impacts, the train paths for special trains, accidents, and other nonspecific operational incidents. The role of traffic management staffs, at all levels, are to bring all these planned and operational constraints into good transport decisions. As a results of their decisions, the trains
should be more safe and as fluently as possible [6]. A prerequisite for this safe and seamless traffic is to receive and provide all relevant information with accurate, timely and understandable information [5].

Before entering, the train on the infrastructure have to be secure activities that relate to the order of the route for the train to the existing rules for the allocation of network capacities. In terms of the Slovak Railways IM (ZSR) establishes so called Shift plan for 12 hours [7]. The Shift plan includes a request train paths for exactly 6 hours and for the next six hours prospectively. Based on this plan of shift is processed subsequently admitting trains on the railway infrastructure according to these routes by the various RU.

Path request must include [3]:
- Identification of the train path;
- Departure station;
- The date and time of departure;
- Destination station.

After confirmation of the route and its subsequent reservation carrier performs operations leading to the assembly and preparation of the train to departure [8]. To ensure the comprehensive preparation of train the sending RU must have access not only to the disclosure of infrastructure constraints, but also to the technical data of the rolling stock and the reference database of goods, in particular with regard to the transport of dangerous substances [5, 6]. After processing and compiling train dispatching carrier must provide information on train composition to IM.

Train report contains [3]:
- Train number and path number;
- Initial station with the date and time of departure;
- Destinations, with expected date and time of arrival at the station;
- Designation of locomotive;
- Length, weight and maximum speed of the train with respect to the technical characteristics of the wagon;
- Train composition with combination of placing and by specifying the beginning and end of the train;
- Application command and control system;
- information on deviations from the agreed specifications of wagons;
- Code UN and labeling of hazardous goods, if such a position in a train wagon;
- Train braking mode and technical specifications used wagons.

![Fig. 1 Activities and information in the relationship between the Railway Undertaking and Infrastructure manager](image)

After entering the train to the rail infrastructure, the IM takes responsible for the train. Throughout the transport route, the IM must inform the RU train running. The RU has the right to ask you to send your location information of the train, information about train location include [3, 4]:
- Current location of the train;
- Train identifiers;
- Plan the train is running on a particular track section;
- Train movement plan for all track sections.
The process of delivering the train may be performed for a whole one RU, or RUs different parts of the route. In taking responsibility for a train between two RUs takes place exchanges of information about [2, 5]:

- The consignments;
- The train.

For the organization of traffic and transport processes, the consignments exchange the following information:
- Notification of the transfer wagon between RU and customers;
- Notification of departure wagon from the departure station;
- Notification of the arrival of the wagon to the train station on the way;
- Notification of departure from the station wagon on the way;
- Notification of the arrival of the wagon to the destination station;
- Notification of delivery wagon to the customer;
- Delivery confirmation of wagon.

2.1. Information Systems in Railway Transport

In the field of railways transport information systems addressing issues concerning the optimal use of means of transport, reducing labor needs, streamlining management work, improve safety and productivity and reduce the cost of transport activity [5, 7].

In terms of management of traffic and transport processes in railway operation it is for managers and proposers need to determine operational requirements for information and communication systems and thus to know the operational processes and information flows [6, 7].

The role of information systems in the transport business is in real-time capture operational situation, support to the efficient management and information providers of transportation services connect with customers [7]. Modern RU are focused on process management, whose purpose is to streamline the company's business processes and customer service support [5, 7].

To increase the level of management is required to analyze and improve their own decision-making processes and modify the organizational structure of the management system. Information system mainly depends on the complexity of the management of the system (i.e. the number and nature of the links and behavior of the elements) and system used with the control (control of the deviations, of targets and so on.) [3, 6]. While demands on the scope, speed and frequency of information depend on the type of process control, level control and management system applied. Generally, these demands at the operational management level. Demands on the level of processing to increase from operational level to the level of strategic management. All these facts underline the close connection of information systems and decision-making processes [9].

The binding rate of information system for managing the process and the related level of versatility is an important consideration in the classification systems. In terms of the bonding strength of the information system management processes, we can talk about two main stages of development:
- Information System;
- Management information system [10].

The information system characterized by the integration of various functional subsystems into one unit. The problem is not with access to the agenda processing tasks [11]. Whilst achieving some degree of information integration processing subsystems, the bond of this process on their own decision-making processes rather loose and subsystem information is relevant enough independence from the control subsystem in the management system.

Management information system already provides a closer connection to the decision-making processes. Generally, entails changes in the organization, methods and quality control work. The management system are widely applied mathematical methods [6]. Such a system has an absolute requirement for application of the principle of data warehousing.

2.2. The Operational Information System

On the side of the IM are the business processes (in terms of operational processes) supported by information systems ensuring supervision of railway routes and traffic management on the railroad. In addition to these two groups it uses them for IS to ensure communication with other infrastructure managers to support decision-making (management information systems) [5, 7].

The IM on Slovak Railways (ZSR) has for its activity created several information systems that support the activities linked to the fulfillment of their main activities as well as ancillary activities.

Basic information systems built to support the "core business" of the Infrastructure Manager is operating information system (PIS). It has based on the proven technology of dynamic motion tracking, status and composition of all kinds of trains on the network of Slovak railways. Its principal task is a strategy encompasses the whole operation of infrastructure and transport of infrastructure with one compact IS [11]. Entering information into the system requires precision and observe the time limit in order to avoid hampering traffic operations [9].

Provides informatics support for process related with [5]:
- planning of train transport;
2.3. The process of Operational Planning with the OIS

Operational management of traffic on the Slovak railways the IM determines the principles of operational management services for all levels of management. It is binding for all employees who are involved in managing the traffic on the Slovak railways and the RU under a contract between the IM and RU [13].

Operational management of traffic on the Slovak railways is a summary of activities of the IM involved in managing, organizing and providing transport on Slovak railways with every RU’s [3, 5]. The planning of train service’s carried out at all levels of operational management. It was provide of shift plans. The proposal of the plan of shift for freight transport is the timetable and requirements RU. Proposals of shift plans submitted for approval to the head changes [4].

Based on an analysis of traffic conditions they are announced targets to ensure optimization in operation. The announced job by own measures are binding on the management by dispatching apparatus of all degrees of operational management and executive offices [10, 14]. It is also binding for all carriers involved in the operation and the management of traffic on the Slovak railways [2, 9].

The planning of train service is carried out at all levels of operational management. It is provided of shift plans. Shift plan is one of the modules around the OIS. Module is first basis for billing of railroad usage [3]. The module also information from an actual Timetable from ZONA IS and from train path requests. Focus module gives detail of running train for next 6 hours [5].

3. The New Methods for Evaluation of Train Routs with Support of Information Systems

At present, the majority of stations dispatchers in operational traffic control have a direct view of rail traffic only within the range of their own controlled stations and adjacent interstation sections.

In the designated scope of operation, the operational control is the responsibility of the operating dispatcher. The traffic dispatcher via the train’s dispatcher information system monitors the train’s traffic. The traffic dispatcher via the train’s dispatcher information system monitors the train’s traffic. His role is to support train management and monitoring [1, 5].
Based on the graphical representation of the current train position and the actual infrastructure constraints (out of operation), it enables full network-wide control of train traffic. The appearance of the VDS user workplace shown in Fig. 3.

![Fig. 3 The appearance of the Train Dispatcher System](image)

A broader view, simultaneously on several operating control points and a few of their interstation sections, is in addition to the dispatching apparatus (with the Train dispatcher system) also the station’s dispatchers who organize on centralized traffic control (with the Graphical-Technological Extension for the station interlocking) [12]. The appearance of GTE is on Fig. 4.

![Fig. 4 The Graphical-Technological Extension appearance](image)

One of the main objectives of the ŽSR Department of Transport is the functionality of the Train Dispatching System, to move to the future multi-license software system, available to all employees involved in all level the management, i.e. the station’s dispatchers. This is the main reason for creating an application called "Track Train Position".

4. The Track Train Position

Track Train Position (TPV) is an application designed for the infrastructure manager to support operative traffic control. The application graphically depicts train rides and realizations of exclusions in the selected track section and traffic points. It provides traffic staff at the station with an overview of the operational situation on selected lines. In the case of extraordinary events and exclusions, it makes it possible to operatively correct traffic decisions and thereby
ensure the continuity of traffic even during lockout or otherwise restrictive activities already at the lowest level of management. The visual of the newly created application shown in Fig. 5.

The user himself creates individual track sections, resp. the routing diagram in any user-friendly way. For technical reasons, the number of traffic points displayed in the graphical sheet is limited to 20 and it is possible to run four graphical sheets simultaneously [13].

Fig. 5 The visual of the Track Train Position [13]

The method of displaying realized as well as planned train routes directly in real time is in principle identical to the displaying as in the Train Dispatching System [13]. The position of the cursor on the affected train path displays the basic train information (Fig. 6) including the engine driver's contact, for traffic control.

Fig. 6 The basic train information’s [13]

From information displayed directly on the GVD sheet, other information, such as [13] is also obvious (Fig. 7):

- The basic type of train, which is represented by the color of the route. Line thicknesses in turn interpret the priorities of individual trains (higher priority trains are shown with a thicker line). Passenger trains are displayed in red, freight trains are black, and train trains are shown in green.
- The actual and planned train movement, which is expressed by the line type. Scheduled train paths are displayed with a colored dashed line, where the line is the prediction of a particular train's driving. The part of the route between the two traffic points in which the train ride is confirmed will change from the original to the full line.

Fig. 7 Examples of other information about train’s paths [13]
Train abnormality expressed by additional characters at the train number, with two stars before and after the train number.

The inclusion of an assisting or pusher locomotive on a train, which is represented by additional characters at the train number, with the symbol "^", whose position before the train number means an assisting locomotive, after the train number the pusher locomotive.

The train's delay from the scheduled timetable, expressed in minutes, at an acute angle of the train path with the station; beyond this value, a numeric code indicating the reason for the train delay may also be given in brackets.

By double-clicking on the train route, a window with more detailed train information will be display (Fig. 8).

According to the application manual, the actualization of train path rendering takes place at the current time, while the traffic history can be viewed for 2 hours and the next 6 hours for the future. Updating traffic development data is in a user-adjustable interval of 120-300 seconds [13].

The practical application of this software tool allows to instantly evaluating traffic at the lowest driving level. This level of management has the ability to make operational changes in crisis situations. Right timely decisions eliminate the undesirable consequences in these situations.

The application is open and, if necessary and the new practical ideas and ideas of the users, the application can be further developed and modified. An example may be the prediction of observing the electrical train sequence interval on the electrified lines between traction dependent trains and the subsequent alerting (dispatcher) of their anticipated non-compliance [3, 5, 10].

5. Conclusions

The allowance approached the functionality of planning the train path with current information systems to support traffic management on Slovak railways. The second part was focused on the application for evaluation this train path with the Train Dispatcher System and the new system of Track Train Position.

The Infrastructure Manager assumes that this version of the application will bring its use and positive response in its practical use as another provider of information support in the day-to-day management of railway traffic [14].

It is important to note that the information systems don’t give the decides on a particular situation [9]. The IS only provide comprehensive support for making a decision to be taken by designated station dispatcher, operational dispatcher or other manager in operational railway transport.

This principle can be applicable and to others railway infrastructure managers.

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The Comparison of the Operation Process for Two Training Aircrafts - Diamond DA 20-C1 and Cessna 150

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\textbf{Abstract}

The article investigated the operating process of two aircraft belonging to the light category. This is performed by analysing the transitional processes of the exploitation process and determining the probability of technical objects staying in particular exploitation states. An interesting issue is the change of readiness depending on the initial state of the system. One of the analytical methods based on the analysis of random processes is the method of Markov processes. It is based on the assumption that the presence of a technical object in different states is a random variable, and its result is the probability of the presence of the technical object in different operating states. In this article, the time changing probability of readiness was determined on the basis of knowledge of the current aircraft operation. Markov stochastic processes have been used as a model to determine aircraft - Diamond DA 20-C1 and Cessna 150 readiness for specific tasks. In order to determine the readiness, the probability of being in one of the investigated states is determined. The analysed states included: standby, pre-flight service, flight, interstate service, after-flight service and hangar service.

\textbf{KEY WORDS:} Markov process, reliability, readiness, Diamond DA 20-C1, Cessna 150

\textbf{1. Introduction}

At the turn of the years, aviation is gaining in popularity, the number of passengers of well-known airlines is increasing and the network of connections is constantly growing. At the same time, it is the safest means of transport. However, in order to achieve this, it is necessary to ensure an adequate level of flight safety. Security is an area that requires constant attention and implementation of changes aimed at eliminating further emerging threats. The broadly understood exploitation that people encounter at every step of the way is an extremely important factor affecting safety. The article investigates the process of operating two aircraft belonging to the light category. This was achieved by analysing the transitional processes of the exploitation process and determining the probability of technical objects staying in particular exploitation states. The analysis of the transition processes of the operation allows the aircraft to be in a state of readiness and avoids stagnation in hangar services.

\textbf{2. The Operational State Model}

The operation process is the transition of aircraft from one operating state to another. At the same time it is a set of events that occur inside the operational state when the aircraft is in this state and it is a set of physicochemical events occurring in the aircraft itself, which are independent of human activities. It is possible that the aircraft will be in two or more operational states at the same time, for example: the supply process will take place in parallel with the aircraft inspection process.

The transition from state to state of the aircraft under operation can be illustrated, by a direct graph or as a zero-one matrix. In this work, the model of operating states is presented in the form of a graph directed and will be the same for both aircraft.

Graphs can illustrate the structure and relationships between states. An aircraft or operating system, as mentioned above, may be in several different operating states at the same time. The vertices of the graph are operational states, and the arrows mark possible transitions between states.
An aircraft may be in one of the states in the operation process:

- $S_1$ is the standby state;
- $S_2$ is the pre-flight service state;
- $S_3$ is the flight state;
- $S_4$ is the interstate service state;
- $S_5$ is the after-flight service state;
- $S_6$ is the hangar service state.

$\lambda_{ij}$ is as process transition intensities or transition rates in the Markov process from state $i$ to state $j$, $(i,j) \in \{1,2,3,4,5,6\}$. The states $S_1$, $S_2$, $S_3$ and $S_4$ are classified as readiness states [1].

Fig. 1 Directed graph of operating states of the aircraft

The system shown in Fig. 1 can be described by the following system of differential equations:

\[
\begin{align*}
\frac{dP_1(t)}{dt} &= -\lambda_{21}P_1(t) + \lambda_{31}P_3(t) + \lambda_{61}P_6(t); \\
\frac{dP_2(t)}{dt} &= -\left(\lambda_{23} + \lambda_{26}\right)P_2(t) + \lambda_{12}P_1(t) + \lambda_{62}P_6(t); \\
\frac{dP_3(t)}{dt} &= -\left(\lambda_{34} + \lambda_{35}\right)P_3(t) + \lambda_{23}P_2(t) + \lambda_{43}P_4(t); \\
\frac{dP_4(t)}{dt} &= -\left(\lambda_{43} + \lambda_{46}\right)P_4(t) + \lambda_{34}P_3(t); \\
\frac{dP_5(t)}{dt} &= -\left(\lambda_{51} + \lambda_{56}\right)P_5(t) + \lambda_{35}P_3(t); \\
\frac{dP_6(t)}{dt} &= -\left(\lambda_{61} + \lambda_{62}\right)P_6(t) + \lambda_{26}P_2(t) + \lambda_{46}P_4(t) + \lambda_{56}P_5(t),
\end{align*}
\]  

(1)

where $P_1(t)$ – the probability that the system is in a standby state; $P_2(t)$ – the probability that the system is in a pre-flight service state; $P_3(t)$ – the probability that the system is in a flight state; $P_4(t)$ – the probability that the system is in an interstate service state; $P_5(t)$ – the probability that the system is in an after-flight service state; $P_6(t)$ – the probability that the system is in a hangar service state.

These probabilities can be determined using the program Wolfram Mathematica.

3. Analysis of the Readiness for a Diamond DA 20-C1 Aircraft to Perform a Training Task

Data for the analysis was collected during exploration process.

The Cessna 150 aircraft is a high-wing aircraft with a fully metal, semi-corup structure. The plane is equipped with a three-wheel fixed undercarriage. Controlled front undercarriage is equipped with a hydraulic-air cushioned shank. What distinguishes this plane from others is the window on the rear side around the rear window [2-4].

Table 1 summarizes the transition rates between particular operating states for the real exploitation process. Table 2 presents the data related to the probability of transitions between particular exploitation states.
Table 1
The transition rates between individual operating states of a Diamond DA 20-C1

<table>
<thead>
<tr>
<th>$\lambda_{ij}$</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>-0.075</td>
<td>0.074</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.001</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>-0.346</td>
<td>0.137</td>
<td>0.209</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>0</td>
<td>0</td>
<td>-1.823</td>
<td>1.823</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S5</td>
<td>0.143</td>
<td>0.399</td>
<td>0</td>
<td>0</td>
<td>-0.545</td>
<td>0.212</td>
</tr>
<tr>
<td>S6</td>
<td>0.358</td>
<td>0.910</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1.468</td>
</tr>
</tbody>
</table>

Table 2
The probability of transition between individual operating states of a Diamond DA 20-C1

<table>
<thead>
<tr>
<th>$p_{ij}$</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
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<tbody>
<tr>
<td>S1</td>
<td>0</td>
<td>0.982</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.018</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>0</td>
<td>0.396</td>
<td>0.604</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>S5</td>
<td>0.263</td>
<td>0.732</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.005</td>
</tr>
<tr>
<td>S6</td>
<td>0.282</td>
<td>0.718</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

These data were then used in the Wolfram Mathematica program. Probability graphs $P$ were generated from the time $t$ in a year perspective. At the initial stage, the tested technical object may be in one of the assumed operational states. The probability of staying in a given state as a function of time has been calculated.

Fig. 2 The probabilities of being in one of the analysed operating states as a function of time, assuming that the initial state was the standby state for Diamond DA 20-C1

Fig. 3 The probabilities of being in one of the analysed operating states as a function of time, assuming that the initial state was the standby state for Diamond DA 20-C1 - enlarged drawing
Fig. 2 shows the probabilities of being in one of the analysed operating states as a function of time, assuming that the initial state was the standby state. On this basis, it can be seen that the probability of an aircraft remaining in a standby state at the initial phase is 100% and decreases over time. After about 30 days, this probability reaches a constant level called the limit probability, which is approximately 24%. The probability of an aircraft being in between-flight service state increases until an estimated 30 days and has since remained stable at approximately 38%. Probabilities for states with lower values are shown in Fig. 3. The probability of the aircraft being in flight condition is approximately 1.5% and the probability of the aircraft being in hangar service state is negligible. The aircraft is likely to be in the state of maintenance before flight at 21% and the aircraft is likely to be in the state of maintenance after flight at 16%.

4. Analysis of the Readiness for a Cessna 150 Aircraft to Perform a Training Task

The Diamond DA 20-C1 is a two-seater tourist aircraft, designed for flight training as an alternative to the most frequently used Cessna aircraft in aviation schools. The recommendation for this aircraft is that it was selected as a basic training aircraft by the US Airforce Academy. This aircraft is manufactured in Canada by the Diamond Aircraft subsidiary in London, Ontario [5, 6].

Table 3 summarizes the transition rates between particular operating states for the real exploitation process. Table 4 presents the data related to the probability of transitions between particular exploitation states.

<table>
<thead>
<tr>
<th>( \lambda_{ij} )</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>-0.090</td>
<td>0.088</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.002</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>-1.907</td>
<td>1.859</td>
<td>0.209</td>
<td>0</td>
<td>0.048</td>
</tr>
<tr>
<td>S3</td>
<td>0</td>
<td>0</td>
<td>-0.100</td>
<td>0.077</td>
<td>0.033</td>
<td>0</td>
</tr>
<tr>
<td>S4</td>
<td>0</td>
<td>0</td>
<td>0.505</td>
<td>-0.507</td>
<td>0</td>
<td>0.002</td>
</tr>
<tr>
<td>S5</td>
<td>1.767</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1.813</td>
<td>0.046</td>
</tr>
<tr>
<td>S6</td>
<td>1.170</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-1.170</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( p_{ij} )</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>0</td>
<td>0.074</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.001</td>
</tr>
<tr>
<td>S2</td>
<td>0</td>
<td>0</td>
<td>0.137</td>
<td>0.209</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>S3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.699</td>
<td>0.301</td>
<td>0</td>
</tr>
<tr>
<td>S4</td>
<td>0</td>
<td>0</td>
<td>0.996</td>
<td>0</td>
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<td>0.004</td>
</tr>
<tr>
<td>S5</td>
<td>0.975</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>0.025</td>
</tr>
<tr>
<td>S6</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Similarly, the probability \( P \) was calculated from the time \( t \) in a year scale for a Cessna 150 aircraft, as shown in Figs. 4 and 5.

Fig. 4 The probabilities of being in one of the analysed operating states as a function of time, assuming that the initial state was the standby state for Cessna 150
Fig. 4 shows the probabilities of being in one of the analysed operating states as a function of time, assuming that the initial state was the standby state. On this basis, it can be seen that the probability of an aircraft Cessna 150 remaining in a standby state at the initial phase is 100% and decreases over time. After about 30 days, this probability reaches a constant level called the limit probability, which is approximately 23%. The probability of an aircraft being in flight state increases until an estimated 30 days and has since remained stable at approximately 62%. Probabilities for states with lower values are shown in Fig. 5. The probability of the aircraft being in between-flight state is approximately 9%. The probability of an aircraft being in a 'pre-flight servicing' state is decreasing, while the probability of an aircraft in a 'in-flight servicing' state is increasing. After about 30 days, these two probabilities converge and maintain a constant value of 1%. The probability of an aircraft in a hangar service state is negligible.

5. Conclusions

The Markov's processes, while satisfying appropriate assumptions, allow to determine the probability in which the analyzed technical object is standing. Concluding on the basis of the performed analysis of probabilities of staying of the studied technical objects in one of the exploitation states, approximate values of probabilities of staying of the aircraft of type Diamond DA-20 and Cessna 150 in the assumed exploitation states were determined. After about 30 days, the probabilities shown in the figures reach constant levels called limit probabilities. It has been assumed that hangar service operations are performed regularly in accordance with the guidelines described by the manufacturer in the operating instructions. The probability for both aircrafts of being in a hangar service state is negligible. Differences in the probability of being in a state of flight result from the more expensive operation of the Diamond aircraft, which is mainly used for night flights. In addition, it is assumed that operations are carried out correctly by appropriately trained personnel. It can be concluded that Cessna 150 and Diamond aircrafts rarely fail.

References

Brexit in Aviation: 2019 Update

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Abstract

Air transport, along with the banking and properties sectors, are industries especially vulnerable to any economic changes. This has been seen on numerous occasions with examples such as the Global Financial Crisis, volcanic ash from Eyjafjallajökull and the 9/11 attacks on the World Trade Centre. Private business travel was especially affected by the Global Crisis, airspace closures across Europe followed the volcanic ash crisis, and significant changes to security had to be implemented following 9/11. Whilst air transport, thanks to long range aircraft performance, connects remote markets around the globe, it has also the ability to boost macroeconomics of a particular region. Air transport furthermore relies on connectivity which is enabled by market access improvements, such as liberalisation, open borders, barrier-free legislation, common market, or a free trade area.

The Brexit 2019 update focuses on the economic and legislative impacts of Brexit on the air transport between the EU and the UK. The paper will examine the liberalisation processes within the European Community that led to deregulation of air transport, as well as evaluating possible models that could serve as a potential template outcome of the ongoing Brexit negotiations. As per the IATA study [1], the areas of interest affected by Brexit will involve: safety and flight operations, ground operations, air service agreements, border management, security, slot management, environmental concerns, labour movements and consumer protection. In particular, this paper focuses on the EU air service agreements, as well as provides a comparison of possible implications of Brexit to the existing UK airlines on their flight operations and labour requirements.

KEY WORDS: Brexit, aviation, air transport, economics, Single European Skies, liberalisation, market access

1. Introduction

The United Kingdom, in their referendum on the 24 June 2016, voted to leave the European Union. David Cameron, the former Prime Minister, decided to step down as a result of the vote, and was replaced by his colleague Theresa May. Under the British constitution the largest political party is invited to form the next Government, by the Monarch. Following the General Election, the Conservative Party was the largest party, but required the support of the Democratic Unionist party from Northern Ireland to form a majority in the House of Commons. Mrs May's declaration to trigger Article 50 and leave the EU in March 2017 was supported by almost 500 MP’s. The government officially requested to leave the EU on the 29 March 2017. This would allow the two parties a two-year period to agree the “divorce” settlement, marking Brexit day on the 29 March 2019. The official Brexit negotiations commenced in the summer of 2017 and were split into three phases - withdrawal conditions, future partnership and transition. As the talks between London and Brussels entered 2019, it became clear that the two-year deadline would not be achieved. Therefore, in April 2019 the UK Parliament voted to postpone Brexit until the 30 October 2019 for further negotiations with EU-representatives to take place. Meanwhile, a transition period was agreed, guaranteeing the United Kingdom continuation of the EU benefits of Free Movement Area until the 31 December 2020.

Historically, the UK has always held a special position in Europe concerning politics and international relations; as a Naval Superpower and a power balancer during the Concert of Europe in the nineteenth century. In aviation matters, the UK holds an extraordinary position and became an aviation pioneer in many areas. To this date, the United Kingdom is the world’s third largest aviation market after the US and China. London Heathrow is Europe’s busiest airport and the world’s seventh with more than 80 million passengers (total passenger traffic) in 2018 [2]. The UK CAA has an extraordinary place within the regulators, providing its expertise for the EASA regulation-making processes. It is estimated that London Heathrow serves about 40% of the transatlantic traffic [3]. The route between London Heathrow and New York JFK became the most profitable route in 2017 with a profit of over one billion [4]. To sum up, the UK is a big player on the air transport market whose opinion on aviation matters has been always highly valued.

This paper is an update to the authors’ previously published article on “Looking Beyond Brexit in Aviation” [5] and highlights EU-UK relationships, the negotiations process on Brexit and especially aviation matters. The authors will expand on areas that enabled the expansion of air travel within the EU, such as liberalisation and the Single European Market, as well as examine how this market access will be affected by Brexit. The previous paper also discussed a possible development of the future “Open Skies” agreement between the UK and US. Following negotiations in early 2018, where it has been agreed that “Open Skies” agreement will morph into an identical UK-US agreement for transatlantic flights. Here the authors will focus on the EU-UK matters only.
2. Integration, Market Access, Liberalisation and Scenarios of Cooperation Models

Europe initially based its unity on economic cooperation with the Coal and Steel Community. However, integration on an economic level had to be accomplished first. In 1972, the European Community was established as a result of the European Economic Community, Euratom and the Coal and Steel Community joining together. Later on, in 1992, the Maastricht Treaty laid the ground for the current European Union. One of the main goals was the setting up of a market area that would have no trade barriers, facilitating the movement of people, goods, and services, between member states. This has progressively resulted in the current state of almost borderless integration under the Single European Market. In air transport, European integration is based on three principles - Liberalisation, “Open Skies” and the European common market [6]. As discussed above, “Open Skies” will be marginally mentioned in this paper as the authors would like to focus on the EU-UK relationships.

Based on the post-WW2 cooperation, the International Civil Aviation Organisation (ICAO) was established as a United Nations body. ICAO’s Freedoms of the Air became the fundamental principles applying to air transport when it comes to the market access. However, the sovereignty of each country is still honoured. Apart from airspace sovereignty, a state can grant the transport of passengers and goods, overfly and landing rights, all based on the nine Freedoms of Air. Therefore, bilateral agreements between the countries are primarily based on respecting the sovereignty of each others airspace and the access to the traffic rights. N.B. Bilateral agreements between the US and some of the EU countries formed a precursor to the “Open Skies” Agreement.

The EU integration in air transport finds its roots in the Chicago Convention of 1944 and subsequently ICAO rules. Based on this, the United Kingdom is a member of several important aviation organisations, agencies and groups within the European and global spheres, such as [6]:

- European Common Integration Area (ECAA);
- European Aviation Safety Agency (EASA);
- International Civil Aviation Organisation (ICAO);
- European Space Agency (ESA);
- Single European Skies;
- GALILEO Satellite Navigation System.

From the international law-making process, a three-pillar external approach to air transport agreements is being applied in the EU [7, 8]:

1. agreements in accordance with the EU law that enforce the position of EU carriers abroad (outside the EU);
2. agreements that support implementation and extension of the European Single Market Area. Such agreements gave grounds for establishment of low-cost airlines in Europe;
3. agreements with third countries, such as the US and Canada that support consumer rights protection, social rights, investment freedoms and environment protection.

To date, no agreement made under the third pillar, with a trading partner outside the EU and other than European Economic Area (EEA) countries, has seen anywhere near the same liberal and free market access opportunities as the EU has enjoyed internally. Meanwhile, the UK has become fully entwined in a global EU aviation policy and linked to negotiations concluded through the EU, both externally and internally. This compares the European integration to a complex honeycomb structure [8].

Whereas the history of European integration goes back to the post war period after 1945, there was a long duration until any liberalisation of the aviation market was achieved. Liberalisation - or economic deregulation- was initiated in the 1970s in the United States. Early Air transport in the US remained intact following the two world wars [9] and had better conditions in terms of the US states being a federation of states already. Deregulation in the US led to a reorganisation of the industry, arrival of low-cost carriers and innovations in the business model. However, the bilateral model of air service agreements granted by the state remained [10].

The liberalisation of air transport in Europe commenced in 1986. Three packages involved [8, 11]:

1. the reduction in restrictions imposed on the number of airlines on certain routes and capacity restrictions allowed market access for smaller airlines that later on transformed into the low-cost carriers;
2. revision of the first package included a greater freedom of price and capacity estimation;
3. allowance of a free market area in air transport between member states, with the condition of fulfilling ownership rights.

In three steps, cabotage, wet lease and free fare establishments have been enabled. Companies such as EasyJet or Ryanair could thus offer European international and domestic flights outside their country of Certification. Borghouwt et al. [12] collected data between years 1990 and 2013 to analyse the impacts on air travel within the former EU15+2. The two non-EU countries being Norway and Switzerland who belong to the European Economic Area (EAA). The analysis shows differences in impact on aviation markets in the three phases. In the first phase (1990-1993), competition decreased between the effective carriers. Second phase (1994-2000) recorded a rapid growth in the number of flights, routes, frequencies and a more intensified hub-and-spoke operation of the flag carriers. The third phase (2001-2013) enabled the rise of low-cost airlines, such as Ryanair (1985) or EasyJet (1995). Full access to the EU aviation market, derestricted cabotage rights (seventh Freedom of Air), encouraged the usage of under-utilised secondary airports, and had a large effect on the low-cost carriers with their rapid gain of market share. However, the liberalised market brought in the issue of the so-called route density problem where the low-cost carriers reduced their route frequencies and extended their average route distances [13]. National flag carriers continued to focus on their own home bases and further optimisation.
However, the growth in their flights or routes stagnated or declined between the years 2000 and 2013. Along with these processes, a consolidation in the aviation market has begun, where some of the legacy airlines, such as Sabena and Swiss Air went bankrupt in 2000. Other traditional airlines de-hubbed or downsized their traditional home carrier. Economically, the third phase was not as favourable as the second phase because it involved adverse economic conditions with high fuel prices and competition from Turkey and the Gulf region.

Overall, between 1990 and 2013, the number of intra-EU 15+2 flights increased by 80 percent, while the number of routes increased by 138 percent [12]. Increased competitiveness led to reduced prices, a higher quality of service and a consistency in terms of safety and security. Common rules have overlapped into areas of customer protection in the event of airline insolvency, delays, damage and personal injury [8].

The UK became an EU member in 1973, a long time before the European aviation market became liberalised. The main reasons for Great Britain joining was economic integration; a resistance to any deeper political integration was pronounced. Historically, Great Britain has always kept a special position in the relationships towards the other countries of Europe - as a naval superpower, Britons had no intentions to conquer their European rivals; and vice versa. The sea protected them as a natural barrier. In the 19th century, during the Concert of Europe, Britain became a balancer between the superpowers in Europe, by strategically choosing which side to support during conflicts or wars. During both World Wars, Great Britain’s entry to wars was delayed until the situation to enter the war has shown as necessary. According to Fox [8], there are two reasons: Great Britain was an empire-builder not a long time ago and is still a major trading power. There is also a kind of a persisting island mentality which prevails above all else, and a resistance to tie up with the continent continues with rejecting to receive orders from the other states or the centre of a supranational organisation as it is the EU. This kind of a sentiment has been rooted within the British mentality since the time of joining the EU, if not before, and has set the country on a drifting course from the EU conglomerate.

Whether a bilateral agreement or flying rights with respect to the ICAO Freedoms of Air have to be exercised, there is a strong interest for both parties to sign a provisional agreement to keep flights operating. A provisional agreement between the EU and the UK on basic air connectivity [14] will enable it to maintain the same privileges up to 29 March 2020, or sooner if alternative arrangements are in place. In the meantime, by setting out reciprocity rights for airlines in the UK and EU, UK airlines will be entitled to enjoy third and fourth freedoms of the air and beyond-EU fifth freedom services for up to five months. On the basis of reciprocity, the UK has taken the view that liberalised markets in air services promote choice and connectivity, and will allow member state airlines to operate from any point in the EU to the UK. It would be up to the EU country concerned to grant an operating authorisation. The aim of reciprocity is also to provide reassurance and minimise disruptions. Regarding the ownership and control, airlines licensed in the UK would have to have to be majority owned and controlled by UK nationals. This might be perceived as an outdated practice not reflecting the reality of the global capital markets [14]. However, it provides a certain level of state protectionism. Cabotage is a very important aspect to some of the UK airlines, especially to the pan European airlines such as EasyJet. The EU has made it clear that UK airlines would no longer be able to operate their intra-EU services and so the UK would have to apply a reciprocal measurement in terms of not approving EU carriers to operate on domestic UK flights. The decision will have extensive implications to companies such as EasyJet, Ryanair and Wizz air and will be discussed in the next chapter. The draft regulation specifies conditions of aircraft leasing. UK registered aircraft will not be admitted for leasing in the EU but the UK CAA, based on individual approvals, will consider granting the permission to aircraft from other EU countries. Regarding codeshare: UK airlines will be able to codeshare with airlines on their services to and from the EU. However, the provision does not include the ability for UK airlines to codeshare with member state airlines on services wholly within the EU. Already permitted codeshares will continue and new codeshares will be subject to approval. During the transitional period, the European Commission will continue to monitor for fair competition. After the transitional period elapses, these responsibilities will move to the UK CAA and the Department of Transport.

Current international policy of the EU is executed via the EU, not single states. In the case of Switzerland, a series of bilateral contracts have been negotiated, this will most likely not recur as the policy is to sign an agreement between the whole EU and a third party country - which, in the case of Brexit, Great Britain will belong to. The authors therefore do not expect that a series of bilateral agreements will be negotiated as this will not be possible anymore. As Brexit talks move on, the uncertainty on what model will Great Britain adopt is still unclear. The Norwegian model requires membership within the EEA (European Economic Area) and fee contribution. The Swiss model counts for free movement of people along with the EEA membership. The Swiss model is also based on a series of bilateral agreements, negotiation of which will be against the current policy of the EU. The authors do not eliminate the possibility of an unique model suited to the current conditions and creating a suitable solution to both parties.

There are several international airlines in the UK market, such as EasyJet, Ryanair, Norwegian, TUI and SAS. Their business models vary case by case depending on their country of registration, or registration of their fleet. Most of these airlines have experienced the benefits and challenges of the liberalised European aviation market - some of them were successful, others had to transform or cease trading. Nevertheless, all of these airlines require an immediate intra-EU operability in case of a Brexit. The most dominant issues are ownerships rights, fleet and personnel interoperability and cabotage; providing domestic and international flights within and outside UK airspace are granted.

3. Market Challenges and Consolidation

An immediate reaction to the Brexit referendum result was demonstrated by the exchange rate of sterling with the euro. Its value fell by 10%. The rate has not increased significantly since then but is prone to small fluctuations with
leaders’ statements and any negotiation progress. A low exchange rate benefits travellers from overseas and UK exports but is less attractive to EU labour on British market. A GDP (Gross Domestic Product) analysis shows a slow decline from the third financial quarter of 2016. The outlook for a GDP growth remains slower in the forthcoming years [15, 16]. Also, IAG shares were recorded down by 20.2 percent at £421.10 on the 24th June 2016 (the day of the Brexit referendum results - authors’ note), while EasyJet shares were 19.2 percent lower at £12.37. Both being the heaviest losers in the FTSE 100 [8].

Flybe, a 40 year old and the largest regional airline in Europe, has been struggling to show a profit since 2010, due to a series of both external and internal issues. Flybe with its fleet of Bombardier Q400 and Embraer jets had to compete with its main rivals EasyJet and Ryanair who were putting their aircraft onto the same routes. Brexit uncertainty did not help Flybe at all - eventually, the company shares fell down dramatically at the start of 2019. Decided by the courts in March 2019, the airline was formally acquired by Connect Airways, a consortium including Virgin Atlantic [17]. Experts argue that Flybe effectively ceased to exist as it will be absorbed and rebranded by Virgin to supply its long-haul network.

The industry has also seen larger airlines ceased to operate, such as Monarch. Both Monarch and BMI Regional, ceased trading due to the macroeconomic developments which in translation, is nothing else other than the Brexit effect. Monarch Airlines, the fifth largest U.K. airline founded in 1967, ceased trading on the 2nd October 2017 after the UK CAA gave the company a 24-hours licence extension due to it’s financial issues on the 30 September, making it the biggest UK airline collapse in history. Monarch had been struggling to show positive financial results previously. However, a weaker pound and Brexit uncertainty, and an increase in terrorist attacks in the Near and Middle East and Europe, did not aid the company to improve its profitability. The company had adopted a low-cost model in 2004, however, Monarch’s entry to the market as a low-cost airline might have been too late to be able to compete with the already settled in rivals [18]. BMI Regional, another collapsed airline, blames mainly Brexit for its bankruptcy. The airline ceased all flights effective of the 16 February 2019, after a long period of financial struggles. Before its bankruptcy, much had been discussed about its buyout by Loganair, since BMI Regional’s aircraft and routes were taken over fairly quickly after BMI Regional ceased trading.

As per IATA’s White Paper issued immediately after the referendum results in June 2016 [19], the outlook was predicting less attractive travel conditions for UK citizens due to the weaker exchange rate of sterling. Due to the uncertainty and possible visa requirements, the same was predicted in terms of visitors arriving to the UK. Three years later after the referendum vote, IATA’s prediction proved to be correct. Less foreign travel has been logged by travel companies in the summer of 2019, especially when it comes to the travel to EU countries. According to Thomas Cook, holiday bookings to non-EU destinations rose by 10% in comparison with the previous year (2018), mainly due to Brexit outcome uncertainty, fear of longer queues at customs, cancelled flights, and the weaker exchange rate of sterling to the euro [20]. Thomas Cook, the oldest holiday operator in the world, reported a loss of 1.5 billion sterling for the first half of the year. The loss had been caused with “little doubt” due to the Brexit uncertainty that forced the customers to delay their holiday bookings. Especially during the first six months of the year there had been “an uncertain consumer environment across all the markets”. Multiple bids for Thomas Cook’s airline have been received as it is trying to raise funds to keep the core business. Thomas Cook has also issued a profit warning earlier this year that decreased the share price from 140 pence a year ago. A third profit warning, that came along with the first half-year results, drove the shares down 17 percent to 18 pence which is as close as in 2012 when the company had experienced a financial difficulty [21]. TUI, another holiday operator, reported a 77% increase in the half-year seasonal loss. The company recognised the demand is weaker due to the summer 2018 heatwave, Brexit uncertainty, and 15 of their Boeing 737 MAX being grounded. The company expects further losses this year if the MAX fleet remains grounded and less demand after holiday bookings is shown. However, TUI flagged these concerns in advance and despite the expected losses, their shares were up by 3 percent at 9,52 euro [22].

The impact on airlines has been in some cases immediate. Low cost carrier EasyJet had to face a fall down on the stock exchange market to a three-year minimum of £10.66 sterling. In the same year, the airline had to contend with French Air Traffic Control (ATC) strike and unfavourable weather at London Gatwick. In the 2016 financial year, EasyJet delivered a profit before tax for the year of £495 million (profit of £6.20 per seat) - which represents a decrease of £191 million from a profit of £686 million (profit of £9.15 per seat) from the previous year 2015 [23].

Several factors such as capacity growth, market competition, inflation pressures, EU261 compensation, wet leasing costs, as well as the above-mentioned ATC strikes and a lower exchange rate of sterling, led to a loss of 18 million sterling in the first two quarters of 2017. Fig. 1 shows the impact of post-referendum development on easyJet’s profits.

Along with all the challenges, the company has decided to create an Austrian AOC (Aircraft Operators Certificate) and transfer a large portion of the fleet in order to secure interoperability in case of a “hard” no treaty Brexit. The estimated cost of this decision totals up to ten million sterling and towards end of June 2019, 136 aircraft are flying under the Austrian flag [24], whereas 163 aircraft are still registered in the UK [25]. EasyJet also owns a Swiss registered sister airline based in Geneve.

International Airlines Group (IAG) consists of a consortium of airlines that are represented by British Airways, Aer Lingus, Iberia and Vueling. British Airways is the only UK based airline amongst them, but expressed their thrust in Government’s undertaking on Brexit negotiations. The main issue for IAG will be the requirement of 50% ownership of British Airways within the UK and 50% EU ownership within the rest of the network. As discussed earlier in the text, the impact of the referendum on airlines has been immediate in some cases (i.e., EasyJet). But IAG did not seem to face such a strong instability in terms of its financial and operational performance, perhaps due to the strong and efficient airlines
composition within the group. The group recorded a quite steady number of passengers transported - 1.99 mil. in 2016 and 2.021 mil. in 2017 [26]. It also performed well in terms of operational profits, as depicted in Fig. 2.

![Fig. 1 EasyJet: financial overview and performance](source)

Wizz Air, another pan European airline, operates flights from Central and Eastern Europe to London airports. Due to Brexit and the general uncertainty on the right to market access, Wizz Air applied for a UK AOC in May 2018. The permission for Wizz Air UK Ltd was received in late 2018 from the UK CAA. From the London Luton base that serves as a hub for flights to/from the European continent, Wizz Air currently operates a total of ten G-registered aircraft. Four Airbus 320 and six Airbus 321 [27]. The company is set to be successful this year as a result of smart fuel hedging. The company also keeps on offering flights with low prices and continues investing into the new UK AOC. Wizz Air maintained a full year net profit but could see that the Brexit uncertainty would affect consumer confidence in bookings towards the end of March 2019 [28]. However, towards the end of the financial year 2018-2019, the carrier recorded a total revenue of 1,948 billion euro in 2018 (1,571 million euro was in 2017). The data involves both the Hungarian and UK registered operations [29].

Ryanair issued a profit warning in January and subsequently, reported a loss in 2018, the first ever since 2014. Amid fare cuts, the company recorded a net loss of 19.8 million euro for the last three months of 2018, saying that an excess winter capacity in Europe and higher fuel costs had cut into its profit [30]. It also decided to close its base in Glasgow earlier in 2019. Ryanair has also applied and subsequently received an UK Air Operators Certificate (AOC) in January 2019 in order to provide both international and domestic UK flights. The company serves several bases in the UK: London Stansted being one of the largest out of its whole network.

Jet2, the low fare and leisure travel operator from the North of England, warns of economic uncertainty and losses
in the year ending March 31, 2020. The summer period bookings have reflected some consumer uncertainty, however, the extension of the Brexit deadline was viewed as positive for travel operators due to the greater certainty for travellers. Jet2 management remains optimistic and adds that a loss cannot be entirely caused by Brexit uncertainty. Jet2 generated revenue of over £2.3 billion sterling in the year 2018, which represents an £0.6 billion sterling improvement from 2017. The operating profit in 2018 was £130.6 million sterling [31].

In case of Norwegian, financial planning has been affected by a fragmentation of the business model. The company currently holds several AOCs - a Norwegian, British, Irish, Swedish and Argentinian AOC. There is currently very little interoperability, meaning that crews from a particular AOC cannot mix but can only fly the aircraft on the respective AOC. As a result of Brexit, only the long haul fleet has been left on the British AOC. Norwegian also operated a base in Edinburgh that has been closed in March 2018 due to high passenger departure tax (APD) and further route unsustainability. Although some costs will apply, Norwegian can use their already established Irish or Swedish AOC’s in order to access routes on the EU market. However, IAG had expressed their interest in a takeover after acquiring almost 5% of the Norwegian ASA shares, which eventually did not come to a positive result. The company is currently going through an extensive cost-saving programme to keep up with market challenges. Norwegian’s financial balance in 2018 saw a net loss of NOK 1,454 million (150 thousand EUR), while the company’s unit costs, excluding fuel have decreased by 12 percent during this period. The figures were strongly affected by 787 engine issues, fuel hedge losses and tough competition [32].

Air France-KLM Group has acquired 31% stake of the Virgin Airlines group. In case the hard Brexit inhibits the UK airline’s ability to operate, Air France-KLM will be able to sell the stake back to the Virgin Group [33]. At the moment, to comply with the EU ownership requirements of 51% ownership by the EU nationals, Virgin Atlantic’s equity is shared between Air France-KLM (31%), Virgin Group (20%) and Delta Air Lines (49%). Annual reports of Virgin Atlantic’s profits have fallen for a second consecutive year as a result of higher fuel costs and economic uncertainty linked to Brexit. It is unlikely to return to profitability until 2021. The company’s pre-tax loss was £26.1 million sterling in 2018, which was down from 49 million sterling in 2017 [34].

Wet leasing and ACMI providers, such as Titan might find difficulties if no agreements after Brexit are in place. Wet leasing is subject to the Regulation (EC) 1008/2008 which only permits EU carriers to wet lease aircraft from non-EU countries for a maximum of 14 months, assuming that they can prove that leasing from within the community is not viable. Lack of a specific agreement on wet leasing thus could be damaging for airlines whose operations are reliant on the ability to wet lease aircraft across the EU-UK border, and there is a serious concern that these opportunities would be damaged by failure to incorporate wet leasing into the Brexit treaty [1]. To note, wet leasing is currently widely used by the UK operators as a result of pilot shortage or delays on aircraft deliveries. The situation around the B787 Rolls Royce “C” package engines as well as current grounding of the 737 MAX 8 adds up on the importance of ACMI providers. The usage of non-EU carriers is not seldom - several A320s were used by British Airways during the cabin crew strike in 2017 and upon UK CAA request when Monarch ceased to trade in late 2017. Also NUK, the British AOC for the Norwegian 787 fleet is using various EU ACMI providers as a result of the Rolls Royce engines issues.

Brexit issues will apply not only to UK airlines - there are other strong players in aviation who based their businesses in the UK. Rolls Royce and Airbus plant are probably those who are impatiently awaiting any Brexit negotiation outcome. The UK is also participating on the costly GALILEO satellite navigation system development. Whether it will continue to participate or will decide to implement its own system with time, is still questionable. Air navigation services will also have to adjust to the new rules; as the airspace controlled mainly by NATS has largely benefited from the Single European Skies [35].

It is estimated that the UK CAA contributed, along with the French CAA, 80-90% to the legislative framework for the EASA establishment. The UK CAA still holds a dominant place and UK Flight Crew licences are strongly respected worldwide. However, EASA is built of both EU member and non-member countries, where the EU member countries hold voting rights. Non-member EU states obtained observer rights only, they have no participation in the voting process. Britain exiting the EU means losing the voting rights and the ability to have an impact on the regulatory decision making process.

The future outlook of the relationships between the UK CAA and the rest of the EASA might have been demonstrated already as the reciprocity of licences validation between the UK and EU has not been confirmed yet. The UK CAA will recognise EASA issued licences, however, UK issued licences are to this date not to be recognised with EASA member states until UK’s place within EASA is confirmed. As a result to secure the flights and crew availability after Brexit, most of the airlines have instructed their crews to convert their licences to an EASA member country, such as Austria for EasyJet to Austrocontrol (Austrian CAA) or Irish AOC in Norwegian Air International to either an IAA licence or Danish licence. As a requirement of the Operator, licence transfer costs are usually reimbursed to the individuals, and represent an additional cost of Brexit to the Operators.

Labour market predicts barriers to movement of, in case of flight crews, highly skilled and highly specialised workforce. To this day, Brexit induced barriers to a free movement of labour are unknown, therefore the cost cannot be estimated. However, as Fox [8] notes, the immigration of skilled labour to the UK, especially of staff working at hospitals and in transport, has been in high demand for decades. Since ways of transport have advanced, the maritime workforce has been replaced by aviation personnel, and if the forecast for a further lack of personnel will come true, a more skilled labour will be required over the upcoming decades.

In summary, a weaker pound and Brexit uncertainty caused “headwinds” to all UK based airlines. The weak pound causes households to hold their expenditure and increases fuel costs, one of the highest expenses of any airline. Terrorist
attacks and air traffic control strikes causing EU261 compensations were an additional cost to the airlines in 2016 and 2017. 2018 marked a heatwave across the UK where customers are holding on with their summer getaways bookings in 2019, hoping for a similar weather than the year ago. Overall, the pound remains at its post-referendum exchange rate of 1,1 towards euro, making a holiday in EU countries more expensive. To counteract this effect and to reduce further loses, discounted holiday packages have been offered - a good news for customers but certainly another wrinkle on the forehead for airline management.

4. Future Development Prediction

The negotiations continue past the deadline of this article (June 2019), and their outcome is still unclear. A very few achievements have been agreed, including matters on the Irish border, a free movement within the European Economic Area and many other important issues such as licensing reciprocity or basic air connectivity. The proper definition of leaving the EU remains therefore unclear as the House of Commons appears to make more statements on what the UK does not want rather than a decision making on a withdrawal process. This leaves the country and the rest of world in an uncertain position where nothing is made clear and little is agreed. In the wake of the development, the Prime Minister Theresa May has been asked to step down from her position on the 24 May 2019 as her proposals on the Brexit deal were turned down by the Parliament on three separate occasions. Elections for the new Tory’s leader, and the Prime Minister, continue throughout June and July. Boris Johnson and Jeremy Hunt are now considered to be the lead candidates for this position. Boris Johnson has made himself clear about being a Brexit supporter and his intentions about an orderly withdrawal on the 31st October 2019 in combination with centrist domestic policies. Jeremy Hunt may have supported the Remain campaign but presents himself as a person who can make the deals, bring the Party together and make Brexit a reality. However, both of the candidates warn from larger risks of a no-deal scenario [36].

Following a campaign and an internal vote in the Conservative Party, the victor is expected to be announced during the week of the 22nd July - this gives the new Prime Minister over three months’ time to negotiate a sensible Brexit treaty. The possibility of new early elections remains once the deal is done, to keep in line with the political culture of the country. Regardless of the name of the new Prime Minister and the withdrawal deal, the transition period will expire on the 31 December 2020 and the UK will no longer be granted benefits of the EU, such as Single European Market or borderless movement. This, in case of a no deal scenario, would revert trading conditions to the World Trade Organisation (WTO) rules. Brexit along with the other issues on the market, brought certain challenges to the aviation market. A liberalised European aviation market removed most of the natural and strategic barriers to entry [37], as well as opened many opportunities to European carriers. By removing trading barriers, liberalisation also amplifies market access and creates new potentials. Despite some negative effects, such as the traffic intervals distribution (80% of routes are served by one or two carriers), financial health of some airlines and secondary airports and a complicated oversight of regulators; [38, 9] liberalisation of European air transport can be assessed as a highly positive as it enabled more people to fly, as well as freed the barriers to skilled workforce movement.

Hill et al [39] concluded a research on the impact of Brexit to businesses and agreed that Brexit is an event associated with a heightened political uncertainty. Consequences of Brexit are far reaching, affecting many government policies - this can be applied to EASA structures or air service agreements which are very complex. The team finds that more internationally orientated firms are less affected by the Brexit uncertainty due to a higher diversification potential. It is the smaller companies that will struggle in the event of a no-deal Brexit - by a comparison, IAG has only one airline based in the UK and their diversification aids in spreading the costs, whereas smaller companies such as Flybe or BMI Regional struggle(d). Wizz Air, with just one base in the UK out of the whole network, reported a record profit in 2018. Hill et al. also state that there is no significant link between Brexit exposure and foreign ownership, reliance on the European Single Market workforce, labour intensity or the extent of EU lobbying - the estimation can be fully analysed once the transitional periods are over. The high Brexit exposure of consumer orientated companies is in line with evidence that households reduce their consumption and increase savings in periods of a higher uncertainty - which is correct as less holiday bookings were made for the summer season 2019 in comparison with the previous years.

5. Conclusions

The European Union and ICAO were established on behalf of the post-war cooperation of states. The Chicago Convention on ICAO has set up the economic configuration of airspace, as we know it nowadays [35] and standardised the rules globally. The EU, by a slow integration, grew into one of the most prosperous economic areas of the world. The United Kingdom became a part of the EU in 1973, almost thirty years after the first members of the union have agreed on an international cooperation. Integration into European structures and cooperation had been a continuous process where the UK was obliged to implement EU rules and laws. This EU legislative has been evolving ever since, making cooperating states entwined legally with each other. Regardless the UK will stay under the European Court of Justice law, removing the existing laws will be a challenge if not an almost impossible task to do. N.B, some legislation in the UK still finds its roots in the laws of Ancient Rome [8]. The real exit from the EU will thus be more complicated and certainly not as romantic as some of the leave voters idealise.

Eventually, the extended long period of liberalisation in air travel predicts a continuous market consolidation, just as we have seen with airlines going bankrupt in the past year. Along with Monarch Airlines and BMI Regional, several
European airlines ceased to trade - such as Germania, Small Planet or Primera. Others struggle (Thomas Cook, Norwegian) or have to reinvent their business models (Flybe).

While the UK is certain about limiting immigration, past years have shown that the country is very much dependent on a workforce supply from other EU countries. It is expected that skilled aviation workforce will be required in the next few decades to meet the expansion demands. Despite this, it is not the authors’ responsibility to recommend anything from this position.

Markets and businesses are more and more concerned that the unstable situation will lead to a no-deal Brexit after the transition period expires. A conversion to the WTO rules would aim to “reset” the current conditions, as well as prepare grounds to negotiate on new deals with trading partners of own choice. An overall worry about a no-deal Brexit is significant. Currently, indications predict the UK would become an outsider in European matters due to its own inability to make sound decisions. Given the arguments the authors have raised in this paper, there is a valid concern that if existing conventions in international relationships and global trade apply, these will negatively affect Britain’s dominant place in aviation. However, the majority of the UK citizens voted for a certain future scenario in the 2016 referendum - this is a result that needs to be respected and followed up. From an aspect of democracy, the Government should do their best to obtain the best result for those who have put their trust into the Conservative Party at the General Elections. The will of the public cannot be ignored, and it seems like that the best way out, is a way out, both for Britain and the EU.

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The Possibilities of Using a UCC in the Czech Republic Cities and Important Criteria Evaluation

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Abstract

The current research of the transport situation in most European cities has shown unsustainability for the future. Due to the increasing number of residents in cities and increasing demand for e-commerce, increased the number of supply vehicles in cities, as well as pollution, congestions and car accidents. The most common solution for effective last mile delivery like vehicles using alternative fuels or electric vehicles for supplying the cities isn’t enough anymore. There is a need to focus on the total number of vehicles in cities and on sufficient use of loading space of those vehicles. An urban consolidation centre (UCC) could be a possible solution to economic, social and environmental problems in cities. This article focuses on possible using a UCC in the Czech Republic cities up to 100,000 residents. The article also provides an evaluation of the essential criteria for sustainability of UCC for the future.

KEY WORDS: urban consolidation centre, sustainability, city logistic, AHP

1. Introduction

In recent years the environmental issues caused by urban freight transport started question future sustainability of many cities all over the world as well in the Czech Republic. The increasing number of vehicles in cities do not just affect the level of congestion and air pollution in cities, but also causes an increased risk of car accidents and affects the liveability in cities as it is. Very often the end-customers want their order to be delivered as soon as possible and force the transport companies to provide inefficient delivery, as a result, a lot of trucks circulating in cities with a low load factor. Transport companies are more concerned about their competitive advantage and prosperities then about future liveability in cities. That is why the city administration, such as cities municipalities or national government, need to come up with a way how to ensure the future liveability of cities. The first step should be realizing and expend knowledge about all the multiples impacts that urban freight transport has in cities and their outcomes. Such as traffic congestions, air pollution and increases risk of car accidents as well as climate change and impacts on the health of residents. On the other hand, there are economic issues like higher logistics cost, the damaged economic competitiveness of urban areas, as a result of the uncontrollable traffic situation in that area. The second step that should be done is reducing the negative impact of logistics activities in cities. The second step will be more complicated, mostly because local authorities do not know how to minimize the negative impacts of logistics activities on the economy, environment and quality of life in the city. It is essential to use different measures of city logistics because sustainable development could be achieved just by creating a synergy effect of those.

2. Research Methodology

The main focus of this article is UCCs. Their history started from the 1970s when the significant attention to the concept of UCC was being paid in the UK and France as well as in the US and Canada. The main ground for such attention were concerns about the environmental impacts of large, heavy goods vehicles in the urban areas and the low load factor of those vehicles [1]. Definition of UCC is not yet definite despite all the written publications about it. UCC can be characterized as a location close to the city or in it, where goods from outside the city are consolidated and delivered by a small vehicle [2]. On the other hand, an UCC is not just a transhipment centre and it is necessary to consider all possible specifics. UCC is a logistics facility, which is situated in the proper distance from the area it will be supplying, with the primary aim to efficient the freight transport in the selected region. In connection with the use of UCC are reported following advantages for freight transport situation in the cities, transport companies, and residents. Environmental and social benefits, which seem to be the most important, could be achieved by more efficient logistics activities in cities. A higher level of planning and implementation of logistics operation could lead to new opportunities like more sophisticated information system [3]. According to some articles, a UCC could be a way to provide “just in time” delivery in cities and by this switching the whole logistics system from “push” to “pull.” In the present time, a lot of companies arranges delivery using “just in time” system, but the efficiency of this system in terms of ecology is still being questioned. Whether we want this system in our cities is one of the many questions that need to be answered, before starting the whole UCC project. Providing costs and benefits analysis is also very important before UCC implementing. It is necessary to understand all the problems and disadvantages that could appear. The first issue during the construction and operation of UCC will be high investments along with the unwillingness of transport companies use UCC. A UCC means another
“stop” in the supply chain, which would mean longer time needed for delivery. Moreover, the UCC could have problems with the quick operation of such a wide range of goods. Other disadvantages of UCC could also appear later, for example, issues with effective organization inside the UCC [4].

The next part of the article would be paying attention to the existing UCCs in Europeans cities, which could be similar to the UCCs in Czech Republic cities. Based on follow investigations will be identified the most important criteria for the sustainability of UCC in the future.

**La Rochelle**

A UCC in La Rochelle has situated about 1.5 km from the city centre. It was aiming to promote delivery by using electric vehicles and reduce traffic congestions in a city centre. The main feature of UCC, which also named Electric UCC, were electric vehicles that were adapted to the conditions of narrow city centres historic streets [5]. From the beginning, a UCC has used public funding from La Rochelle, but in the initial planning of the project was emphasized that UCC need to achieve it is own financial viability [4]. A UCC had several stakeholders such as the city of La Rochelle, the number of commerce and industry and the French minister of transport. Regardless none the stakeholder presents the public sector, they evaluate the initiative very positive, according to the transport companies the platform was well-situated with satisfactory terminal staff. Transport companies saved about 3 hours a day on the car by using a UCC and eliminated the stress of their drivers, which did not have to drive through the city centre. The only drawback as transport companies reported was a higher price for the service (3.75 euro/parcel) [5].

The using of UCC in La Rochelle is voluntary. On the other hand, the city administration supports it by providing the restriction for vehicles with a loading-capacities higher than 3.5 tons. They could enter the city but only in the time window from 6:00 am to 7:30 am [6]. The weak interest of retailers and transport companies to integrate into the system has become a crucial factor for future operations of UCC. An insufficient number of consignments jeopardize financial viability in the first phase of the project [7].

**Leiden**

A UCC in Leiden was open due to government initiative to improve urban freight delivery in the city. The basic requirements for UCC were financial viability, voluntary use and environmentally friendly vehicles [4]. After several years of unsuccessful operation, the UCC has been closed. The main reason for its failure seems to be the unwillingness of stakeholder to join the initiative, which led to an insufficient number of consignments and financial troubles. The estimated number of shipments needed for its successful operation was estimated at 1500 shipments per day. The minimum number of shipments to cover UCC operating costs was 600 shipments per day. In reality, a UCC had a problem reaching about 400 shipments per day [4]. The unwillingness of stakeholders to cooperate could have been a result of the inappropriate location of UCC, which was far away from the highway. Bad marketing communication leads to misunderstanding the purpose of UCC by stakeholders [8].

**Bristol (Broadmead)**

A UCC in Bristol has been established to provide supplies to the shopping area Broadmead. A UCC has located about 12 km from the serving area and close enough to the strategic road network. The use of UCC is voluntary, but a UCC is not financially viable and has a strong dependency on city councils’ subsidies [4]. The first step in the creation of the UCC was a survey of retailers by face-to-face interview techniques. The survey aims to provide a list of customers, which would be willing to use UCC. The scheme utilizes new technology like electric, low-emission freight vehicle as a vital part of the project. As a result of using a UCC were reduced vehicle trips into Bristol centre for retailers participating in the scheme for about 68%. A UCC offers to the customer a lot of value-added services, which have a very positive evaluation. The only problem is with financial viability because a UCC still needs more customers to cover the cost of operation [9].

### 3. Results of the Research

A UCC seems to be a suitable solution for improving the current city logistics situation in the cities of the Czech Republic and for ensuring sustainable city logistics for the future generation. Some studies have shown the interest of Czech Republic cities municipalities in the city logistics issues. The city logistics measures could contribute to the improvement of the current situation and prevent the uncontrolled development of the city logistics situation in our cities in the future. According to the analysis below, UCC aims to improve the current traffic situation in cities, especially in connection with environmental and social policies and also with an accent on the quality of life in cities. Very often, the attention of the city municipalities was mainly focused on the main objectives of the UCC like location and type of vehicles that will be used to provide transportation. On the other hand, the main questions like who, how and for how long will ensure the financial side of the UCC project, stayed unanswered. In other cases, assumptions about future economic self-sufficiency of the UCC was way too unrealistic. That is why the main problem of existing and unsuccessful UCCs was the financial viability that directly affected the sustainability of the UCC. Based on the above analysis, it is clear that future funding of UCC is an underlying problem that needs to be solved before the UCC project starts. In most cases, the city municipalities are willing to cover UCCs costs for the start period. But even after several years of operation, some UCCs are still dependent on the city's subsidies, mainly because of the lack of shipments in the UCC.

The number of customers of UCC and a number of shipments going thought a UCC seems to be a critical factor
for its prosperity. Based on the above analysis, it can be argued that several factors directly affect the number of shipments, for example, whether UCC is mandatory to use or not. Mandatory use of UCC will require a change of legislative but ensure a high number of customers for UCC. On the other hand, the voluntary use of UCC seems to be an easier way, but there is still a problem with the number of customers. Most of UCC used a combination of voluntary use of UCC and restrictions on supply vehicles entering the city that are not from UCC. The popularity of UCC is also affected by the proper location of UCC. Drivers will not have to drive through cities and waste time in traffic jams. On the other hand, the inappropriate location of the UCC may be one of the reasons for its failure, as it was in the Leiden case. The quality of services and price for using a UCC are other vital factors that affect the popularity of UCC.

Despite the voluntary use of UCC in Bristol, more and more customers want to use it, mainly due to the high satisfaction of existing customers with the quality of services provided by UCC. It is important to note that the services offered by UCC should not be limited to so-called primary transport services. It is also very required for UCC to provide value-added services to the customers. The quality and extent of which is again crucial to ensure the prosperity of the UCC. According to the research mentioned above, marketing communication is a very critical factor, which affects the popularity of UCC among customers. The main effort of marketing communication should be focused on explaining the key reasons and valuable benefits of UCC utilization to the traffic situation in the city, quality of life in the city and the residents of the city.

The success of the UCC and the important criteria for its future prosperity may vary from the point of view of different stakeholders. In general, UCC, as any other project, can be evaluated from the perspective of internal and external stakeholders. Internal stakeholders are organizations that invest in the project or operate the project. Another group of stakeholders is external stakeholders, which could be transport companies, receivers or end-customers. Internal stakeholders in the case of UCC project are cities municipalities and government institutions, as well as certain private organizations that could be involved in the financing of UCCs or could be participating in the operation of UCC. From their point of view, the important criteria of UCC success can be followed (Table 1).

<table>
<thead>
<tr>
<th>Important criteria for the successful operation of UCC (internal stakeholders)</th>
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<tbody>
<tr>
<td><strong>Financial Viability</strong></td>
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<tr>
<td>Number of consignments</td>
</tr>
<tr>
<td>Price for using UCC</td>
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<tr>
<td>Operational costs</td>
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<tr>
<td>The range of value-added services</td>
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<tr>
<td>Price of value-added services</td>
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As it is clear from the previous table, for internal stakeholders, the key indicators of UCC success are the financial viability of UCC and accomplishing the set objectives.

On the other hand, the key criteria which determine the success of the UCC may be different for an external group of stakeholders which are transport companies, receivers and final customers in the case of B2C business (Table 2).

<table>
<thead>
<tr>
<th>Important criteria for the successful operation of UCC (external stakeholders)</th>
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<tbody>
<tr>
<td>Type of UCC (mandatory, voluntary, voluntary with restrictions)</td>
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<tr>
<td>Price for using UCC</td>
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<tr>
<td>Value-added services</td>
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<td>Quality of services</td>
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<td>Marketing communication</td>
</tr>
<tr>
<td>Location</td>
</tr>
</tbody>
</table>

As can be seen from the previous table, the criteria for successful UCC projects could be different from the point of view of external stakeholders. The conflict of the interests between internal and external stakeholders may be a major problem in the process of creation and operation UCC.

To find out which criteria will be the most critical for implementing a UCC in the Czech Republic cities, we have applied an AHP method based on several discussion with experts in the field. To avoid duplication in the criteria, the financial viability and the type of UCC were eliminated from the AHP method. The results of the AHP method are shown below (Tables 3-5).
Table 4

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Price</th>
<th>Quality of services</th>
<th>Collaboration</th>
<th>Location</th>
<th>Marketing communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
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<td>0.39</td>
<td>0.27</td>
<td>0.29</td>
</tr>
<tr>
<td>Quality of services</td>
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<td>0.39</td>
<td>0.27</td>
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</tr>
<tr>
<td>Collaboration</td>
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<td>0.08</td>
<td>0.13</td>
<td>0.27</td>
<td>0.29</td>
</tr>
<tr>
<td>Location</td>
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<td>0.12</td>
<td>0.06</td>
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<td>0.18</td>
</tr>
<tr>
<td>Marketing communication</td>
<td>0.08</td>
<td>0.08</td>
<td>0.03</td>
<td>0.05</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Table 5

<table>
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<th>Category</th>
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<th>Rank</th>
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</tr>
<tr>
<td>Quality of services</td>
<td>26%</td>
<td>2</td>
</tr>
<tr>
<td>Collaboration</td>
<td>18%</td>
<td>3</td>
</tr>
<tr>
<td>Location</td>
<td>14%</td>
<td>4</td>
</tr>
<tr>
<td>Marketing communication</td>
<td>6%</td>
<td>5</td>
</tr>
</tbody>
</table>

The AHP method examining the most important criteria of the UCC's success in relation to the Czech Republic's conditions has shown interesting results. The price for using UCC has become the most important criteria. Nowadays, when the price for goods transport is higher in the Czech Republic compared to other EU states. It can be assumed that a significant increase in the price will be a crucial factor for external stakeholder. Quality of services provided by UCC is also a fundamental criterion. The high level of competition in the transport services market forces providers to focus on quality more than ever before. In the case of using UCC for last mile delivery, direct contact with the customer would be lost and thus control on the quality. That is why the security of transport companies about the quality of services provided by UCC is essential.

It is very important to provide good services to the final customers. Otherwise, the external stakeholders will not be using a UCC or will be searching for a way how to leave out a UCC of the supply chain. Collaboration with stakeholders is also related to the future viability of UCC. Stakeholders need to realize all of the reasons for supplying the cities thought UCC, so they will not become in a way and will be cooperative. It could be the most significant barrier for the Czech Republic cities to provide a functional and self-sufficient UCC.

The right location as one of the success factors of UCC implementing was mentioned in every publication. A UCC should be located near the city it will be serving. So, there would be a possibility of using small cars for delivery to the city or some alternative ways, for example, cargo bikes. On the other hand, it is necessary for UCC to be as close to motorway or railways as possible, so transport companies, which need to drop off the shipments in UCC, do not affect transportation in the city with heavy vehicles.

The criterium „number of shipments” was intentionally eliminated from the AHP method. In the Czech cities’ conditions with no existing UCC yet and with high competition in the area of transport services, providing last mile delivery thought UCC would be a significant change. It can be assumed that a lot of external stakeholders will see a UCC as an unwanted competition barrier. Therefore, a possible UCC project should be based on mandatory or voluntary with restrictions concept. In other words, most shipments will be forced to go through the UCC.

For this reason, the number of consignments needs to be calculated as a first thing in the pre-project phase of UCC. Based on how many shipments will be delivered within the city each day, the city municipalities should decide whether it is worth building the UCC on not. That is why the criterium „number of shipments” is not a variable, but it is a major input condition that needs to be considered before the UCC project is implemented.

4. Conclusion

Several UCCs in Europe have been analysed to determine the most important criteria for the successful operation of UCC in Czech cities. Research has been focused on cities up to 100 thousand residents, the cities with similar UCCs have been chosen to be analysed. To better understand the critical criteria of UCC implementing have been selected two successful UCC, one in France, La Rochelle and one in the UK, Bristol and one failed attempt of UCC implementation in the Netherlands, Leiden. Based on literature reviews [3, 5-7] have been selected five criteria which seem to be the most critical for the successful UCC operation in every city. The results of AHP method showed that the most critical criteria are the price of services, which transport companies or final customers need to pay for an item delivered through the UCC. It could lead from the economic situation and the fact that most customers think that delivery costs are quite high at the time. So, in the future, any increases in price will be seen as a negative and unwanted change. The quality of services provided by UCC and collaboration of internal and external stakeholders are the following critical criteria for the future success of UCC. Location of UCC which could affect the future price and availability of UCC for the transport companies is as much important as a collaboration between stakeholders.
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Research on the Impact of Electric Motors Placed in the Wheel Hubs of the Vehicle on the Dynamics of Maneuvers of Acceleration and Braking

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Abstract

The article presents issues related to steerability and stability of a vehicle equipped with electric motors placed in wheels. It also presents the results of research tests and simulations of a vehicle performing acceleration and braking maneuvers. The tests were carried out for a homogeneous surface with a high coefficient of adhesion and for the road surface with different adhesion levels under the left and right side of the vehicle (µ-split). The article includes the description of the mathematical model used during the simulation. The last part of the article presents simulation results for different vehicle construction solutions and for surfaces with different adhesion.

KEY WORDS: vehicle motion dynamics, electric vehicle, electric motors in wheels, µ-split road surface

Nomenclature

\( F_{sk}, F_{yk}, F_{zk} \) – component forces of the interaction between road surface and the wheel (\( k = 1, 2, 3, 4 \)); \( M_{sk} \) – aligning moment; \( F_{an} \) – air drag; \( m \) – vehicle mass; \( L \) – the mass moment of vehicle inertia about the z-axis; \( \psi \) – yaw angle; \( \delta_k \) – steering angle of the wheel (for rear wheels \( \delta_k = \delta_k = 0 \) is assumed); \( I_k \) – the mass moment of inertia of the wheel about its axis of rotation; \( \phi_k \) – wheel rotation angle (\( k = 1, 2, 3, 4 \)); \( M_k \) – drive moment; \( r_d \) – dynamic radius of the wheel; \( f_k \) – substitutive coefficient: \( f_k = \frac{F_{sk} - f_k \cdot F_{zk}}{C_{op}} \); \( M_{sk} \) – braking moment; \( f_k \) – rolling drag coefficient; \( C_{op} \) – tyre peripheral stiffness index (the same for all wheels); \( \gamma_{ko} = \gamma_k(F_{sk}, F_{zk}) \), has a value calculated in the previous time moment when the equations of motion are integrated; \( N_k = F_{sk} \) – normal forces acting on the vehicle wheel (\( k = 1, 2, 3, 4 \)); \( \alpha_k, \beta_k, \gamma_k, \gamma_{ko} \) – coefficients calculated for the assumed model of cooperation of the rubber wheel with the road surface according to Dugoff [11].

1. Introduction

The restrictions on emission of toxic compounds from exhaust gases emitted by vehicles have forced automotive concerns to produce zero-emission cars. The result of this process is the production of cars powered by electric motors. The production cost and reliability of electric vehicles is contingent on the configuration of their drive system.

There are also works on simplifying the construction of electric vehicles involving the elimination of the clutch, gearbox and in some solutions also the main transmission with the differential mechanism. It allows automotive concerns to build mobile platforms on which any shaped bodies can be mounted. There are vehicles on the market in which, as far as drivetrain is concerned; only the engine from internal combustion to electric motor has been changed. There are also vehicles in which larger modifications have been introduced including the elimination of the clutch, gearbox, differential, axles and, in the extreme case, mounting the electric motors in the wheels of the vehicle [8]. This solution is not new, since a vehicle with electric drive motors placed in wheels was already developed by Ferdinand Porsche and Jacob Lohner in 1898 [10].

Each vehicle design solution has its advantages, but it also has disadvantages. Placing electric motors in vehicle wheels increases the inertia of the wheels and increases the unsprung masses. It affects the dynamics of vehicle movement, steering, safety and the comfort of vehicle users. The study of these vehicle features was carried out by many authors [1-4, 6]. Requirements for electric motors mounted in wheel hubs are increasing, because with relatively small overall dimensions they must have a large torque necessary to start and accelerate the vehicle. The requirements for controlling the electric motors while driving on curves of the road are also greater [5, 7]. Increasing the unsprung masses also affects the behaviour of the vehicle during acceleration and braking of the vehicle, especially on surfaces with different coefficients of adhesion under the wheels of the right and left side of the vehicle. The article presents the results of braking and acceleration analysis on a straight section of the road. The tests were carried out for roads with a dry and clean surface with a high coefficient of adhesion and for roads with different coefficients of adhesion under the right and left wheels of the vehicle (µ-split). A way of assessing the behaviour of the vehicle while moving on such surfaces has also been proposed.
2. Vehicle Tests

Taking into account the currently existing infrastructure of charging stations for electric vehicles and analysing the available electric motors that can be installed in wheel hubs of vehicles, it seems that, at present, the most preferred solution is to assemble electric motors in cars intended to be driven mostly in cities. Such motors are produced, among others, by Protean [9] and KOMEL [1].

Traction tests were conducted on a B class vehicle (gross vehicle mass ≈ 1300 kg), equipped with two 80 kW electric motors and a maximum moment of 400 Nm. For cars with a heavier weight, a solution with four drive motors should be used to obtain a suitably high driving performance.

The preliminary tests were carried out in two mass configurations: standard vehicle and vehicle supplemented by additional masses simulating the presence of electric motors on the rear axle. The installation of additional masses that simulate the motors in the wheels resulted in an increase in the total weight of the vehicle by 70 kg. Additional masses simulating the mass of the motor rotor were attached to the rear wheel rims and the stator masses to the suspension elements. It was assumed that the suspension spring rigidity and shock absorber damping coefficient are the same for both configurations. These parameters were further used in the validation of the rear suspension simulation. To conduct the analysis of vehicle motion dynamics, the parameters of the SMzs200S32 motor by KOMEL have been used (Fig. 1).

3. The Scope of Simulation Tests

The aim of the authors was to show the differences in the behaviour of vehicles powered by an internal combustion engine and electric motors placed in wheels. The homologation standard specifies that in the case of vehicles powered totally or partially by an electric motor or motors permanently connected to the wheels, all tests must be carried out with the motors connected [15]. In the research, it was assumed that the mass of a vehicle equipped with an internal combustion engine will be similar to the one of a vehicles equipped with an electric drive (only the masses of the wheels and their moments of inertia will increase). In the case of comparing vehicles with motors placed on the front or rear axle, all drive torque will be generated by these electric motors. In the event that both axes are driven, the torque will be separated by 50:50. To simulate the motion of the vehicle, an own calculation program of the vehicle motion model was used [14]. The comparisons concerned the parameters of the vehicle movement during the manoeuvres of rectilinear acceleration and braking.

The following three cases of power transmission solutions with electric motors placed in the wheels were considered:

- electric motors placed in the rear wheels of the vehicle;
- electric motors placed in the front wheels of the vehicle;
- electric motors placed in all wheels of the vehicle.

Simulation results were compared with the results obtained for a vehicle with an internal combustion engine. The vehicle behaviour was analysed on the surfaces with:

- uniform coefficient of adhesion ($\mu = 0.8$);
- different coefficients of adhesion under the right and left wheels of the vehicle ($\mu$-split - $\mu_1 = 0.8$, $\mu_2 = 0.3$).

Vehicle braking was simulated on a rectilinear section of the road, taking into account the operation of the ABS system.

4. The Simulation Model Used to Analyse the Movement of the Vehicle

In order to conduct a theoretical analysis of the impact of mounting of electric motors in vehicle wheels on the dynamics of motion, a mathematical model of the vehicle was developed. [14].
In the model, the vehicle's basic movement was described using Cartesian coordinate system (position and orientation). The vehicle was treated as a set of rigid solids connected by flexible elements, resilient and damping. Flexible ties were imposed on the suspension movements and the turning movements of the front wheels.

To analyse the dynamics of the car a quasi-spatial model, which has 11 degrees of freedom, has been adopted. The model of cooperation between the rubber tyre wheel and the road surface developed by Dugoff, Fancher, Segel [11, 12] and modified by Uffelmann [13] was used.

The model adopted some simplifications, which assume, among others, that:
- the road surface is perfectly flat, horizontal and non-deformable;
- the impact of the drive system on the road wheels is taken into account in the form of driving moments;
- the characteristics of elastic elements of suspensions and tyres will be linear;
- pivot axle is perpendicular to the road surface.

Fig. 2 shows the scheme of the analysed system.

According to the markings from Fig. 2, the equations of vehicle and wheel motion take the following form:

$$m\ddot{x}_c = \sum_{k=1}^{4} F_{sk} \cos (\psi + \delta_k) - \sum_{k=1}^{4} F_{sk} \sin (\psi + \delta_k) - F_w \cos \psi; \quad (1)$$

$$m\ddot{y}_c = \sum_{k=1}^{4} F_{sk} \sin (\psi + \delta_k) + \sum_{k=1}^{4} F_{sk} \cos (\psi + \delta_k) - F_w \sin \psi; \quad (2)$$

$$I \ddot{\phi}_k = \sum_{k=1}^{4} \left\{-b_k \left[ F_{sk} \cos \delta_k - F_{sk} \sin \delta_k \right] + a_k \left[ F_{sk} \sin \delta_k + F_{sk} \cos \delta_k \right] + \sum_{k=1}^{4} M_{sk} \right\}; \quad (3)$$

$$I \ddot{\phi}_k = M_k - M_{sk} - F_{sk} \cdot r_k + F_{sk} \cdot \dot{f}_k; \quad (k = 1, 2, 3, 4), \quad (4)$$

where $F_{sk}, F_{sh}, F_{sk} - \text{component forces of the interaction between road surface and the wheel (} k = 1, 2, 3, 4).$

In addition, it was assumed that for $k = 1, 2, 3, 4$ forces acting on wheels in the plane of the roadway, and aligning moments, are expressed by the following formulas:

$$F_{sk} = \alpha_k \cdot N_k; \quad (5)$$

$$F_{sk} = \beta_k \cdot N_k; \quad (6)$$

$$M_{sk} = \gamma_{sk} \cdot F_{sk} + \gamma_{sk} \cdot F_{sk} + \gamma_{sk} \cdot F_{sk} = \gamma_{sk} + \gamma_k \cdot N_k, \quad (7)$$
where \( \gamma_i = \alpha_i \cdot \gamma_{\text{ak}} + \beta_i \cdot \gamma_{\text{sk}} \).

Based on the vehicle model adopted in this way, the original computer program was developed. In this program, the configuration of the surface under the wheels of the tested vehicle was defined. The program provides the possibility to simulate the operation of the ABS system. The course of the drive and braking torque was set for individual wheels.

5. Analysis of Vehicle Motion with Electric Motors Mounted in Wheel Hubs During Manoeuvres of: Acceleration and Braking

Comparing acceleration of the vehicle on a straight stretch of road with a high coefficient of adhesion (\( \mu = 0.8 \)) with acceleration on the road with different coefficients of adhesion under the right wheels (\( \mu = 0.3 \)) and the left wheels of the vehicle (\( \mu = 0.8 \)) it was noticed that in the first case, the distance travelled in the first 8 seconds is between 37 and 43m and in the second between 32 and 37m. Larger moments of inertia of the wheels affect the speed after the 8th second of the vehicle’s movement. To evaluate the dynamics of motion, an accelerating rate index was determined from dependence (Eq. (8)).

\[
AR = \frac{F_{\text{DRIVE}_i}}{m \cdot g},
\]

where \( F_{\text{DRIVE}_i} \) - driving force for the \( i \)-th drivetrain solution; \( m \) - vehicle mass; \( g \) - gravity acceleration.

The average accelerating rate of the vehicle, without increased wheel mass and higher moments of inertia by the drive motors is almost constant and amounts to \( \sim 0.14 \) and after assembly of electric motors in wheels it has decreased to \( \sim 0.12 \). The acceleration on the road with different coefficients of adhesion, results in the reduction of the average accelerating rate to \( 0.105 \). The drivetrain solution with the electric motors located in the hubs of all wheels was characterized by the smallest accelerating rate (Fig. 3.).

The relative change of the accelerating rate (Eq. (9)) was determined by comparing accelerating rate for vehicles with drivetrain equipped with electric motors in wheel hubs to drivetrain with internal combustion engine.

\[
ARR = \frac{AR_i}{AR_{\text{Drive_ICE}}},
\]

where \( ARR \) - relative accelerating rate; \( AR_i \) - accelerating rate for the \( i \)-th drivetrain solution; \( AR_{\text{Drive_ICE}} \) - accelerating rate for the drivetrain with internal combustion engine.

Fig. 3 Comparison of relative accelerating rate of a vehicle for various drivetrain configurations: (Drive_ICE) with an internal combustion engine; (Drive_el) with electric motors in the wheel hubs
The acceleration of a vehicle equipped with electric motors mounted in wheel hubs requires overcoming additional inertia resistance resulting from the increase in masses and moments of inertia of the drive wheels. Generally, this reduces the intensity of the acceleration. During the simulation, it was assumed that the drive torque will be the same for the vehicle, no matter what kind of engine drives it. In fact, at low engine speeds the torque of an electric motor is greater than that of an internal combustion engine, which can improve this relationship.

In the case of acceleration of the vehicle on the road surface with different coefficients of adhesion, the relative accelerating rates are lower. The only exception is when the electric motors are mounted in the rear wheel hubs, in which case the accelerating rate is greater than in the case of the drivetrain with combustion engine.

The vehicle stopping distance on a straight stretch of road with a high coefficient of adhesion (\(\mu = 0.8\)) is from 16.5 to 17.5 m. In the case of braking on roads with different coefficients of adhesion on the right and left side (\(\mu = 0.8; \mu = 0.3\)), stopping distance is extended to 23.23.5 m. To evaluate the dynamics of motion, a braking rate index, was introduced, determined from equation (10).

\[
BR = \frac{F_{\text{ABS}}}{m \cdot g}.
\]  

The braking rate on a road with a high coefficient of adhesion (\(\mu = 0.8\)) obtains values from 0.668 to 0.651 (Fig. 4.). Braking on the road with different coefficients of adhesion reduces the braking rate to 0.392-0.367. The vehicle with electric motors mounted in the hubs of all wheels is characterized by the lowest braking rate indices. This is due to the increase in mass and moments of inertia of the wheels, which during the operation of the ABS system change their rotational speed, which affects the acting of this system.

![Fig. 4 Comparison of relative braking rate of a vehicle for various drivetrain configurations: (ABS_ICE) with an internal combustion engine; (ABS_el) with electric motors in the wheel hubs](image_url)

The relative change of the braking rate (equation 11) was determined by comparing braking rate for vehicles with drivetrain equipped with electric motors in wheel hubs to drivetrain with internal combustion engine.

\[
BRR = \frac{BR_i}{BR_{ABS\_ICE}},
\]  

where \(BRR\) - relative braking rate, \(BR_i\) - braking rate for the \(i\)-th drivetrain solution, \(BR_{ABS\_ICE}\) - braking rate for the drivetrain with internal combustion engine.

Braking of a vehicle equipped with electric motors mounted in wheel hubs requires overcoming the additional inertia resistance resulting from the increase in masses and moments of inertia of the drive wheels. Differences resulting
from the assembly of electric motors in the wheel hubs with respect to the drivetrain system with the internal combustion engine are relatively small. The additional load on the front wheels with the mass of electric motors increases the relative braking rate on the roadway with different grip coefficients ($\mu$-split). The additional load on the rear wheels causes a slight reduction in the relative braking rate.

6. Conclusions

The paper presents preliminary simulation tests of a vehicle powered by electric motors placed in wheel hubs. The motion of a vehicle powered by an internal combustion engine (smaller wheel masses and their moments of inertia) was also analysed. The analysis was based on calculations using the original program described in the literature [14]. In order to validate the model, tests of the real vehicle were performed with additional masses imitating electric motors in vehicle wheels.

The use of electric motors located in the wheel hubs to drive the vehicle not only effects on the comfort of driving, but also will change the moments of inertia of the wheels. Especially during acceleration and intensive braking, an increase in masses and moments of inertia of the wheels will result in lowering both the accelerating rate and the braking rate of the vehicle. The change in the relative accelerating rate is greater than the relative braking rate. These changes result mainly from the change of wheel loads and their moments of inertia.

References

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Analysis of the Issue of Flying in the Area Using Free Routes

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Abstract

The thesis generally describes the airspace of free flight routes. It focuses on the benefits of applying such an airspace concept, whether for air operators in the form of cost savings on aircraft operations and speed, as well as for the general public in terms of environmental protection. The work describes the benefits of introducing FRA in the airspace of the Slovak Republic, which shows how much fuel and time can be saved by using airspace with free routes. At the same time, it points out the impact of FRA application on flight trajectories and compares the difference between the trajectory between free routes and the previously used ATS routes. The work also includes a comparison of the production of emission gases produced by using the ATS routes and the FRA concept.

KEY WORDS: free route airspace, airspace, flight routes, direct routes

1. Introduction

The attractiveness of air transport is steadily increasing, demand is steadily growing, and so is the number of flights. As demand increases, the number of airplanes needed to transport people, goods or mail is growing. The growing number of aircraft in the air has posed a problem in the form of insufficient airspace capacity. In the past, this problem caused a flight delay, so it was logical to find a solution to this problem. However, in addressing this problem, it is considered that, in addition to changes in airspace capacity across countries, changes in airspace across the European Union are needed to increase airspace capacity.

2. Free Route Airspace

2.1. Introduction to Free Route Airspace

The concept of free airspace consists of providing air traffic services, whereby the operator can choose a route of flight with only a few restrictions (these restrictions are entry and exit points that the operator must respect and must avoid areas such as TRA or TSA). By using classical airspace, the operator would have to use standard flight paths without optimization. In free air, most operators choose a route that we could describe as a line between the entry point and the exit point. If for some reason it is not possible to fly directly from A to B (for example, to avoid a hazardous area), additional points can be specified. Such points may be published navigation points or points with specified coordinates. The following Figure 1 shows the basic FRA principle 1.

Fig. 1 An example of a flight information area
Fig. 1 shows an example flight information area (FIR) where ENTER and INTRO are entry points and ALTAV and EXITO are exit points. SNA is the VOR point and REKRA is the RNAV point. Where FRAs are in place, green routes would be accepted. Routes displayed in red would be rejected by the ATC flight plan processing system. The route between INTRO and ALTAV would be rejected because it passes through the hazardous area and, in the case of ENTER and ALTAV, this route passes through an area outside the FRA. Routes will only be approved if the route does not cross the hazardous area and must also be in the airspace where the FRA is implemented (e.g. the route between ENTER and EXITO). If it is not possible to fly directly from A to B, other waypoints can be used to fly or select a random point based on coordinates.

2.2. Free Routes Planning

It is now widely known that the current air traffic management system will not be able to ensure the growth of air traffic. In addition, it is assumed that in the near future there will be a level where there is no longer room to meet the company's expectations and the needs of safe and economic air travel. Therefore, further improvements in airspace capacity will be required, which can only be achieved through the restructuring of existing forms of air traffic management. In order to improve the current scenario and the need for route optimization, current sources of inefficiency in air transport need to be addressed. There are five categories of sources of inefficiency that are shown in the following figure 1.

![Fig. 2 Inefficiency categories](image)

Fig. 2 we can see a graphical representation of sources of inefficiency. Between these five categories of inefficiency, if we do not take into account adverse weather, the structure of flight routes is the biggest source of inefficiency.

Within free flight routes (FRA), users can freely plan their routes between entry point and departure, without linking to the route network. Therefore, the implementation of the FRA brings many benefits to users of this airspace, allowing users to achieve an optimal route and not to fly through any checkpoint. Despite existing challenges, this is considered to be one of the most cost-effective changes in the provision of air traffic services (ATS) in Europe. Using the FRA can reduce flight time, reduce CO2 emissions and reduce fuel consumption, as most flights will use the shortest possible routes. It also provides fewer conflicts and better weight optimization because the same number of aircraft is deployed on multiple routes. However, it is important to ensure that such airspace is properly implemented so that the disadvantages do not outweigh the advantages of the airline's third flight system. The most benefits of introducing this route system will only be achieved if the FRA is set up in large areas where appropriate measures need to be taken to avoid further conflicts 1.

3. FRA Advantages and Disadvantages

The European airspace is very congested and causes great delays. The workload of air traffic controllers has reached generally accepted limits. The anticipated increase in traffic requires new innovative methods to overcome these barriers. One of the innovative methods that can solve the current problem of increasing air traffic is the introduction of FRA.

In order to address the need for changes in the air traffic management system, new measures have been simulated and deeply studied to achieve a better global solution. Free route airspace has been introduced and used in several countries in Europe. By 2019/2020, it is estimated that 60,000 - 70,000 NM will be saved per day. In this chapter, we will further describe some of the basic advantages and disadvantages of the FRA airspace concept 1.

3.1. Advantages

Free route airspace is a highly supported flight route system. Based on an analysis carried out in 2003, line capacity can be increased up to five times while saving several million dollars if aircraft were allowed to fly without restrictions in the FRA. In addition to increasing capacity and saving money, air traffic safety should also be increased. The emergence of potential conflicts will be reduced, mainly due to the fact that the current structure has a limited number of roads, which at some points will concentrate traffic 4.
The introduction of the FRA brings a number of benefits, especially to airlines, which will be given greater freedom to choose the best flight plan route and to avoid the constraints imposed by the fixed line network. The most important benefits of introducing FRA include:

- reducing mileage;
- reduction of CO2 emissions due to reduced flight time;
- shortening the flight time because most flights will use the shortest line of two points;
- reduction of waste fuels, also due to reduced flight time and other optimal flight profiles;
- the gradual introduction of FRAs can reduce security risks;
- low cost of implementation on ANSP - in most cases, the FRA is implemented;
- supported at existing ACC devices;
- value optimization - FRA generally reduces the difference in distance between the planned ones;
- the route and the route, which in turn reduces the amount of fuel that is needed and potentially permits greater payload [2].

3.2. Disadvantages

The introduction of FRA also brings several disadvantages. In addition to the difficulty in changing air traffic procedures in the current flight route network, there could be conflicts between the aircraft at the expected points where the flight routes intersect each other. However, in FRA aircraft, they must be expected to fly in almost any possible direction, which means that conflicts can occur at any point in the sector, which increases the workload and complexity of finding conflict by the air traffic controller. Improving conflict detection software could ensure that there is no excessive workload for air traffic controllers and, at the same time, warn them of potential conflicts, which would help increase air traffic safety.

Like any new system or technology, the FRA also has drawbacks. However, the disadvantages of the FRA concept do not outweigh the benefits, so focus on them in order to get the best out of the concept. The main disadvantages of FRAs are:

- this will require air traffic controllers to be even more vigilant in the course of control than before;
- increasing the number of potential conflict situations seems to be one of the main problems. Conflict situations can be difficult to detect as a result of enlargement and an increase in conflict points. These conflict situations occur shortly after the aircraft enters the FRA space;
- in the case of FRA timely implementation, traffic flows need to be optimized so as to undermine the smooth transition [1].

4. FRA in the Slovak Republic

Since 2016, DCT (direct) flight planning has been used in the Slovak upper airspace, which means that FRA has been implemented as a DCT since 2016. However, at the time of working on the implementation of DCTs, it was decided at EU and Eurocontrol level that DCT was not a FRA. From March 28, 2019 it was possible to plan flights in CTA Bratislava over FL245 with the shortest planned routes: for example, PATAK DCT LALES or vice versa PEPIK DCT BALAP (Fig. 3).

Fig. 3 Upper airspace planning in accordance with FRA rules
BRAFRA is a Slovak airspace that fulfills the conditions of airspace of free routes. This concept is applied in Class C airspace and is determined by the vertical limit, the range of which is defined by FL245 - FL660 flight levels 6.

4.1. Proposal for Restructuring of FRA in the SR and Exploring the Benefits

When processing FRA implementation in the Slovak airspace, we were also thinking about how to improve the current status of FRA. We have been considering a possible reduction in the vertical limit in order to make the concept even more beneficial by increasing FRA airspace, thereby increasing airspace capacity. Thus, aircraft operating under FL245 could fly under the FRA rules. We have considered reducing the vertical limit so that, for example, turboprop aircraft, which usually do not fly above FL245 (for economic reasons), could fly in accordance with FRA rules. We have considered reducing the vertical limit from FL245 to FL195 because these flight levels in the FL195 - FL245 range are also commonly used by turboprop aircraft.

In the event that the vertical limit is reduced and the airspace of free airways is introduced lower than at present, the restructuring of the Slovak airspace would be appropriate. For example, if the vertical limit is reduced from FL245-FL660 to less than FL245, it would be necessary to redefine the current restricted and dangerous areas, as well as the many temporarily allocated and reserved areas so that they do not interfere with their upper boundaries in the free route airspace. Since most of the restricted areas are military areas that are frequently used, it will often be necessary to circumvent these areas. In the current airspace structure under FL245 could create places where air traffic would densify.

4.2. Exploring the Benefits of Shifting the Vertical Limit of FRA

In this part we will discuss the benefits of introducing FRA in the airspace of the Slovak Republic under FL245. Since all changes in air traffic are made to improve the safety and efficiency of air traffic, exploring the benefits of introducing the FRA aims to bring how much fuel and time can be saved by using the Free Route Airspace.

Based on the airspace observation through the Flightradar24 web application, we have selected a few direct tracks that were most used during our airspace tracking with this app. We then compare selected direct lines with the respective permanent ATS lines and calculate the amount of fuel saved and time on these lines at the end of the work.

4.2.1. Comparison of Direct Routes with ATS Routes

As mentioned above, in order to demonstrate the benefits of introducing FRAs in the airspace of the Slovak Republic, we have selected a number of straight lines, the distances of which we will compare with the distances that the aircraft would have to fly if they flew over the same entry and exit points after permanent ATS routes. The Table 1 shows the entry and exit points of the straight lines, the distances of these lines and the shortest distances of the respective ATS lines with respect to the entry and exit point [5, 7].

Variables:
- ENTRY - entry point to SR airspace;
- EXIT - exit point from SR airspace;
- DCT - The length of the straight line from the entry point to the exit point;
- ATS - the length of a permanent air traffic service line with respect to the flowing entry and exit point;
- DIFFERENCE - Distance difference between permanent ATS lines and straight lines.

<table>
<thead>
<tr>
<th>ENTRY</th>
<th>EXIT</th>
<th>DCT (NM)</th>
<th>ATS (NM)</th>
<th>DIFFERENCE (NM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAREG</td>
<td>BABKO</td>
<td>130,7</td>
<td>141,5</td>
<td>10,8</td>
</tr>
<tr>
<td>MAREG</td>
<td>MEBAN</td>
<td>130,5</td>
<td>138,1</td>
<td>7,6</td>
</tr>
<tr>
<td>ABLOM</td>
<td>MEBAN</td>
<td>131,4</td>
<td>135,2</td>
<td>3,8</td>
</tr>
<tr>
<td>ABLOM</td>
<td>BABKO</td>
<td>132,3</td>
<td>138,6</td>
<td>6,3</td>
</tr>
<tr>
<td>MREG</td>
<td>MALBE</td>
<td>219</td>
<td>219,1</td>
<td>0,1</td>
</tr>
<tr>
<td>TOVKA</td>
<td>MALBE</td>
<td>219,7</td>
<td>220,9</td>
<td>1,2</td>
</tr>
<tr>
<td>MALBE</td>
<td>MAKAL</td>
<td>168,1</td>
<td>168,1</td>
<td>0</td>
</tr>
<tr>
<td>ALAMU</td>
<td>BABKO</td>
<td>121,3</td>
<td>133,7</td>
<td>12,4</td>
</tr>
<tr>
<td>ODNEM</td>
<td>ALAMU</td>
<td>81,6</td>
<td>82,1</td>
<td>0,5</td>
</tr>
<tr>
<td>ODNEM</td>
<td>ERGON</td>
<td>88,7</td>
<td>88,7</td>
<td>0</td>
</tr>
<tr>
<td>AMRAX</td>
<td>BABKO</td>
<td>91,4</td>
<td>102,9</td>
<td>11,5</td>
</tr>
<tr>
<td>KEKED</td>
<td>PODAN</td>
<td>53,7</td>
<td>54,2</td>
<td>0,5</td>
</tr>
<tr>
<td>KEKED</td>
<td>LENOV</td>
<td>50,1</td>
<td>50,1</td>
<td>0</td>
</tr>
<tr>
<td>LITKU</td>
<td>BABKO</td>
<td>93,1</td>
<td>105,7</td>
<td>12,6</td>
</tr>
<tr>
<td>LITKU</td>
<td>MEBAN</td>
<td>73,6</td>
<td>102,3</td>
<td>28,7</td>
</tr>
</tbody>
</table>
On the basis of the monitored data, it can be stated that the direct track segments brought with them a significant shortening of flight routes compared to the ATS lines. For some lines, the distance between the straight line and the ATS line is very small. However, even such a slight shortening of the flight path at first sight has a significant impact on the efficiency of air traffic in the long term and also has a positive environmental benefit [5].

The next step in our research was to recalculate the input values with the average fuel consumption of the selected airplane types, the average speed of the airplanes and the fuel price, specifically the JET A1 aviation fuel, which IATA publishes on its website. We have selected several types of aircraft. We selected the aircraft in 3 categories: short, medium and long range. It should be noted that the following fuel consumption figures are indicative given that the same type of aircraft may have different consumption at the same speed and altitude, and this largely depends on the weather conditions on the flight path.

The following values were used for the purpose of calculations:
- average Travel Speed 417.4 (kt);
- current value of aviation fuel price 665 ($/t);
- average fuel consumption of selected aircraft types 79.4 (kg / min);
- CO2 per kg of fuel 3.15 (kg).

For the purposes of calculations, the following aircraft consumption and speed data, as shown in Table 2, were required.

<table>
<thead>
<tr>
<th>Aircraft code</th>
<th>Fuel consumption (kg/min)</th>
<th>Travel speed (kts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320</td>
<td>45.1</td>
<td>459</td>
</tr>
<tr>
<td>A330</td>
<td>103.0</td>
<td>466</td>
</tr>
<tr>
<td>A340</td>
<td>117.4</td>
<td>426</td>
</tr>
<tr>
<td>B73C</td>
<td>55.5</td>
<td>437</td>
</tr>
<tr>
<td>B767</td>
<td>85.3</td>
<td>471</td>
</tr>
<tr>
<td>B74B</td>
<td>209.7</td>
<td>452</td>
</tr>
<tr>
<td>ATR 72</td>
<td>8.0</td>
<td>272</td>
</tr>
<tr>
<td>D328</td>
<td>11.5</td>
<td>356</td>
</tr>
</tbody>
</table>

From our investigation and comparison of direct flight routes and ATS overflight routes in the lower airspace, it can be assessed that reducing the vertical FRA limit from the current FL245 - FL660 to FL195 - FL660 would bring even more benefits. It would reduce aircraft operating costs and shorten flight time. Table 3 points out that the implementation of FRA and the conduct of flights on direct routes entail, in addition to a positive economic benefit, an environmental effect. The implementation of the FRA plays an important role in reducing the CO2 emissions produced [7].

<table>
<thead>
<tr>
<th>Summarizing comparative values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total distance (NM)</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>ATS Route</td>
</tr>
<tr>
<td>DCT Route</td>
</tr>
<tr>
<td>Different</td>
</tr>
</tbody>
</table>

Reducing the FRA's lower vertical limit would shorten flight trajectories by 96 nautical miles. There will be a decrease in the amount of fuel consumed, in our case, on average; almost 1096 kilograms of fuel will be saved on the track being monitored, which means that the cost of aviation fuel in the amount of less than 728,639 USD is saved on the IATA website. This calculation relates to the JET A1 aviation fuel price stated on April 12, 2019. As mentioned above, the use of FRAs has also made it possible to shorten the flight time, with the tracks being tracked down by almost 14 minutes, which may seem negligible. However, if the number of flights carried out is taken into account, even a small reduction in flight time at first sight will be of great importance.

At present, but especially for the future, the issue of environmental protection is very important. In this context, we have also decided to highlight the benefits of shortening flight trajectories from this perspective. From the results of our calculations it is possible to know that at a shorter distance less fuel is consumed, which means improvement not only from an economic point of view but also from an ecological one. For flights made over the ATS flyover lines, less than 67,634 kilograms of CO2 emissions were produced, which is 3,451 kilograms more than in the case of direct line flights.
5. Conclusion

As a result of globalization, demand for air transport continues to grow. However, the expansion of the air force also brings some negative factors. For example, flight delays, airspace density, increased fuel costs, and so on have been eliminated. The European airspace required changes to be made. Such a change, which is expected to improve the current airspace capacity situation, is a FRA concept.

In addition to increasing airspace capacity, this initiative is mainly aimed at increasing the efficiency of air transport. By examining our benefits, we have confirmed that the use of FRA, and thus the associated use of direct routes, will save not only time but also the fuel to carry out the flight. This is a big positive for air operators, bringing them many options for flight planning.

However, the question is whether the reduction of the vertical limit is appropriate in the Slovak airspace with respect to the airspace structure. Whether the aforementioned reduction in the vertical limit with the aforementioned benefit will also bring some disadvantages related to the FRA's lower limit. The main limiting factors limiting us to the introduction of FRAs in airspace under FL245 include the fragmented airspace structure under FL245 - the number of frequently used published military areas. The presence of airports in the states neighbouring the Slovak Republic, especially in the west, is one of the factors that limit the implementation of our proposal to lower the FRA's lower vertical limit to FL195, mainly because of the complexity of traffic in the vertical FIR. After a thorough review of the airspace of the Slovak Republic under FL245, its use, and after reviewing the advantages and disadvantages of a possible reduction of the vertical limit, we concluded that a possible reduction of this limit would bring a number of complications regarding airspace structure and airspace management.

In conclusion, the introduction of FRAs in European airspace has great potential, both economically and environmentally. And in order to make the most of the concept, the Member States of the European Union need to agree and unite in the charging policy for the use of airspace and the provision of navigation services. At the same time, the restructuring of its airspace would bring a higher effect for the Slovak Republic.

References

Smart City Concept of Selected Cities in the Czech Republic

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Abstract

The article deals with Smart City concepts and strategies of selected cities in the Czech Republic. The concept of Smart City has become a point of interest in scientific publications and in public sector over the past ten years. It is a concept of applying sustainable development of cities principles based on the use of modern technologies to improve quality of life and make governance more efficient. This concept is widely used in the field of transport, which can be more effectively addressed by using appropriate information and communication technologies. The article presents an approach to this issue in the Czech Republic with a focus on recommendations and methodologies provided by the Ministry of Regional Development. The concepts and strategies of selected cities are analysed and then compared, with a particular focus on transport in the context of recommendations and methodologies.

KEY WORDS: sustainable urban mobility plans, Smart City concept, sustainable development

1. Introduction

Sustainable urban development poses a major challenge to the planet's future in the 21st century, relative to the contribution and adaptation to climate change, natural resource consumption, energy transition (oil transition), population mobility, well-being and security, pollution, global economic growth [1, 2]. In the context of Smart City, urban traffic can only be dealt with as a single unit, i.e. by comprehensive regulation of freight, individual, public, cycling and pedestrian traffic. The European methodology for Sustainable Urban Mobility Plans (SUMP) serves this purpose. The last decade has transformed societies in an unprecedented way. The development of communication technologies is deeply reflected in almost all people's activities. Information technologies greatly influence the way people do business, how people organize human societies and how people care about the environment: the three pillars of sustainability. The transport sector is one of the fastest growing economic areas in Europe and worldwide. The article presents an approach to this issue in the Czech Republic with a focus on recommendations and methodologies provided by the Ministry of Regional Development. The concepts and strategies of selected cities are analysed and then compared, with a particular focus on transport in the context of recommendations and methodologies.

2. Theoretical Background

SUMP is a modern and very current topic. The term SUMP is found in scientific articles over the past 5 years [3-7]. The SUMP is a strategic plan proposed by the European Commission as a policy tool for a new planning paradigm in the Europe. SUMPs are local transport plans that should include a long-term and sustainable vision of cities, be based on extensive citizen and stakeholder participation processes, and serve as a means of coordinating cross-sectoral policies in order to respond effectively to people's mobility needs [8]. The SUMP concept considers a functional urban area and assumes that plans will be developed in collaboration across different policy areas and sectors across different levels of government and administration and in cooperation with citizens and other stakeholders [9]. Various options are available for urban mobility, including congestion charges, car sharing systems, eco-driving support, etc. [10]. There are currently many examples of the application of these measures in European cities; for a summary of the applications see [11]. According to the European Commission and the Green Paper on Urban Mobility [12], urban transport in the European Union is responsible for almost 40% of CO₂ emissions from the total transport sector and 70% of other pollutant emissions [13]. Cities are in charge of developing a SUMP, whose main objective is to provide and promote alternative means of transport for passenger cars [14]. Mobility is a factor...
contributing to urban energy consumption. In terms of energy, mobility is a part of the transport sector, and therefore the characteristics of urban mobility need to be taken into account when planning transport issues [15]. Mobility is heavily dependent on the private car and its use has a significant impact on fossil fuel consumption [16]. The relationship between urban development and mobility is largely dependent on the modes of transport and the speed at which they move [17, 18].

The need for the active participation of all sectors of society in consultations and decisions on sustainable development and urban future planning was already formulated in the Brundtland Report in 1987 [19]. It was soon recognized that sustainable mobility planning had to be complemented by processes to address the impact of increasing urban traffic. In Europe, some countries have adopted, at an early stage, comprehensive transport planning policies that would lead cities to develop and implement these plans [20]. The term Smart City concept is a very important term in the context of SUMPs. Recently a new concept of urban management called Smart Cities or the Smart City concept has been found in scientific literature, as evidenced by numerous articles and conferences and various other activities taking place on this subject almost daily [21]. Smart City is a fuzzy concept that is not yet well defined and not fully understood [22 - 24]. There are many ways and directions that try to explain what a Smart City concept is and what it actually includes [25]. Popular descriptions of the Smart City concept include: sustainable development, intelligent and associated urban systems, innovative urban approaches, especially in spatial planning and urban planning [26]. In fact, the whole Smart City concept is designed and focused on finding smart ways of accessing and developing the interconnectedness of innovative and modern technology solutions that will enable everyone in the city to achieve better coexistence in an urban environment [27]. At a global level, different priorities in the development of Smart Cities: in North America the focus is on smart grids, in Europe for recovery and sustainability, in Asia more on urbanization and eGovernment issues, and most in Latin America to promote transport. The fact is that a Smart City is not a top-down concept, but a bottom-up concept, because the Smart City concept is based on the use of technology to solve urban problems [28].

3. Materials and Methods

In Europe, there still doesn’t exist any unified methodology for the Smart City concept. Most of the cities go their own way in order to gain new experience following with their pros and cons sharing. The methodology of the Smart City concept is available on the website of the Ministry for Regional Development of the Czech Republic [29]. This methodology is intended as a guide on how to access to the Smart City solutions. It defines Smart City attributes that result in a unified table which consists of 16 components (see Table 1).

<table>
<thead>
<tr>
<th>Higher unit</th>
<th>Nr.</th>
<th>Component</th>
<th>Example of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: organizational</td>
<td>1</td>
<td>Political commitment</td>
<td>Smart city vision</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Organization and responsibility</td>
<td>City department and responsible person</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Strategy / action Plan</td>
<td>Strategic and action plan for vision implementation</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Cooperation and long-term partners</td>
<td>Working group (with minutes)</td>
</tr>
<tr>
<td>B: community</td>
<td>1</td>
<td>Activates and connects</td>
<td>Application / website for collecting ideas and comments</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Creates and manages communities, supports a self-development</td>
<td>Motivation and support programs for residents</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Shares (sharing economy)</td>
<td>Sharing concepts (housing, workplaces, means of transport, etc.)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Cultivates a public space</td>
<td>Zoning plan visualization, street space categorization</td>
</tr>
<tr>
<td>C: infrastructural</td>
<td>1</td>
<td>Area coverage</td>
<td>Technology and full area regulation</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Multipurpose solution</td>
<td>One investment / technology to cover multiple purposes, a system synergy</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Integrated solution</td>
<td>One central administration subject</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Open solutions</td>
<td>Open data</td>
</tr>
<tr>
<td>D: final</td>
<td>1</td>
<td>Quality of life: a digital, open and cooperative city</td>
<td>Variety of services, space for business</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Quality of life: a healthy and clean city</td>
<td>Environmental impact on residents</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Quality of life: an economically interesting city</td>
<td>Financial impact on residents</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Brand with a great reputation</td>
<td>Media image of Smart city programs</td>
</tr>
</tbody>
</table>

They also represent a unified step-by-step procedure leading to the real social change which the concept sets. These components are divided into 4 consecutive higher units (organizational, community, infrastructural and final). The Smart City concept presents a program change driven by the city management. It is a sequential process, not only an actual state.

The aim of the article is to analyze and compare Smart City concepts of selected cities with a particular focus on transport in the context of the methodology. The concepts of cities Pardubice and Hradec Králové were monitored. Both
are regional cities with over 90 thousand of inhabitants [30].
In Table 2 below there are listed fundamental characteristics of the two selected cities, as mentioned above.

Table 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Pardubice</th>
<th>Hradec Králové</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Inhabitants</td>
<td>90 335</td>
<td>92 917</td>
</tr>
<tr>
<td>Area [m²]</td>
<td>83</td>
<td>106</td>
</tr>
<tr>
<td>Private/personal cars *</td>
<td>263 037</td>
<td>290 255</td>
</tr>
<tr>
<td>Motorcycles *</td>
<td>69 325</td>
<td>71 977</td>
</tr>
<tr>
<td>Buses*</td>
<td>1 171</td>
<td>752</td>
</tr>
<tr>
<td>Public City Transport (number of lines)</td>
<td>35</td>
<td>42</td>
</tr>
</tbody>
</table>

*The data is for Pardubický region, Královéhradecký region respectively

These two cities have been selected for the reason that the abovementioned methodology should be used, as recommended, primarily for implementation of Smart Cities programs in a more complex manner and such conditions can be expected mainly in large cities and agglomerations. The methodology, for this objective, creates own categorization of cities. This categorization of cities includes the size of cities in the CR (defined by the number of inhabitants) as well as functional typology of cities and municipalities under the overall structure of settlements (that means the functional category of municipalities/ranking of a municipality, administrative and territorial divisions and other functions that a municipality provides to its wider area according to its rank). Both of the selected cities are cities of Category B (from 40th. to 150th. inhabitants); these are larger cities with a more developed public transport system, statutory towns.

To meet the objectives of this article content analysis has been carried out. This analysis is based on publicly available documents and information that is available on web pages of both cities. The recommendations from the methodology were used to assess the level of fulfilling the individual components of the methodology for transport – points from a pre-defined points scale/rank were allocated. For the purposes of this article the evaluation scale 0 – 5 was applied, the higher the evaluation the higher the level of quality of the fulfillment of the individual criteria/component. The authors of this article did the evaluation independently. The total points evaluation represents the arithmetic average of the points allocated to the individual components of the concept by the individual evaluators.

This evaluation was realized with the knowledge that the concept of Smart City can be implemented only by using overall system approach to the individual city agendas that must be mutually interlinked. This is indeed a complex process that requires the achievement of synergy effects. In the framework of this article and with regard to the used methods the individual components of the concept were evaluated in an isolated manner and only based on publicly available information. For complex evaluation it was essential to execute more complex analyses.

4. Results and Discussion

Table 3 shows how the cities Pardubice and Hradec Králové meet individual components of the Smart City concept in the field of transport.

From the results of the analysis (see Table 3) it issues that both cities got the highest number of points in the Component A.1, that is Political Commitment and Visions that are included in the strategic plans of both these cities or alternatively their are included in political program statements. They give attention to building a well functioning transport system that would be environmentally friendly with a major role of public transport in these systems.

Promotion of knowledge of these issues as well as developing outstanding reputation is supported by component D.4. which is represented by various press statements and short information programs broadcasted in local televisions (EastBohemia broadcasting and Hradec internet television). Pardubice fulfils component A.2 by the act of establishing committee for strategy and Smart City; Hradec Králové has established commissions for transportation and for cycling promotion; both commission closely cooperate with city strategy development department. Both Pardubice and Hradec Králové have city strategy documents available, (strategy concepts respectively) of Smart City. Pardubice put focus on intelligent parking, electro mobility development, bike and car sharing and on having smart transport information available. In the strategy document the most advanced concept is the concept of the system for monitoring available/free parking spaces. Hradec Králové divides the concept of Smart City in the transport area into 4 main areas. These are: Hradec Králové as the city of cyclists, transport organization (that includes: intelligent transport system and smart parking) smart public transport and electro mobility. When regarding the transport system as a whole unit both cities have the most developed strategy for cycling transport. In relation to this these cities have established special web portals www.pardubike.cz and www.cyklohradec.cz that serve the purpose of information exchange. The support to cycling transport takes the form of organization and implementation of various events (for instance events “Cycling to Your Work Place“ and “Mobility Week”). Both cities have also week areas. These areas are: lack of e-portal for collection of comments and ideas from citizens. Citizens of both of these cities can only participate in public hearings; they can submit their comments/feedback only via the official filing/registry office or via the relevant officer. Regarding the development of strategic partnerships in the Smart City area Pardubice city cooperates with Smart City Point and Hradec Králové co-operates with s GIST, s.r.o.
Table 3

Fulfilment of the Smart City concept in the field of transport in selected cities

<table>
<thead>
<tr>
<th>Higher unit</th>
<th>nr.</th>
<th>Component</th>
<th>Pardubice</th>
<th>Hradec Králové</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: organizational</td>
<td>1</td>
<td>Political commitment</td>
<td>3.3</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Organization and responsibility</td>
<td>2.3</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Strategy / action Plan</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Cooperation and long-term partners</td>
<td>2.2</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Activates and connects</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>B: community</td>
<td>2</td>
<td>Creates and manages communities, supports a self-development</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Shares (sharing economy)</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Cultivates a public space</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>C: infrastructural</td>
<td>1</td>
<td>Area coverage</td>
<td>1.7</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Multipurpose solution</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Integrated solution</td>
<td>2.2</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Open solutions</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>D: final</td>
<td>1</td>
<td>Quality of life: a digital, open and cooperative city</td>
<td>2.2</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Quality of life: a healthy and clean city</td>
<td>1.7</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Quality of life: an economically interesting city</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Brand with a great reputation</td>
<td>3.0</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Source: [authors based on 32, 33]

Transport research is done to find out more about the transportation behaviour of citizens under the infrastructure area. Pardubice, compared to Hradec Králové, uses more of cycling counters that are located in major transport points where large flows of cyclist are expected. Regarding public municipal transport both cities strive to provide better information to citizens by means of information boards that contribute to easier transport in the city. Pardubice operates Geoportal. On this Geoportal citizens can get information about parking and about transport situation (for instance about existing and planned road closures, about traffic accidents and similar). Hradec Králové currently focuses mainly on integrated parking system developed based on licence/concession agreement with company ISP Hradec Králové, a.s. In the area of open data (C.4) Pardubice offers results of transport research and as well provides information via the abovementioned Geoportal where any citizen can obtain various information in order to improve the quality of life in the city. Hradec Králové established the portal Opendata that has a large potential. However currently it does not provide much useful information. Regarding communication via social networks Hradec Králové is more advanced since Hradec communicates also via Youtube, Instagram and via its own Internet television next to the already standard communication channels (Facebook and Twitter). In the quality of life area both cities show approximately same results and in both cities support to cycling transport and preservation of green areas in the city are the dominating activities.

Fig. 1 Smart City Framework with 16 hierarchically organized components
Currently there are no economic incentives for citizens not owning/using cars compared to citizens owning more that one car. The future will show whether those citizens, whose behaviour is more environmentally friendly, compared to conventional behaviour, receive any economic benefits for such behaviour.

Fig. 1 shows summary results of evaluations for individual higher units for both cities. The resulting value of the higher unit is calculated as an arithmetic average/mean of evaluations and their individual components.

5. Conclusions

The objective of this article was to analyse and consequently compare Smart City concepts in the area of transport in selected cities with the methodology recommended by the Ministry for Local Development of the Czech Republic. Cities Pardubice and Hradec Kralove are currently in the initial, preparatory phase respectively in the area of smart solutions in transport. The Smart City concept has political commitment, which is obvious from strategy plans of both cities and from various media presentations that promote the Smart City idea. In the area of transport both of the analysed cities are most developed in the area of cycling transport. In this area they have already developed and designed strategy and action plans that are step-by-step implemented. From the analysed documents it is clear that both cities have already defined the key issues in the transport area, which have to be dealt with. Among such issues are the growing number of transport vehicles and the related parking issues and the transport density and intensity within the city issues. Both cities have available solutions in place that shall be step-by-step implemented while they strive to utilize synergy effects (for instance building an intelligent transport system within the Hradec-Pardubice agglomeration).

Acknowledgement

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References

Application of Statistical Analysis to Investigate the Relation Between Road Roughness and Vehicle Vibrations

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Abstract

The paper investigates the relation between the longitudinal road profile and momentary variation of the vehicle body vertical acceleration. In particular, changes of the road profile are investigated near points where the acceleration has large maxima or minima. The vehicle motion has been simulated using a quarter-car model and random vertical road irregularities generated with the power spectral density for the class-B road. The relation between the local road roughness and the extrema of the vehicle acceleration was investigated with the statistical method previously developed by one of the co-authors. The performed analysis clearly identifies the characteristic variation of the road profile that leads the peaks of acceleration.

KEY WORDS: random road excitations, statistical method, vehicle suspension

1. Introduction

Random vibrations of a vehicle are a serious problem in its operation due to lowering safety and ride comfort, even leading to health hazards to drivers. For these reasons, reduction of vibration level and construction of more advanced vehicle suspensions and driver’s seats have been a subject of intense investigations for many years [2, 3, 10]. Various control algorithms are used, from the simplest two-state to adaptive systems whose aim is a quick response to any change in vehicle vibrations [9, 10]. However, since the control of vibrations with random waveforms is difficult due to changing operating conditions, passive systems with constant parameters of damping and stiffness without control systems still predominate in the construction of the vehicle suspension [11].

The ride comfort is determined by vehicle body vibrations to which travelling passengers are exposed to. The standard method of the comfort evaluation [4] is based on the root-mean-square (rms) acceleration values in frequency bands (with the centre frequencies from 0.8 to 80 Hz) and calculations of synthetic comfort indices using respective frequency-dependent weighting functions. In particular, this method was previously used for evaluation of the ride comfort in railway vehicles moving along the track with random irregularities [7], while the spectral analysis was also found useful in investigating the risk of derailment [8]. In the spectral approach, the ride comfort depends on the transmission of the road excitations with various wavelengths (or equivalent frequencies for a specific vehicle velocity) to the sprung mass representing the vehicle body. This process is described by the spectral transmittance function whose module is defined by the ratio of the power spectral density (PSD) of the body acceleration to the PSD of the excitation representing the road profile. However, the ride comfort indices determined with the spectral distributions of input and output signals depend only their overall variations on test road sections and do not account for momentary increase of the vehicle body acceleration (peaks) at discrete times which can also affect ride comfort or even represent a health hazard to passengers. For this reason, additional comfort indices that account for such discrete events can be introduced like it is done in railway applications [1]. However, the relation between acceleration peaks and road excitations is not straightforward to determine and needs to be investigated. This problem is undertaken in the present paper based on simulation of the vehicle dynamics moving on a rough road surface and subsequent application of the statistical method developed by one of the co-authors and previously applied to investigate local track irregularities leading to locally enhanced dynamical responses of a railway vehicle [6]. The aim of the present work is to find specific variations of longitudinal road profile that lead to large momentary extrema of the car body vertical acceleration.

2. Vehicle -Road Model

The analysis of random vehicle vibrations due to road excitations requires an integrated investigation of road roughness and vehicle dynamics [11]. There are generally three fundamental elements in a typical model of a vehicle dynamical system: the wheels, the suspension with springing and damping, and the car body. In the initial stage, a quarter-car model with passive suspension is used for the analysis of the vehicle vibrations (Fig. 1). According to it, the equations of the vehicle motion can be written as follows:

$$m \frac{d^2 z_1}{dt^2} + c_1 \left( \frac{dz_1}{dt} - \frac{dh}{dt} \right) + k_1 (z_1 - h) + c_2 \left( \frac{dz_1}{dt} - \frac{dz_2}{dt} \right) + k_2 (z_1 - z_2) = 0;$$  (1)
where $h$ - the longitudinal unevenness of the road (road profile), i.e. the vertical road irregularity varying in the longitudinal road direction. It is a function $h(x)$ of the vehicle position $x = vt$ along the road or a function $h(t)$ of time $t$ for a specific vehicle speed $v$. The parameters of this model are given in Table 1.

![Diagram](image)

**Fig. 1 Road–vehicle model with passive suspension**

### Table 1

<table>
<thead>
<tr>
<th>Model parameters</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_2$ (sprung mass)</td>
<td>462.5</td>
<td>kg</td>
</tr>
<tr>
<td>$m_1$ (unsprung mass)</td>
<td>47.8</td>
<td>kg</td>
</tr>
<tr>
<td>$c_2$ (suspension damping)</td>
<td>2247.1</td>
<td>N.s/m</td>
</tr>
<tr>
<td>$k_2$ (suspension stiffness)</td>
<td>21.5</td>
<td>kN/m</td>
</tr>
<tr>
<td>$k_t$ (tires stiffness)</td>
<td>253.6</td>
<td>kN/m</td>
</tr>
<tr>
<td>$c_t$ (tires damping)</td>
<td>141.2</td>
<td>N.s/m</td>
</tr>
</tbody>
</table>

The numerical simulation based on Eqs. (1) and (2) and the subsequent analysis of vehicle vibration and road excitations was conducted for a B-class road profile (in accordance with the international ISO 8608 standard [5]) with a sufficiently long mileage (4 km) treating excitation as a random stationary process. According to the theory of stochastic processes [12], the random road excitations $h(t)$ with the PSD function $S_h(\omega)$ defined in a frequency range $(\omega_1, \omega_U)$, can be represented as the sum of $N$ harmonic signals with the frequencies $\omega_k = \omega_c + k\Delta\omega$ ($k = 1, \ldots, N$; $\Delta\omega = (\omega_U - \omega_1) / N$), the variable amplitudes $A_k = \sqrt{2S_h(\omega)\Delta\omega}$ and independent random phases $\Phi_k$.

$$h(t) = \sum_{k=1}^{N} A_k \cos(\omega t + \Phi_k).$$

(3)

This formula serves for numerical generation of random road excitations using their known PSD $S_h(\omega)$ given in the ISO 8608 standard and a random number generator to obtain values of $\Phi_k$ with the uniform probability distribution in the interval $[0, 2\pi]$.

### 3. Results

The generated road profile $h(x)$ and corresponding variations of the vehicle’s sprung mass acceleration $a_s(x)$ (where $x = vt$) obtained in simulations are shown for a 500 m road section in Fig. 2. As it is seen, the vehicle acceleration strongly varies during the motion and attains large extreme values (minima and maxima) at some few discrete times. However, the comparison of the plotted $h(x)$ and $a_s(x)$ does not reveal a clear relation between the large peaks of $a_s(x)$ and the local variation of $h(x)$ that leads to the occurrence of such peaks.
The determination of such a relation is the main aim of this work. It is done by analyzing the variations of the longitudinal road profile $h(x)$ and vertical acceleration $a_z(x)$ in the vicinity of the positions $x_k$ where large extrema of $a_z(x)$ occur. For this purpose, the maxima and minima of $a_z(x)$ are investigated separately. In particular, for the considered maxima, it is required that $a_z$ is greater than some large threshold value which leads to identifying a small number of peaks $a_z(x_k)$ and their positions $x_k$ ($k = 1, \ldots, M$). In an exemplary simulation of the vehicle motion at speed $v = 80\text{km/h}$, thirteen ($M = 13$) acceleration peaks (maxima) with $a_z(x_k) > 1.8\text{m/s}^2$ are identified. The variation of vertical acceleration $a_z(x)$ of the vehicle body and vertical road irregularities (longitudinal road profile) $h(x)$ close to the positions of these peaks are plotted with thin colour lines in Fig. 3. Although some similar patterns for different peaks can be noticed within a few meters from the peak positions, the signals $h(x)$ and $a_z(x)$ include large random parts which make it difficult to visually determine characteristic variation of vertical road irregularities that leads to the peaks of the vehicle body acceleration.

To extract such a variation, as a function of the distance $u = x - x_{\text{peak}}$ from the peak location, the random part of $h$ is largely removed by calculating the statistical average [6] of the vertical road irregularities in the vicinity of the peak positions:

$$h_{av}(u) = \frac{1}{M} \sum_{k=1}^{M} h(x_k + u). \quad (4)$$

This average dependence well represents the non-random (common) part of the road irregularity $h(x_k + u)$ around the locations $x_k$ of the acceleration peaks. A similar formula can be used to find the average dependence of any dynamical response around the positions of the acceleration peaks, in particular, of the vehicle body acceleration itself.

The resultant average dependences $h_{av}(u)$ and $a_{zav}(u)$ are plotted with thick black lines in Fig. 3. The analysis of these dependences shows that large maxima of the acceleration occur at the locations around which the average longitudinal road profile has the characteristic pattern with a large minimum (depression) at the peak position and a few smaller oscillations with an estimated $7\text{m}$ period. An analogous statistical analysis shows that a similar localized oscillatory pattern of the average irregularities $h_{av}(u)$, but with a large maximum (bump) at the very peak position ($u = 0$), is present around the locations of large negative peaks (minima) of the body acceleration (plots not shown).
Fig. 3 Road profile $h$ (upper panel) and vertical body acceleration $a_z$ (lower panel) (thin colour lines) around the points $x_k (k=1,\ldots,M=13)$ where $a_z(x_k) > 1.8 \text{m/s}^2$ and their averages $h_{av}$, $a_{zav}$ (thick black lines) as functions of the distance $u = x - x_{peak}$ from the peak position, for $v = 80 \text{ km/h}$ and a 4000 m section of class-B road.

A similar shape of the average dependences of the road profile in the vicinity of the acceleration peaks have been obtained for other values of the vehicle velocity $v$ (Fig. 4). However, the width of the depression in the road profile around the position of the acceleration peak (maximum) grows linearly with increasing the car velocity. Such a linear dependence on $v$ is clearly seen if $h_{av}(u)$ is plotted as a function of time distance $\tau = t - t_{peak} = u/v$ from the times at which the peaks occur. Indeed, it is found that that after such a rescaling the width of the depression in the resultant function $h_{av}(\tau)$ around the moment $\tau = 0$ when the acceleration peak occurs is very similar for various car velocities. This means that the time in which the vehicle crosses the depression in the road is almost the same for different $v$.

Fig. 4 Average vertical road irregularities $h_{av}(u = x - x_{peak})$ in the vicinity of the road locations where maxima of the vehicle body acceleration $a_z$ with values larger than 1.5 m/s² and 2.2 m/s² occur for the vehicle velocity of $v = 60 \text{ km/h}$ and $v = 140 \text{ km/h}$, respectively, on a 4000 m section of class-B road. The rescaled average dependence $h_{av}(\tau = u/v)$ (where $\tau = t - t_{peak}$ denotes the time distance from the peak occurrence) is shown in the lower panel.
Thus, it can be interpreted that a large acceleration peak arises due to excitation of a particular vehicle vibration mode by a depression in the road profile with the width $L = \nu T$ corresponding to the oscillation period $T$ of this vibration mode. Here, let us also note that since the depressions in the road profile leading to acceleration peaks (maxima) are different for different vehicle velocities, these characteristic patterns and the resultant acceleration peaks are usually located at different positions on the road for different $\nu$.

4. Conclusions

The statistical method previously developed for analysis of discrete events related to running safety in railway vehicle-track systems is now successfully applied to a vehicle-road system with a random longitudinal road profile. In particular, the relation between the local road profile and momentary increase of the acceleration of the car body is investigated based on the results of simulation of the vehicle motion on a rough road surface. The calculations of statistical averages of the road excitations and the resultant dynamical responses around the road locations where large peaks of the body acceleration occur reveal the characteristic pattern in the variation of the vertical road irregularities that leads to the acceleration peaks. The dependence of this pattern on the vehicle velocity is further investigated by representing it in the time scale and its relation to the vehicle’s vibration modes is indicated.

References

Design of Model for the Calculation of Railway Tunnel Vulnerability

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Abstract

Rail transport is composed by a group of interconnected and interactive parts that fulfill an important job or task. These include means of transport, management and information system, human resources, but the most important is transport infrastructure. An inevitable prerequisite for maintaining its functionality is to correctly identify the vulnerability of its key elements, including tunnels and so the following article deals with the design of a vulnerability model. We want to contribute to increasing the focus on the vulnerability of the key elements of the railway infrastructure, which becomes not sufficient attention at present.

KEY WORDS: infrastructure, rail transport, vulnerability

1. Introduction

The development of human society is accompanied by the development in the field of its protection. High numbers of means of transport, advanced transport networks as well as computer-aided modernization bring not only enormous demands on safety but also on preventive measures and vulnerability assessment.

However, we could see very often that infrastructure managers deal with these facts only when happens a major property-related accident and an accident with consequences to human health or even life. That is why many people around the world are increasingly highlighting the need to occupy with the vulnerability of critical infrastructure, what gives international impulses to the emergence of projects and tools and then taking security measures.

These facts have led us to select a topic, which concrete output is a model for calculating the vulnerability of key elements of rail infrastructure. It is based on the correct identification of risks that threaten the key elements of the designated track section, and is also related to the hypothesis of our work that the vulnerability of key elements can be assessed on the basis of quantitative and qualitative information on key element parameters. These were obtained by scientific research methods, mainly by analysis, in our case of ŽSR statistical data, and by consultations with rail transport experts.

The performed analyses showed that there is currently no system for assessing the vulnerability of railway infrastructure, even though that its importance and significance is growing.

The key elements are based on a number of criteria (the uniqueness and importance of the railway object, the difficulty of its renewal and others) identified from the transport infrastructure and the management and information system, which are the most important components of the transport system. Our choice is also justified by the fact that most of the accident events are related to railway infrastructure equipment or infrastructure equipment failures.

We did not take into account the elements related to means of transport, human resources and repair capacities, because it would spread too much the issue of work.

In this article, we approach the tunnel vulnerability assessment model and set the criteria for setting the rating.

2. Vulnerability of Key Elements of Rail Transport

Threats to the safety of any transport can be assumed on the basis of two facts, namely: the design features of the track elements and the geographic circumstances of the environment where they are located and the occurrence of the particular accident events so far.

We consider the first category of threat, for example physical properties of the structural elements of the track, geographic and meteorological environment, existence of bypass lines, etc., as a constant state of the element and we can assume its threat based on knowledge of behavior of certain materials, their physicochemical properties, but the environment in which the element is located. For example, we consider altitude, geological subsoil, average rainfall, etc.

We analyzed these threats by determining the maximum threat level and determining the percentage of their possible occurrence.

To determine the level of risk to the second category of risks (identified as environmental risk), we used the railway safety analysis published by ŽSR every year. In them we can find real numbers of individual accident events that happened in the past calendar year.

These analyzes are needed to obtain statistical data that is relevant to the proposed vulnerability assessment model. This model is based on the assumption of certain threats and on the real data obtained from the operation of specific
sections of the railway. In doing so, we assume that if an accident happened to some extent over the past few years, it would be about the same year.

The relationship between the number of accidents, infrastructure and vulnerability can be described: reducing vulnerability reduces the number of accidents, while increasing the security and operability of the infrastructure. Ensuring smooth and secure operability is the main objective of any infrastructure, which is closely related to the efforts to reduce the number of accident events that have arisen and have a major impact on railway infrastructure safety and operability. The vulnerability of individual key elements is determined by the design features of the element and the risk of the immediate surroundings of the element. Vulnerability, however, can also be expressed by the proportion of the total number of certain accident events to the total number of all accident events (designated as \( m_1 \) in the calculation) and the total track length (in the calculation as \( n_1 \)), which directly affects the number of accident events. Reducing vulnerability results in fewer accident events and vice versa. Reducing the number of accidents related to rail infrastructure has a direct impact on increasing its safety and uptime.

The tunnel vulnerability assessment model is based on the proposed general model to calculate the vulnerability of key elements (Fig. 1).

The general model consists of 11 steps, with the first three steps being the same for all key elements, the bridge, the wide track, the station and the tunnels. Differences arise in the third step. This chapter will briefly describe the proposed criteria and parameters for tunnel vulnerability assessment.

Fig. 1 A model for the calculation of railway tunnel vulnerability
In step, a railway safety analysis (accident analysis) needs to be performed. Part of the first step is also the delimitation of the area of interest. The second step is to identify key elements in the area of interest (bridge, tunnel, wide track, marshalling yard). In our article we will only deal with the tunnel. The third step is to describe the key element. In the fourth step, it is necessary to identify the threats to the tunnel that are later taken into account when setting the parameters. The fifth step is to establish the main vulnerability assessment criteria. The main criteria are set to be the same for each key element (bridge, tunnel, track width, marshalling yard) and express their basic characteristics: K1: detour route, K2: design properties, K3: element importance, K4: transport performance, K5: environmental risk. In the sixth step, the main criteria are assigned parameters that determine the individual characteristics of the key elements. The key criteria parameters of the key elements differ. In the following section, the criteria we have proposed for tunnel vulnerability assessment will be presented.

### 3. Criteria for Tunnel Evaluation

Tunnels are engineering constructions that are built wherever it is necessary to overcome natural or artificial barriers. The reason is to improve directional or altitude ratios, as well as reduce driving time. Although expensive to build, they are mainly built to save operating costs [1].

**Alternative route – K1**

The first major criterion for a tunnel is a detour route. The parameters determining the detour route are three, namely: the length of the detour route P1, the number of detour routes P2 and the full value of the replacement P3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>length of the detour route P1</td>
<td>Represents the length of the detour route relative to the original route.</td>
</tr>
<tr>
<td>number of bypass routes P2</td>
<td>The number of available alternative routes.</td>
</tr>
<tr>
<td>full substitution P3</td>
<td>The full value of the replacement route.</td>
</tr>
</tbody>
</table>

The basic assumption is that the detour route is longer than the original route, generally expressed by the x sign. For this reason, we consider the starting point for the calculation of the extension of the detour route to the original route, which is expressed as a percentage. The 100% increase in detour is the situation when the route is doubled. In the case of a larger increase, we no longer consider the use of a detour because we assume that the dispatcher will choose either to wait or to secure operational processes in another way, e.g. by bus. Possible extensions are defined in five categories, which are assigned percentages.

<table>
<thead>
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</thead>
<tbody>
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</tr>
<tr>
<td>full substitution P3</td>
<td>The full value of the replacement route.</td>
</tr>
</tbody>
</table>

The usable detour must be able to replace the original route to a greater or lesser extent. The value of the importance of this criterion is less the more detour routes exist. The percentage of compliance with the criterion is inversely proportional to the number of possible detours.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
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</tr>
<tr>
<td>full substitution P3</td>
<td>The full value of the replacement route.</td>
</tr>
</tbody>
</table>

For the purpose of this criterion, the percentage of substitution means that the route is able to substitute the original route.

**Tunnels**

Tunnels are engineering constructions that are built wherever it is necessary to overcome natural or artificial barriers. The reason is to improve directional or altitude ratios, as well as reduce driving time. Although expensive to build, they are mainly built to save operating costs [1].

**Design features – K2**

At present, the tunnels are managed by ŽSR 76, of which 69 are monorail and 7 are double-tracked with a total length of 43,974.82 m [2]. Fulfillment of this criterion is determined by several parameters: tunnel length, age, track speed, and finally whether the tunnel is single or double track.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>tunnel length P1</td>
<td>Represents the length of the tunnel.</td>
</tr>
<tr>
<td>tunnel age P2</td>
<td>Represents the age of the tunnel.</td>
</tr>
<tr>
<td>line speed P3</td>
<td>Represents the operating speed of the tunnel.</td>
</tr>
<tr>
<td>track number P4</td>
<td>Represents the number of tracks of the tunnel.</td>
</tr>
</tbody>
</table>

For example, the tunnel age has an impact on the erosion of retaining and doorframes, cladding walls, as well as interior cladding plasters. For older tunnels, there is an increased risk of destruction of these elements and their fall. The oldest in Slovakia is the Lamač tunnel, which was completed in 1848 and is 170 years old. Therefore, we have set the rating scale in multiples of 30 years.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>tunnel age P2</td>
<td>Represents the age of the tunnel.</td>
</tr>
<tr>
<td>line speed P3</td>
<td>Represents the operating speed of the tunnel.</td>
</tr>
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</tr>
</tbody>
</table>

Tunnels designed for high speed require increased safety measures, so we assume that the higher the line speed is allowed for the tunnel, the higher the fulfillment of the criteria. At present, trains run at a maximum speed of 140 km/h in Slovakia, and our evaluation of the fulfillment of the criterion also depends on this.

<table>
<thead>
<tr>
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<th>Description</th>
</tr>
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<tbody>
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</tbody>
</table>

As the tunnel is a closed structure, it must be taken into account whether the tunnel tube is single or double-track. The tunnel accident is in most cases caused by a human factor, but in the event of a collision between two trains, the consequences of their collision are diametrically different depending on the width of the tunnel tube. With a monorail tunnel, the mass of trains has nowhere to "bend" and therefore deforms against each other. In a wider tunnel that is wider, the deformation consequences are reduced by the "mass" of the trains moving sideways. Based on these facts, we have assigned a 100% single-track tunnel and a 50% double-track vulnerability value.
We obtain the quantification of the total value of the tunnel construction property criterion as the arithmetic mean of the subcriteria mentioned above.

**Meaning of the element – K3**

We consider the meaning of an element according to whether or not it is part of an important railway route.

**Parameter – part of pan-European railway corridors – P1**

This parameter is evaluated by a level of yes/no. If it is part of the pan-European railway corridors, we assign a value of 100% and, if not, 0%.

**Parameter – part of RFC international rail corridors – P2**

We also evaluate this parameter with a simple yes/no statement. If the element is part of the international rail corridors, we assign a value of 100% and if not 0%.

**Parameter – the importance of transport in economic terms – P3**

In the case of route evaluation, which is not part of the two above-mentioned criteria, we will consider it also in terms of economic importance for Slovakia. The fulfillment of the criterion is set according to the categorization of railway lines in Slovakia. As an example, the main category 1 lines have a 100% value assigned.

The quantification of the total value of the element's meaning criterion is obtained as the arithmetic mean of the sub-criteria given above.

**Transport performance – K4**

**Parameter – operating track load**

Traffic performance for each route is determined by the operating load of the track, which divides the tracks into several categories, referred to as the "track line". According to the table given in the ŽSR TS3 standard, the line is divided into six rows, which are determined by the amount (in millions) of the so-called gross tonne per time unit 1 year. The operator of the route recalculates every year the actual operating load of the individual sections of the line into which the quantity of transported goods and the number of transported persons enter. In the case of single-track sections, the load is calculated for both driving directions, but in the case of multi-track sections, the load is calculated for each track separately for both driving directions [4].

In determining the fulfillment of the vulnerability criterion, we assumed that most of the lines are included in the third or fourth series. An example of a track belonging to the second category is the Žilina – Vrútky section. We assume that the most loaded lines are the most vulnerable, while low traffic loads are assigned a lower percentage of vulnerability. In this case, the evaluation of the transport performance criterion will be defined by a single value only, by meeting the criterion of the operational load vulnerability of the track.

**Environmental risk – K5**

When assessing the risk of the environment, we use data related to the identification of threats to individual key elements of rail transport infrastructure.

**Parameter – geological threat – type of rock terrain – P1**

Geological terrain, usually the slope into which the tunnel is excavated, affects not only the slope slopes, the slope pressure, but also the intensity of water seepage. These facts expressing compliance, coherence of the rock, tectonic faults, longitudinal cracks are expressed by so-called. a geological type that identifies several standards. For the sake of simplicity, in accordance with the standard STN 72 100124, we have determined only three types of rock, namely rock, semi-rock and soil. Their strength makes drilling difficult, but reduces the risk of spillage and damage, so rock rocks are considered to be the most stable, as the most threatening of the soil tunnel construction [5].

**Parameter – meteorological threat – water leakage – P2**

Larger length tunnels have, to a greater or lesser extent, a stable indoor environment throughout the year, which is only minimally influenced by external meteorological threats. Icicles, which are predominantly in older tunnels, are considered a potential threat to traffic. Icicles, which can sometimes be longer than two meters, can seriously endanger the health and safety of passengers, especially because of the risk of breaking the window. For this reason, ŽSR is introducing new tunnel heating technologies that were first used in the Ružomberok Tunnel in 2018. This is a pilot project that ŽSR monitors and evaluates to determine the operating costs and effectiveness of this solution [6].

Since this threat is currently only a few weeks of the year, we have designed the breakdown of this parameter based on the hydrological conditions in the tunnel. We assume that in the old tunnels, where there is a lot of water leakage, it is possible to assume the occurrence of a problem related to the emergence and occurrence of icicles. For this reason, we propose a simple breakdown that takes into account the tunnel's hydrological conditions and possible vulnerabilities associated with the occurrence of icicles, which can seriously affect the safety and smoothness of rail traffic.

**Parameter – technological threats – access to tunnel and fire protection equipment – P3**

The main danger to the tunnel is a fire that is a combination of heat, flames and smoke. Several factors have an impact on increasing or reducing risk. The first and most important is the existence of firefighting equipment that is mandatory in modern tunnels, but usually does not exist in the elderly. Their absence in many tunnels is compensated by a nearby source of water, whether in a natural source, e.g. river or lake, or in an artificially built hydrant or fire tank. Another factor is access to the tunnel portal, which deteriorates or improves the access of the fire engine to possible fire intervention. For longer tunnels, it must also be taken into account whether good access is possible to both tunnel portals or just one. Access can be hampered by vegetation and unprepared surroundings of the railway line, as well as whether
there is a wide track or bridge bridge, another tunnel or other building objects behind the tunnel. By combining these two factors, we expressed the risk of the environment. Also the clogging of the tunnel drainage system, the drainage pipes in shafts, may increase the risk of the tunnel, but since conversations with element managers know that the functional tunnels are regularly inspected and cleaned, this risk is not taken into account.

Parameter – technological threat – rail quarry – P4

The rail quarry is referred to as C1 in ŽSR’s Z17 and is part of the Incident category. It is a failure of the railway upper, which requires safety, traffic and administrative measures to be taken for security reasons. The causes that can cause rail deflection include excessive stress in rails with non-welded rails due to low temperatures, long-term effect of flat wheels, exceeding of permitted track load, cold steel breaking, notch effects of rail defects that cause fatigue-brittle fracture [7]. Since the fracture can occur anywhere on the rails, we need to know the vulnerability value for this threat. To calculate the rail vulnerability value for rail risk, we will take into account the two criteria (to increase objectivity). And this: \( m_1 \), in which we consider a time period, so we take into account the number of occurrences of this threat per time unit, in our case 1 year. The second value is \( n_1 \), which takes into account the number of occurrences of the threat in relation to the total length of the track. Since we have assigned the same weight to both values, the arithmetic mean will be considered the final value of the parameter vulnerability.

\[
m_1 = \frac{\text{average number of rail quarries per year}}{\text{total number of all 1 year accidents}} \times 100.
\]

\[
n_1 = \frac{\text{average occurrence of the phenomenon in 1 year}}{\text{total length of railway lines in SR in km}} \times 100.
\]

The overall vulnerability of the criterion is expressed as the arithmetic mean of the values of \( m_1 \) and \( n_1 \).

Parameter – technological threat – signaling error – P5

Another parameter is a signaling error that is categorized as C – Incidents. A signaling error is understood to be a condition of the signaling device which results in signaling, signaling, indication, etc. a less restrictive state than the one required. A limiting condition is a failure of a safety device that directly threatens the safety of rail transport [7]. Examples of such disorders may be e.g. a condition that allows spontaneous or forced displacement of the switch or derailleur in a closed train or shunting path; incorrect information on the freedom of the electric track; a condition which allows the signaling signal to be illuminated on the signal at a time when the conditions or late illumination of the signal and others are not met. Vulnerability will be evaluated on the basis of two criteria, namely \( m_1 \) and \( n_1 \), whereby the resulting percentage of vulnerability is obtained by the arithmetic mean of these values.

\[
m_1 = \frac{\text{average incident count - C3 signaling error}}{\text{number of all incidents in category C (C1 to C5)}} \times 100.
\]

\[
n_1 = \frac{\text{average error count C3}}{\text{total number of all accidents}} \times 100.
\]
The total vulnerability of the parameter is expressed as the arithmetic mean of the values of $m_1$ and $n_1$. The quantification of the total value of the criterion $K5$ of the environmental risk is obtained as the arithmetic mean of the sub-criteria.

4. Verification of the Proposed Model

The model was verified on the line Žilina – Vrútky. Track is one of the most important lines in Slovakia with the highest traffic intensity. There are three tunnels on this line. The main criteria were weighted based on the experience of the experts and then calculated the vulnerability, as an example of the evaluation of the Strečno III Tunnel (Table 1).

<table>
<thead>
<tr>
<th>Main criterion</th>
<th>Weight</th>
<th>Vulnerability value</th>
<th>Resulting vulnerability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass trail</td>
<td>0,25</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>Construction features</td>
<td>0,20</td>
<td>70</td>
<td>14</td>
</tr>
<tr>
<td>Importance of the element</td>
<td>0,27</td>
<td>100</td>
<td>27</td>
</tr>
<tr>
<td>Transport performance</td>
<td>0,10</td>
<td>75</td>
<td>7,50</td>
</tr>
<tr>
<td>Environmental risk</td>
<td>0,18</td>
<td>34,79</td>
<td>6,26</td>
</tr>
<tr>
<td>Sumary:</td>
<td></td>
<td></td>
<td>79,76</td>
</tr>
</tbody>
</table>

The calculated values need to be assessed against the range of possible minimum and maximum vulnerability values of the individual elements, determined by the fulfillment of vulnerability thresholds for each criterion. On this basis, we can determine the value of the vulnerability in relation to the scoring scale (Table 2).

<table>
<thead>
<tr>
<th>Scale for tunnel vulnerability</th>
</tr>
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<tbody>
<tr>
<td>min.</td>
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<tr>
<td>14,47</td>
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</tbody>
</table>

The vulnerability values of the three tunnels on the track were as follows: Strečno I Tunnel – 75.26%, Strečno II Tunnel – 77.76% and Strečno III Tunnel. – 79.76%. Vulnerability of all three evaluated tunnels Strečno I., Strečno II. and Strečno III. (KP3 – KP5) is determined as high.

5. Conclusion

From these values it follows that the most vulnerable tunnel is Strečno III, which is also the oldest tunnel of all three. The evidence that we have found indicates that the vulnerability of key elements of rail infrastructure can be calculated by a model proposed that takes into account selected quantitative and statistical information. The proposed model takes into account the key parameters of the key elements and their real situation is reflected in the calculated vulnerability of the element. It is necessary to pay increased attention to the safety of this track section, namely in terms of financial subsidies, maintenance of older buildings, better access to tunnel portals, as well as increased compliance with work and technology disciplines. As the high rate of accident events is caused by operational failures of infrastructure equipment, it is necessary to increase their functionality by regular inspection and maintenance.

References

4. ŽSR, predpis TS3 Železničný zvršok.
Trends in Aviation Accidents During Flight Training

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Abstract

In this article we tried to identify trends in aviation accident involving pilots in training. We used data from 5 different countries within Europe region from 2013 to 2018. We focused on all types of training provided by different types of eligible organizations, for example PPL training, glider pilot training, ultra light pilot training. We identified several patterns which may be used in future to increase the safety of aviation trainings. This article also briefly discusses new type of the training organization, declared training organization. We suggested how this article may be used as a reference material to determine safety level of future declared training organization.

KEY WORDS: accident, ECCAIRS, Flight Training, ATO, DTO

1. Introduction

The scope of this paper is to discuss possibilities how to use the ECCAIRS (European Coordination Centre for Accident and Incident Reporting Systems) database to find out information about level of safety concerning pilot training. We focused on data from years 2013-2018, but because ECCAIRS is not implemented equally we were not able to retrieve data from all countries within these years. This inequality within the retrieved data is very important topic which is discussed in detail. We provide comprehensive statistics of accidents from Czech Republic, UK and France, involving student pilot during training.

2. Source of Data About Safety in Aviation Training

All data presented in this paper all obtained from ECCAIRS. ECCAIRS is divided into two separate database systems. All EU countries have obligation, according to Directive 376/2014 [3], to maintain national version of the database. In this national database the country has to keep records about all accidents and incidents concerning the country (country of registration, country of operator, geographical jurisdiction, etc.). On the base of these national databases is founded European repository. An issues which we identified during the work on this paper is fact that national rules about which data has to been sent in the European repository are different. Different countries have different rules about which type of information has to be transmitted to the European database. The main problem is especially different minimum of aircraft maximal take-off mass from which is obligatory to send the information about the incident to the European system. Therefore working only with European repository may lead to distortion of the data. This area is discussed within EASA countries and in the future this difference shall be minimised, but today we were not able to find data from different countries which would completely comparable.

ECCAIRS database is consistent from several attributes, which is possible to assign to the incident. To achieve higher comparability, complementing attributes shall be added during investigation of the incident by the inspector. This should lead to unification of the attributes because they shall be added by inspectors who are familiar with the attributes system and Directive 376/2014 [3].

The composition of attributes is dedicated to achieve maximal information about the incident. Attributes are assigned to technical problems, avionics failure, ground incidents, ATC error, etc. There exist around 400 of these attributes. This high number of attributes may lead to a discrepancy within usage of the attributes between countries and even between different inspectors.

For our paper we use the parameter - presence of a pilot with the student pilot licence on board (ECCAIRS attribute “License Types”) – to filter out all such incidents. Therefore the following data in tables 1, 2 and 3 are only connected to incidents with attribute student pilot on board. If this attribute was not filled in, or if the information was not included in European repository, we don’t account that incident.

The data set was then analysed by other key factors involved in the incident. This feature of the ECCAIRS allows to bind a specific factor which lead to the accident, or which factors occurred during the incident. We use these factors to find common aspects which influenced the incidents.

3. Comprehensive Comparison of Incidents Involving Student Pilot

We used anonymous data from national database of Czech Republic, as well as European repository. As mentioned
earlier, because of deviations between the national standards about reporting national data to European repository, we had to find countries with similar standards. Therefore we can’t use data across all European countries because from several countries are data not in necessary quality or quantity. Therefore we limited the selection only on following countries: Great Britain, France and Czech Republic. We also examined data from Poland, Latvia, Slovakia and Germany, but for each country we found an issue which disqualified the country from our comparison.

Also as mentioned before, the decisive factor about incorporation of the record in our research was presence of student pilot on board. Therefore if there was an incident involving ATO, for example during maintenance, ground handling, etc., and there was no student pilot on board we don’t take these accidents into account.

Comprehensive statistics about accidents occurrence during flight training is in Tables 1, 2 and 3.

**Table 1**

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**Table 2**

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**Table 3**

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</table>

*Note: detailed data contains only 4 main categories (Airplanes, ULA, helicopters and gliders), other categories are not included*

4. Discussion of the Data

Because only comparable category from Tables 1, 2 and 3 is Accident we further discuss only occurrence of accidents, we don’t consider incidents and severe incidents.

Total number of trainings, within different countries, is difficult to estimate because different types of organizations are involved. Very roughly we may estimate that in France is about 40 000 sport and general aviation pilots. In UK is more than 20 000 of such pilots. In Czech Republic is the number of these pilots about 3000. Therefore if we presume that number of flight trainings will be corresponding with these numbers, we would expect that number of accidents during the training in Czech Republic will be significantly lower.
Despite that, number of reported incident seems from ECCAIRS data seems to be similar. This would lead to conclusion that either aviation training in Czech Republic is much less safe than in France or that ECCAIRS data from Czech Republic and France are burdened by a disproportion which make their comparison difficult.

Based on information about training incidents in Czech Republic there is no significant difference between probabilities of occurrence of an accident between different types of flying device. Numbers of accidents responds to the number of training which are similar fro PPL(A,S) and ultra light training. Number of helicopter training is significantly lower as well as number of accidents, but the accident number is too low to find any correlation. Similar trend was found also in UK and France. The number of accidents is proportionate to the number of trainings. Therefore we don’t find any information which would lead to presumption that one type of flying device would be more prone to accidents during training.

5. ECCAIRS Data Quality

During data preparation for the paper we found that there is inconsistency between countries and even inspectors within the same country how they work with filling of attributes and factors. For example often there is stated only the top factor which influenced the incident, but other factors are not stated. It is very probable that many other incidents involving flights with student pilot on board cannot be studied because in the database this parameter is not filled, because presence of the student pilot on board was not the primary cause of the incident or for inspector, this fact was not so important to fill it in. This inconsistency is very significant and we strongly recommend change of this praxis.

6. ATO and DTO Comparison

Application of the aforementioned data and their future development is especially important in combination of introduction of new type training organization. This new type of training organization is called declared training organization DTO. DTO was introduced by AMC and GM material to PART-DTO, Directive 1178/2011 [2].

DTO is eligible for the most common types of training PPL and LAPL for aircraft, sailplane, helicopter, balloon and airship. Therefore in near future it is probable that DTOs will provide more trainings than ATO.

For DTO there are several reliefs in terms of necessary personal and safety system. For example No mandatory Ops / Training or Management System manuals, operations from non certified aerodromes, etc. [1]

I the near future it will be very interesting to observe if there will be any difference in development of accidents in ATO and DTO. If there will be difference then it may lead to presumption that reliefs in the safety standard of the DTOs is too benevolent. If there will be no difference in rate between accidents and flight training between ATO and DTO then it may lead to conclusion that safety standards for DTO are sufficient, and maybe even the ATOs standards may be lowered. But to be able to get such a conclusion based on the data from ECCAIRS it would be necessary to equalize the way how different countries work with ECCAIRS database. At present situation it seems that based on ECCAIRS are tainted by systematic error and only several countries are directly comparable.

Our future work will also focus towards addition of information from Poland. Poland start to fill in European repository from 2017 and data seems to be comparable with other three countries, we didn’t use them because there are only two years of these data.

7. Conclusion

Database ECCAIRS seems to has a great potential to be used as a tool to validate if the difference in safety system of DTO will lead to different numbers of accident between ATOs and DTOs. To achieve this potential it would be necessary to maintain same level across EASA countries with same principles with respect to unification of attributes usage and set rules which incidents from national database has to be send to European repository.

References


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Abstract

Currently, various types of solutions supporting sustainable transport are being sought around the world. One of the possibilities is to replace vehicles with the classic drive with hydrogen-powered cars. According to data the number of vehicles sold around the world in 2017 was 6,500. It is forecasted that over 70,000 vehicles will be sold by 2020, and by 2021 at least 11 vehicle manufacturers will introduce hydrogen cars into their offer. Due to the increase in global interest in hydrogen-powered cars - the work was dedicated to the use of this type of vehicles in urban transport systems. The aim of the work is to analyze the current transport policies related to hydrogen vehicles in Europe and the United States. The methodology was based on the analysis of the functioning of the policies including the main factors affecting the increase in the number of hydrogen-powered vehicles - tax breaks and incentives. On the basis of the comparison compiled in the prepared review, the SWOT analysis connected with the development of hydrogen services in cities was carried out. In the text were also presented selected examples of implementations hydrogen-powered vehicles in urban transport systems. The result of the analysis allowed for the preparation the list of recommendations for the implementation of this type of vehicles in urban transport systems and during the development of national policies dedicated to hydrogen-mobility.

KEY WORDS: hydrogen-powered vehicles; hydrogen transport policy; hydrogen vehicles in urban transport systems; sustainable transport solutions

1. Introduction

The current transport situation of cities is connected to implementing various types of solutions that could contribute to improving the negative impact of motorization on the environment and society. There are many ways to achieve this situation in line of sustainable transport development. For example, there kind of activities are related to: mobility or “green” mobility management, implementing shared mobility solutions, shaping the attitudes of “new mobility approach” in the society, transport means integration, transportation cost optimization or creating the new, sustainable infrastructure [6, 7, 21, 24, 35, 36]. The other group of solutions dedicated to the sustainable transport development is related to the alternative-powered vehicles. Although the idea of using alternative-powered vehicles is not new, the public opinion is mostly focused on electric or gas-powered cars, there is also the alternative possibility – to use hydrogen-powered vehicles. What is more, exactly the hydrogen-powered vehicles are called as “zero-emission” cars [1, 2].

According to the data, the number of hydrogen-powered vehicles sold around the world in 2017 was 6,500 [18, 19]. It is forecasted that over 70,000 vehicles will be sold by 2020 [20], and by 2021 at least 11 vehicle manufacturers will introduce hydrogen cars into their offer [20].

Due to the niche in current interest in the topic of hydrogen-powered vehicles – the author dedicated this article to the conception of using hydrogen-powered vehicles in urban transport systems. The aim of the work is to show the analysis of the current transport policies related to hydrogen vehicles available in Europe and the United States. The methodology was based on the analysis of the functioning of the policies, tax breaks and incentives dedicated to the hydrogen-powered vehicles. The work also includes the part connected to the advantaged and disadvantages of implementing that kind of vehicles to the urban transport systems. On the basis of the literature review and own experiences, author presented the SWOT analysis. The last part of the paper is presenting recommendations for creating the new policies or guidelines dedicated to the topic of hydrogen-powered vehicles in urban transport systems.

2. Hydrogen-Powered Vehicles in Urban Transport Systems

Hydrogen-powered vehicles are type of cars equipped with the electric motor working with the fuel, hydrogen cell [27]. That kind of vehicles is also called as Fuel Cell Vehicles (FCV) or Fuel Electric Vehicles (FCEV) [26, 27]. The first hydrogen-powered vehicle was presented by the example of Allis-Chalmers farm tractor in 1959 [28, 29, 37]. From that time, hydrogen technologies spread very wide and many of hydrogen-powered cars from the concept to the regular offer vehicles were produced. The main problem that these type of cars are not so much popular around the world, is the lack of the necessary infrastructure. Hydrogen-powered vehicles to be able to function smoothly in urban transport systems, require a dense hydrogen charging infrastructure, which would resemble the current vehicle refueling stations. According to Ludwig-Bölkow-Systemtechnik, 152 hydrogen stations are currently in operation in Europe, 136
in Asia, 78 in North America [11]. Of the 369 hydrogen stations worldwide, 273 are publicly accessible and can be used like any conventional retail stations [20]. In Germany, 17 new public refueling stations started operation in 2018, further consolidating Germany as the country with the second largest public hydrogen refueling infrastructure globally with 60 public stations, ahead of the USA (42 stations) and only surpassed by Japan (96 public stations). A total of 48 hydrogen refueling stations were opened worldwide in the past year [20].

In the cities there are undertaken many initiatives that are dedicated to the improving the level of transportation sustainability [3, 4]. In the case of hydrogen-powered vehicles in urban transport systems, there are many undertaken initiatives connected to urban public transport solutions shared-mobility, taxis and autonomous vehicles. For example in Paris is functioning a network of 100 taxis powered by hydrogen [32]. In European cities started to appear demonstration hydrogen-powered buses [22]. Buses are available in such cities like: San Remo, Bolzano and Milan (Italy), Aargau (Switzerland), Frankfurt, Hamburg and Düsseldorf (Germany), Eindhoven, Groningen and Arnhem (Netherlands), Antwerp (Belgium), Oslo (Norway), Aberdeen (Scotland) [33]. Under various projects, hydrogen power stations have appeared in: Aberdeen (Scotland), Antwerp (Belgium), Bolzano (Italy), Brügg (Switzerland), Hamburg (Germany), Hür (Germany), Karlsruhe (Germany), London (United Kingdom) Britain), Milan (Italy), Oslo (Norway), Rotterdam (Netherlands), Stuttgart (Germany) [33]. Also some car-sharing projects were dedicated to hydrogen energy like the BeeZero system launched in Munich (Germany) [34]. While the market for vehicles operating in organized transport systems is growing more and more it very difficult in the case of vehicles belonging to individual owners [8]. It is therefore important to focus on appropriate policies and incentives for both vehicle manufacturers and infrastructure to integrate transport system and encourage them and society to change their mind about hydrogen vehicles [9, 10].

3. Hydrogen-Powered Transport Policies

Using hydrogen as the alternative fuel cell in vehicles is a complicated process, that need to a process that needs to be properly explained to the individual countries society. In the case of United States of America in 1992 in the Energy Policy Act hydrogen fuels was discussed [30]. It was the first national legislation dedicated to the topic of hydrogen vehicles. The act indicates the need for large-scale research connected to hydrogen, its production, use and storage [30]. The following years were spent on conducting research and development activities on the use of hydrogen. Many activities have also received federal support. Within the framework of pro-hydrogen activities, various kinds of laws were prepared. The main regulations contain among others [5, 12, 14, 30, 31]:

- Comments on CATO Institute Briefing Paper No. 90, "Hydrogen's Empty Environmental Promise" of 2004;
- The Energy Policy Act of 2005 directed the Energy Secretary;

In the regulations can be found various incentives for the society connected with using hydrogen vehicles, like:

- alternative-fuel and vehicle labeling requirements;
- alternative-fuel infrastructure tax credit;
- fuel-cell motor vehicle tax credit;
- hydrogen fuel excise tax credit;
- improved energy technology loans.

The privileges are dependent of the different states, because also some stated announced their own policies. Depending on the state, privileges may apply, among others: reduction of taxes for buying hydrogen-powered vehicles and reduced taxes for refueling them, reduced taxes for manufacturing hydrogen-powered cars, grants for development infrastructure dedicated to hydrogen-vehicles, fueling infrastructure loans and alternative fuel tax refund for taxis [30]. The states that are most heavily involved in hydrogen activity include: Colorado, District of Columbia, Maryland, New York, Oklahoma and West Virginia.

In the case of the European Union, there is no specific legislation with incentives related to hydrogen policy as in the United States. But the European Union Commission has supported development of hydrogen and fuel cells since the early 1990s. Research has mainly been directed at improving performance and durability and reducing costs. Also the hydrogen-powered vehicles and fuel cell technologies were mentioned in the European Strategic Energy Technology Plan presented along with the Energy Policy Package in January 2008 [13]. In the following years, many pilot projects were implemented to implement post-mining vehicles, including buses. In total, over € 470 million has been allocated for the development of research over the period 2007-2013 [13].

The European Union promotes several research and innovation projects on hydrogen within the Horizon 2020 framework. These projects are managed through the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), a joint public-private partnership that is supported by the European Commission [13].

Also the European Commission has set up an informal group of experts, composed by representatives from the ministries in charge of energy policy in EU Member States. This expert group, called the Hydrogen Energy Network (HyENet) aims to support national authorities in charge of energy policy to develop on the opportunities offered by hydrogen as an energy carrier [13] The First meeting of the Hydrogen Energy Network (HyENet) held 26th June 2019 in Brussels [13].
4. Hydrogen-Powered Vehicles in Urban Transport Systems - SWOT Analysis

Based on the analysis of the functioning of systems, examples of the operation of hydrogen vehicles in urban transport systems and literature analysis, a SWOT analysis on the development of hydrogen-powered vehicles in cities has been prepared. Detailed analysis is presented in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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<tbody>
<tr>
<td>- Hydrogen-powered vehicles are the cleanest technologies (environmentally friendly).</td>
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<tr>
<td>- Hydrogen technology is possible to use in all types of vehicles.</td>
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<td>- Widespread availability of hydrogen as the element that can be used in fuel cells.</td>
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<td>- Endless resources of the hydrogen in the environment.</td>
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<tr>
<td>- Reduction of harmful emissions during combustion.</td>
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<tr>
<td>- Low operating costs of hydrogen-powered vehicles and fuel efficiency compared to classic fuels.</td>
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<tr>
<td>- The efficiency of the generators does not depend on the nominal power of the device and the degree of its use.</td>
<td>- High costs associated with the construction of hydrogen storage, transport, distribution networks and infrastructure.</td>
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<tr>
<td>- Difficulties with hydrogen storage.</td>
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<tr>
<td>- Hydrogen can be very flammable.</td>
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<tr>
<td>- Expensive materials for catalysts (especially precious metals).</td>
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<table>
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<tr>
<th>OPPORTUNITIES</th>
<th>THREATS</th>
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<tr>
<td>- The possibility of any location of the power station with fuel cells that can generate energy in the place of its direct collection, what almost eliminates losses related to the transmission of electricity and heat.</td>
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<tr>
<td>- The possibility of fuel reforming inside the cell in high temperature cells.</td>
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<tr>
<td>- Possibility of production the hydrogen from various raw materials and with using various methods.</td>
<td></td>
</tr>
<tr>
<td>- Orientation of policies towards sustainable forms of transport.</td>
<td>- No development trend in the field of alternative mobility and with trends in the case of infrastructure for refueling vehicles with hydrogen.</td>
</tr>
<tr>
<td></td>
<td>- The significant increase in hydrogen prices.</td>
</tr>
<tr>
<td></td>
<td>- Discontinuation of the production of hydrogen-powered vehicles for the benefit of classic electric vehicles.</td>
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</tbody>
</table>

The results of the analysis show that strengths are able to take full advantage of the opportunities associated with the development of hydro-mobility. Strengths are also able to overcome the threats, because currently all actions undertaken by countries in the world are directed towards the search for alternative forms of transport. Therefore, the discontinuation of production of hydrogen-powered vehicles or the discontinuation of infrastructure due to currently invested in pro-hydrogen projects seem unlikely to exist. Weaknesses will make it possible to take advantage of opportunities, due to high economic benefits and sustainable development issues. Weaknesses do not exacerbate the threats because threats mainly result from trends and world-view approaches to the hydrogen policies, not the disadvantages of hydrogen technologies [15-17, 23].

Prepared analysis allowed for the development of recommendations regarding the creation of national policies on hydrogen fuels as an alternative source of transport, as well as support for cities wishing to implement transport systems based on the use of hydrogen-powered cars.

5. Hydrogen-Powered Vehicles Development - Recommendations

The analysis of policies regarding the implementation of hydrogen vehicles to urban transport systems, as well as the SWOT analysis made it possible to develop recommendations for countries and cities that would like to enrich their transport offer with hydrogen-powered cars.

First of all it is necessary to make a decision regarding the whole concept of the national implementation of hydrogen technologies. It is important that the activities include technical issues such as the construction of
infrastructure but also legislative aspects and the provision of appropriate tax breaks or privileges. Without meeting these conditions, the country will deals only with individual initiatives and not with organized activities leading to the full development of the hydrogen vehicle market in a given country.

The next step is to take appropriate work with the industry and development work with scientists to ensure that the hydrogen technologies implemented are as cheap as possible and could cover the largest possible scale of operation.

It is also worth mentioning establishing appropriate cooperation with enterprises that can equip cities or states with hydrogen infrastructure or also with hydrogen taxi or car-sharing systems.

Another important but very important element is proper education of the society [25]. Currently, a very big problem is to encourage people to use electric vehicles. A similar problem may therefore be getting the public to use hydrogen-powered vehicles. However, in order for educational activities to be effective, it is important to establish a long-term policy and to build appropriate infrastructure.

6. Conclusion

In conclusion, hydrogen-powered vehicles have a chance to become the future of alternative forms of transport in the world. However, to make it happen, it is important to draw attention to a number of strengths and weaknesses as well as opportunities and threats of this undertaking. Europe compared to the United States is at the beginning of its path both in terms of hydrogen drive policy as well as in the case of adequate infrastructure or the number of owned vehicles. Therefore, if countries want to base on the implementation and development of the number of hydrogen vehicles in transport systems, it is worth focusing on developing long-term policies, defining tax breaks or any benefits for society. However, for this to happen, the first step is to develop transport development plans based on the use of hydrogen and the concept of creating hydrogen charging stations. Then it will be possible to implement a policy of sustainable transport development using the purest transport technology that is hydrogen technology.

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Monitoring and Verification of Compliance with the Standards of the Time Availability of the Universal Postal Service

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Abstract

The paper deals with the verification of time availability standards of universal postal service thus the determination of the confidence interval the mean value of the waiting time of customer for the prevising of universal postal service. The first postal directive (97/67/EC) obliges European Union Member States to determine the quality characteristics of the universal postal service. In particular, these include transit times of mail, availability of universal postal service (time and location), reliability and regularity. The regulatory authority checks annually the availability of randomly selected or problematic (in the past) access and contact points of the public postal network by the requirements of the postal licence. It is also important that the range of hours to the public and time waiting at the counter were the most adapted to the requirements of customers. In the long term, the time availability has a low customer satisfaction value. It is therefore in the interest of the provider to monitor and address this fact. The paper presents the result of the research using statistical methods of interval estimation of parameters by measuring individual waiting time of sample of postal customer. The key aspect for the interpretation of the results is a comparison of the standards with the results of the verification time availability.

KEY WORDS: universal postal service, quality, requirements for the quality of universal postal services, time availability, confidence interval

1. Introduction

Perception of the quality of postal services by the customer is often different from that of the provider. It is therefore crucial that the quality of the postal service is assessed based on objective criteria and measurements. At the same time, the requirements should also be conceived about the needs and requirements of customers, as they significantly affect customer satisfaction [18, 23, 27]. The quality of the universal postal service is also a prerequisite for increasing the competitiveness of its provider in the postal market.

2. Theoretical Approaches and Analysis of the Current State

The provider of universal postal service has a significant position in the country's national economy as is often in charge of public services. On the one hand, its presence in the postal market is defined by the obligation to ensure the universal availability of services, but on the other hand, he should stay competitive. Both the Universal Postal Union and the European Commission are still keen to maintain a basic range of services under the regulated universal service, subject to compliance with established quality standards [24]. By the Directive 97/67/EC of the European Parliament and of the Council it means the offer of postal services, which serves to ensure the minimal satisfaction of the needs of all users of postal services on the entire territory of the State so as to ensure the availability of access points of the public postal network and contact points of the public postal network, under the same conditions, in defined quality, for fair price, every working day with at least one collection and delivery a day [5, 22].

Under these conditions, member states are obliged to provide a specific field of postal services. This basic framework mentioned in the Postal Services Directive (97/67/EC, amended by Directives 2002/39/EC and 2008/6/EC) is defined as minimal (that is, the obligation for member states to provide universal service at least at this level) and is implemented into national legislative systems of individual member states’ conditions. However, the Postal Services Directives also define the basic framework of qualitative requirements, with member states obliged to set standards on their own [2, 24].

Among the critical aspects of the quality of universal postal service (such as transit time and reliability), which are perceived significantly by customers as they are also part of customer satisfaction, is the availability of postal service, which is recognized in two dimensions as the local (geographical) dimension expressing the distance of the access point [10, 19, 25] and the time dimension usually defined by two respectively three factors - the opening hours for customers, the regularity of mail pick-up and delivery of postal items per day/week, but also the average waiting time for the service to be provided directly to the post office [20]. The control and monitoring of the development of individual quality parameters is the responsibility of the independent regulatory authority as well as the universal service provider itself. In most cases, several tools in the area of diagnostics and quality management can be used [5, 7, 16, 22].
2.1. Accessibility, Availability and Time Availability of the Postal Services

The term accessibility is composed of two words - access and ability, i.e., the ability to access [11]. Many authors are still dealing with the definition of accessibility [8, 21, 28]. Accessibility is the ease with which we can achieve a set goal from a given location using a transport system. Availability is also understood as the acceptability of the effort and time needed to achieve a particular goal. Accessibility is a measure of the strength and extent of geographical relationships between residents and their socio-economic activities [26]. The relatively benevolent understanding of availability is advantageous in terms of its extensive application possibilities. The issues of accessibility measurement, different approaches and applications related to accessibility issues are discussed by many authors [4, 6, 12-15, 29]. It is, therefore, an essential factor determining the provision of many types of services, especially those linked to infrastructure, whether transport, social, educational, health or the like. Especially in the sphere of performance in the public interest, it is essential to legally define this parameter.

In the field of postal services, accessibility is often also expressed by the notion of availability, especially in relation to time (opening hours for the public, waiting times ...).

The qualitative aspects focusing on the time available in most EU countries are determined by the frequency of collecting and delivering consignments on weekdays, as well as opening hours for the public, based on the size of the settlement or distance to the nearest access point. However, some countries have included in the availability time factor also a factor in the average waiting time to be provided with universal service. In addition to the Slovak Republic, it is also Belgium (the universal service provider is committed to ensuring that 80 to 90% of customers have less than 5 minutes of waiting time for universal service provision) [30].

In the UK, a universal service provider must provide postal services to meet user needs and meet quality requirements. The Provider is obliged to declare to the Regulatory Office once a year a list of complaints (including dissatisfaction with waiting times) related to the availability of universal service (geographical and timewise) [30].

The time availability of universal postal services in the Slovak Republic is defined by the opening hours for the public set for individual postal offices about the number of inhabitants. The minimum time range for opening hours is prescribed by the Quality Requirements of the universal service, as set by the regulatory authority of Slovak republic. The range of opening hours for the public and waiting time at the postal counter are essential indicators of the quality of postal service as for the public and are a frequent subject of complaints and other claims. Therefore, the regulatory authority regularly focuses on performing opening hours compliance checks and also prescribes a maximum waiting time for universal service, which must not be more than 12 minutes at peak time, which represents the average of two consecutive hours with the highest service intensity. In 2018, the universal service provider submitted 21 proposals for exemption from the availability of 107 post offices. Of these, 11 recommendations concerned the permanent change of opening hours for the public at 49 post offices, with one exception not being granted totally [31, 32].

Within the scope of the state supervision, the regulator carries out checks of the time and territorial accessibility of universal service, which are carried out nationwide in the territory of the Slovak Republic and includes assessment of compliance with the quality requirements, including justification and assessment of exemptions and their impact on postal users themselves (e.g., inclusion of specific sites between places without delivery service, areas with irregular or limited delivery). The satisfaction assessment about the "time availability" parameter is shown in Table no.1.

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<tbody>
<tr>
<td>Opening hours for the public (in the morning)</td>
<td>83.6</td>
<td>83.2</td>
<td>81.4</td>
<td>74.6</td>
<td>76.8</td>
<td>83.9</td>
<td>94.0</td>
<td>93.0</td>
</tr>
<tr>
<td>Opening hours for the public (in the afternoon)</td>
<td>75.8</td>
<td>79.0</td>
<td>76.0</td>
<td></td>
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</tr>
<tr>
<td>Waiting time at the postal counter</td>
<td>64.2</td>
<td>56.0</td>
<td>55.0</td>
<td>67.8</td>
<td>64.4</td>
<td>66.6</td>
<td>75.0</td>
<td>75.0</td>
</tr>
<tr>
<td>Total satisfaction</td>
<td>76.0</td>
<td>73.3</td>
<td>72.3</td>
<td>74.1</td>
<td>76.5</td>
<td>78.6</td>
<td>79.0</td>
<td>79.6</td>
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</table>

3. Objective and Methodology

This paper aims to present the results of the control measurements related to the verification of compliance with the time availability standards for the parameter "waiting time at the counter". It is presenting the results of a partial task related to the evaluation of parameters of the universal postal service about time availability. To achieve the goal, statistical methods of interval parameter estimation were used to determine the confidence interval based on the actual time measurement at the counter at selected post offices and point parameter estimation.

An interval estimate of a baseline parameter is called an estimate using a numerical interval in which the estimated parameter is located with a certain probability. The concept of interval estimates and confidence intervals was defined by Jerzy Neyman in 1937. The primary task of interval estimation is to determine the upper and lower endpoint of the range [1, 3, 9].

In the interval estimation for the mean value of the base set, we use the sample mean \( \bar{x} \), which is the basis for determining the confidence interval for the mean value of the baseline, as well as the standard error of the baseline \( s \). The standard error of the baseline is estimated by using the standard deviation \( \sigma \), with a deviation or a limit for dispersing
values from the average. We define it as the square root of the range itself \([1, 3, 9]\).

\[
s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2},
\]

where \(x_i\) - all of the \(x\)-values; \(n\) - the number of items in the sample.

To determine the confidence interval for the median value of the baseline, we used 95% and 99% estimate reliability. The selected file has a large enough range. We determine the confidence interval for the mean value of the base set by a two-sided confidence interval (thus determining the lower and upper limits of the interval in which the mean value of the base set moves, the average customer waiting time in our case). We define it as

\[
P\left( \bar{x} - t_{1-\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} < M < \bar{x} + t_{1-\alpha/2} \cdot \frac{\sigma}{\sqrt{n}} \right) = 1 - \alpha,
\]

where \(\sigma\) - standard error; \(1 - \alpha\) - estimate reliability; \(t\) - has a normalized normal distribution, and therefore \(t_{1-\alpha/2}\) - the value of a normalized normal variable (according to the tables of the distribution function for a standard normal distribution) and for \(\alpha = 0.05\) then so \(t_{1-0.025}\) = 1.96; \(\alpha = 0.01\) then so \(t_{1-0.005}\) = 2.58; \(M\) - the mean value of the base file.

The point estimate of the base file, the average customer waiting time for the post office counter is the median. It is a mean value indicator that is not affected by extreme values. It divides the set of statistical data arranged in ascending order into two equally numerous parts and is considered a quantile. Similarly, we determine the \(Q_1\) lower quartile and \(Q_3\), the upper quartile for our measurements \([1, 3, 9]\).

4. Results and Discussion

Measurement of waiting time for customer service at the counter was carried out at selected post offices in the defined area of the universal service provider. The selection of facilities suitable for testing was linked to the following aspects:

- a negative assessment of the facility from previous measurements;
- absence of a ticket system in the post office;
- size of the post office (type category L, XL);
- universal mailboxes in the post office.

The control measurement was carried out in March 2019 on days, which are also intended as pay dates (social benefits, pensions, etc.), where increased traffic to post offices is anticipated. The measurement time was defined by the "peak operation time" for the tested post office and ranged between 1.00pm – 5.00pm. To ensure the objectivity of the results, the measurements were carried out by trained testers using a certified measuring device.

The organization of work on tested post offices is secured by so-called universal postal counter that are capable of serving the customer with any requirement within the scope of the universal service (all universal services at one service site, including other services from the commercial postal and non-postal service portfolio). 70 measurements were made at each of the facilities tested.

An establishment classified as L (large) has an average recalculated several employees in the previous calendar year of 10-49. A facility classified as type XL (extra-large) has an average recalculated several employees in the prior calendar year of 50 and more. The L and XL category tested facilities are comparable in terms of performance load per employee. A post office with no ticketing system is forced to physically monitor the number and frequency of incoming customers throughout the day for the purpose of organizing work appropriately (number of postal counters open during the day) so as not to create unintentionally long waiting lines in front of the counters, which has a negative impact on customer service staff (increased error rate). Likewise, it is a situation where it is indispensable to realistically measure customer service and wait time in real time, as there is no other independent method (e.g., the analysis of the ticket system’s data allows to find out the waiting time data for each site as well as the typology of services used).

Evaluation of basic measurement characteristics

Since the average is only an informative figure on the so-called "central tendency" of the variable under consideration in our case of waiting time, it is appropriate to list this mean characteristic with its confidence interval. From the measured sample, we obtained information about the central tendency of the behaviour of the whole system (waiting time throughout the day in the monitored facility). The confidence interval for the average thus gives us information on the range of values the actual mean of the entire system could be (at a given level of certainty).

Examination of the measured values was tested at a significance level of \(p = 0.01\) and subsequently at a reduced significance level of \(p = 0.05\), thereby increasing the confidence interval due to higher confidence in the estimation. The confidence interval width also depends on the number of respondents in the sample. The closer the number is to the actual number in the entire system, the more reliable the average of the sample is found. Measurements were designed about the real number of customers entering the queue at the counter during the typical working day within the defined time interval and thus, the number of measurements sufficiently represents the given situation. Based on the probability distribution test, we assume that the values take on a normal distribution.
The specified standard.
time for a given facility will be between 95.84 and 145.54s, which represents a time reserve of 574.46 seconds against
(78,66%) reserve against the specified standard (720 seconds). It can also be stated that with 95% reliability, the waiting
customers waited for more than 243.25 seconds. The shortest waiting times were measured at the L 4 post office, where
stated that less than a quarter of customers waited for service at this facility less than 64.77 seconds, but a quarter of
for serving and completing their services for more than 147.5 seconds and half of the customers less. While it can be

The results show (Table 2) that half of the customers in the tested post office 1 (type category L - see line 1) waited
for serving and completing their services for more than 147.5 seconds and half of the customers less. While it can be
stated that less than a quarter of customers waited for service at this facility less than 64.77 seconds, but a quarter of
customers waited for more than 243.25 seconds. The shortest waiting times were measured at the L 4 post office, where
the measured results indicate that half of the customers waited to be served less than 89 seconds and half of the customers
more than 89 seconds, while the average waiting time, in this case, is 120.09 seconds. The deviation from the
average waiting time, in this case, is 106.09 seconds. With a 99% probability, it can be stated that the customer waiting
time at the counter in the L 4 facility will be within the range of 87.98s - 153.65s, which represents a reserve of 516.35 seconds
(78,66%) (Table 3).

Comparing waiting times with a set standard

A different situation was found in the XL 3 facility, where the peak waiting times were measured significantly
longer than in other tested establishments but the standard norm was not broken. The average waiting time was set at
321.46 seconds, which is almost 2.7 times more than the one with the shortest waiting time. Half of the customers waited
for less than 316.5 seconds, but a quarter of customers waited for more than 421.25 seconds. While the waiting times of
that facility indicate that it was heavily exploited at peak time, with 95% probability we can say that the waiting times
during the daily opening hours will be in the range of 292.08 - 350.84 seconds with a 99% confidence in 282.78 - 360.14s,
which represents a reserve of 574.46 seconds against the specified standard.

5. Conclusions

Time availability is an essential indicator of the quality of postal services when considering the perception of the
public. Its individual components, whether opening hours for the public or waiting time at the counter, along with the
time of transportation, are frequent topics of discussion, especially in professional circles, but also at the level of
regulatory authorities. However, statistical data suggest that these are aspects that are significantly involved in customer submissions and complaints. As already mentioned, the time availability as a quality parameter is set out in Directives of European Parliament. In most countries, this parameter is set only about so-called opening hours of the post office. However, the Slovak Republic's regulatory authority has also added the "waiting time at the counter" factor to the time availability and set a maximum allowable value of 12 min (720 seconds). It is therefore imperative to carry out checks on compliance with the maximum waiting time for operators at individual facilities. In some cases, these controls are provided in the form of data evaluation, which is provided by the customer ticketing system already implemented in many facilities. For other facilities and especially problematic ones (capacity limitations about customer service, complaints, dissatisfaction, high work error rate) it is necessary to realize these measurements repeatedly, especially in the form of physical measures of actual waiting times there.

The results of the waiting time at the counter at the time of peak operation showed positive results. No measured value has exceeded the set standard and statistically estimate the average waiting time interval is set in a range that guarantees 95% but 99% that during the entire working day of the facility, the waiting time will belong to that interval. Thus, it can be stated that the current capacity monitored postal offices (end points of the postal network) by the facility from the customer is sufficient.

However, as we know, the waiting time at the counter is not only subject to compliance with established standards but is also subject to customer satisfaction research (table 1). However, these assessments are influenced by the subjective perception of the customer, which is controlled by various factors, especially emotional factors. Often, the customer will negatively evaluate the waiting time, even when this waiting time is really minimal. Here, the satisfaction of the customer's requirements is only in his head and can (but does not have to) meet the real situation. It is, therefore, up to the provider to consider creating optimal conditions in the premises of the postal operations so that the customer does not perceive the waiting time negatively. In particular, it is done mostly by a pleasant atmosphere, airy and calm spaces, pleasant colours, and so on.

In the future, however, the "staffing of the facilities" appears to be a problematic aspect related to the waiting time. Postal businesses in Europe face a shortage of manpower in individual parts of the offices, especially in transport but also in shipment sorting (increasing number of packages). The Slovak universal provider also encounters these problems more and more frequently, and in some economically more developed regions with a significant labour shortage (even in other sectors), this problem is also significant in the positions of counter clerks. It is therefore a global problem for the national economy, but this is not a simple task for the universal service provider, which is obliged to provide service to the entire area of the country in the same quality (which has set standards).

Acknowledgement

VEGA 1/0152/18 Business models and platforms in digital space

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The Research of the Causality of the Distribution of the Flow of Hazardous Cargo Between Railway and Road Transport

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Abstract

The methodology is proposed in the article for the assessing of the competitiveness of railway transport against road transport while transporting hazardous cargo. Making an assumption that the above-mentioned competitiveness is defined by the ratio of hazardous cargo transported by railway and road cargo within the period being analysed, it is analysed how this ratio changes with the following economic indicators changing: domestic product, unemployment and the general extents of cargo (not only hazardous) being transported. It has been identified that the ratio of hazardous cargo between railway and road transport mostly correlates with the general extent of cargo being transported.

KEY WORDS: railway transport, road transport, distribution of the flow, hazardous cargo

1. Introduction

Analysing the peculiarities of transporting hazardous cargo, the question of the competitiveness of railway transport against road transport arises more and more often [1, 2]. The time, price and safety usually affects the competitiveness of the services of transporting cargo. It goes without saying that the same factors also determine the competitiveness of transporting hazardous cargo. The notion itself “Hazardous Cargo” shows a special meaning of safety. A lot of researches proved that railway transport is safer than road transport. The advantage of railway transport against road transport with regard to safety is usually reasoned by a smaller comparative number of accidents, i.e. in railway the number of accidents for one ton of cargo, transported one kilometre, is smaller. This circumstance makes us believe that railway transport should be more competitive than road transport while transporting hazardous cargo. The authors of the article make an assumption that the ratio of the amount of hazardous cargo, transported by railway and road transport within the period analysed, correlates with the main economic indicators of the country: gross domestic product, unemployment and the general extents of cargo (not only hazardous) being transported. Also, the authors reason the idea that according to the above-mentioned reliance it is possible to assess a real competitiveness of railway transport (while transporting hazardous cargo) against road transport. The researchers have been analysing the peculiarities of transporting hazardous cargo for a long time and there is valuable information in literature with regard to this question.

The incentive to perform this research occurred having got acquainted with the Master’s Thesis of the Master student of VGTU, A. Bernatavicius [3]. In the above-mentioned thesis the aspects of transporting hazardous and oversize cargo on the roads and by railway are analysed. The author of the above-mentioned research suggests evaluating the competitiveness of railway transport using multi-criteria AHP methodology. 6 experts were questioned, the work of whom is directly related with transporting hazardous cargo on the roads and by railway, as well as the experts who are good at concerning transporting hazardous cargo. The experts were the representatives of the companies of different types of activities, concerning transporting hazardous cargo. They were chosen, because the versatile qualitative evaluation of the competitiveness of railway and road transport was aimed at while questioning the representatives of both railway and road transport.

Questionnaires, consisting of two parts, were given to the experts: part 1 of the questionnaire – the research of the significance of the criteria; part 2 of the questionnaire – the comparison of the modes of transport according to the criteria analysed. Firstly, the experts assessed the significance of criteria. The matrixes of double comparison of the significance of the criteria were made. Having evaluated the significance of the criteria analysed, having identified their priority meanings, the opinion of the experts about the competitiveness of railway transport while transporting the cargo of the types analysed according to each criterion separately is assessed. Then, according to the levels of the significance of criteria and calculated priority meanings of the modes of transport, the general priority is specified, which shows which mode of transport is better to choose while transporting hazardous cargo. In such a way the author identified that in the above-mentioned case railway transport is more competitive by approximately 80 per cent. In the scientific community such a method is known as AHP method. On one hand, the use of the method is an interesting solution, as this method is applied for the researches of the opinion of specialists [4]. However, in the above-mentioned work only attention to the researches of the experts is paid, whereas objective reasons are not analysed (it is normal, as the method is intended for that).

The young scientist of VGTU Marius Mikulenas analyses the impact of globalization on the flows of transport, as well as the distribution of the flows of cargo in railway and road transport [5]. In the research it is stated that aiming to
increase the competitiveness of railway transport against road transport, it is necessary to improve the quality of transporting by railway. The theoretical evaluation of the means of redirecting cargo flows from road to railway transport in Lithuania is provided in the research, as well as the infrastructures of transportation by road and railway transport are compared and the amounts, nomenclatures, the directions of transportation are statistically described. In her researches the scientist from Lithuania N. Batarliene analyses the possibilities how the transportation of hazardous cargo can be mathematically described using probability theory, the aim of the above-mentioned description would be to compare the expenses of the transportation using different modes of transport \([6, 7]\). However, the above-mentioned research ended without having identified the common patterns of essential probabilities. There are researches that evaluate the safety of freight transport through the prism of technical condition, but it is a separate topic \([8, 9]\).

The aim of the research described in this article is to identify, according to the statistics of the hazardous cargo transported by Lithuanian railway and road transport, which economic indexes are mostly related with the ratio of the amount of hazardous cargo transported by railway and road transport within the period analysed: gross domestic product, unemployment level or the total extents of cargo transported (not only hazardous).

2. The Methodology of the Research

In mathematical sense the competitiveness of the service of transporting hazardous cargo can be defined as the ratio of the amount of hazardous cargo transported by railway and road transport:

\[
R_{R,A} = \frac{L_R}{L_a}, \tag{1}
\]

where \(L_R\) – the amount of hazardous cargo, transported by railway within the period analysed, million tons; \(L_a\) – the amount of hazardous cargo, transported by road transport within the period analysed, million tons.

Three functions of ratio \(R_{R,A}\) of the amount of hazardous cargo transported by railway and road transport are made in order to evaluate the correlation of economic indicators:

\[
\begin{align*}
R_{R,A} &= f(X_{GDP}); \\
R_{R,A} &= g(X_U); \\
R_{R,A} &= h(X_L),
\end{align*}
\tag{2}
\]

where \(X_{GDP}\) – the gross domestic product of the country, milliard EUR; \(X_U\) – the level of unemployment in the country; \(X_L\) – the total amount of the cargo transported, milliard tons.

The values of square \(R^2\) of correlation coefficient are calculated for every of these functions, according to this value the strength of correlation is evaluated: the value of which function \(R^2\) is bigger, correspondingly it can be stated that this factor stronger correlates with the ratio of the amount of hazardous cargo transported by the above-mentioned modes of transport. The authors of the article further consider that factor to be the main (most important) factor determining competitiveness.

3. The Process and Results of the Research

The data used for the research according to the statistics of Lithuanian transport system is provided in Table (this data is easily accessible in public space) \([3]\).

<table>
<thead>
<tr>
<th>Year</th>
<th>The amount of transported hazardous cargo, million tons</th>
<th>The ratio of the amount of cargo (R_{R,A})</th>
<th>GDP, milliard EUR</th>
<th>The total amount of cargo, million tons</th>
<th>Unemployment level, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Railway transport</td>
<td>Road transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>12.31</td>
<td>1.399</td>
<td>8.80</td>
<td>121.3</td>
<td>2012</td>
</tr>
<tr>
<td>2013</td>
<td>13.63</td>
<td>1.535</td>
<td>8.88</td>
<td>120.7</td>
<td>2013</td>
</tr>
<tr>
<td>2014</td>
<td>13.02</td>
<td>1.712</td>
<td>7.61</td>
<td>123.3</td>
<td>2014</td>
</tr>
<tr>
<td>2015</td>
<td>11.57</td>
<td>2.03</td>
<td>5.70</td>
<td>127.1</td>
<td>2015</td>
</tr>
<tr>
<td>2016</td>
<td>12.99</td>
<td>2.16</td>
<td>6.01</td>
<td>127.1</td>
<td>2016</td>
</tr>
<tr>
<td>2017</td>
<td>12.68</td>
<td>2.893</td>
<td>4.38</td>
<td>131</td>
<td>2017</td>
</tr>
</tbody>
</table>

While analysing the statistical data provided in Table, one of simpler and more accessible ways is chosen – MS Excel software. Using it, the schedules of the extents of the ratio of the amount of hazardous cargo transported by railway
and road transport \((R_{R,A})\), dependence upon gross domestic product, unemployment level and total cargo transported (not only hazardous) are made, as well as the values of square \(R^2\) of correlation coefficient are calculated.

The dependence of ratio \(R_{R,A}\) of the amount of hazardous cargo transported by railway and road transport (a year) upon the gross domestic product of the country is shown in Fig. 1.

![Fig. 1](image1)

In Fig. 1 it can be seen that with the domestic gross product increasing, the value of the ratio \(R_{R,A}\) is decreasing. Therefore, with rising economics, the extents of transporting hazardous cargo are increasing for the benefit of road transport and to the detriment of railway. The value of index \(R^2\) is bigger than 0.8, thus tendency is real, but the value of this index will also have to be compared with the corresponding values of other correlations. The dependence of ratio \(R_{R,A}\) upon unemployment level in the country is shown in Fig. 2.

![Fig. 2](image2)

In Fig. 2 it can be seen that with unemployment increasing, ratio \(R_{R,A}\) increases. It is probable that this trend is a logical continuation of the consistent pattern seen in Fig. 1. Here the value of square \(R^2\) of correlation coefficient is more than 0.87 – it is an even stronger correlation.

The dependence of ratio \(R_{R,A}\) upon the total amount of cargo transported in the country (also including hazardous cargo, and not only them) is shown in Fig. 3.

The tendency seen in Fig. 3, as well as in Figs. 1 and 2, means that with economics rising, the value of ratio \(R_{R,A}\) changes to the detriment of railway transport. Meanwhile, the value of index \(R^2\) is even bigger here – there it is more than 0.99 – especially strong correlation.
It is obvious that all the three factors respectively analysed in the diagrams (gross domestic product, unemployment level in the country, the total amount of cargo transported) strongly correlate with the ratio of the amount of hazardous cargo transported by railway and car transport. The biggest square ($R^2=0.991$) of correlation coefficient is when function fragment is the total amount of cargo. Therefore, it can be reasonably stated that the factor mostly determining the distribution of hazardous cargo between railway and road transport is the total amount of cargo.

4. Conclusions

Both gross domestic product and unemployment percent and the total flow of cargo transported are the essential factors determining the ratio of the amounts of hazardous cargo transported by railway and road transport, as the values of square $R^2$ of ratio correlation with them are from 0.824 to 0.991.

The total flow of cargo transported the most strongly correlates with the amount of hazardous cargo transported by railway and road transport (the value of the square of correlation coefficient equals 0.991), it means that namely this dependence has to be analysed assessing the competitiveness of the latter modes of transport in the market of transporting hazardous cargo.

With the total flow of cargo transported increasing, ratio $R_{R,4}$ of the amount of hazardous cargo transported by railway and road transport decreases, and this evidences the lack of the competitiveness of railway transport.

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References

Calculation of the Loads of a Lifting Seat Drive Shaft for Transportation of Disabled Persons

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Abstract

The article deals with the description of a device, namely a lifting seat, which is intended for transportation of disabled persons. It is designed for mounting for indoor staircases in buildings of public as well as private sector. The designed device is composed of several structural units, which satisfy carrying and driving functionalities. In this article the calculation of the loads acting on the drive shaft due to operational conditions is presented. Moreover, this important structural part is analysed by means of FE software in terms of strength and its design is optimised in order to reduce the cost price, because it is a series produced product.

KEY WORDS: lifting seat, drive shaft, loads, finite element method, strength analysis, optimisation

1. Introduction

The main task of handling machines for disabled persons is the palliation or the complete abolition of daily troubles, which obstruct to full life. These troubles are connected with moving of disabled persons and also older people, who have problems with walking up the stairs as well as during recovery after severe injuries. By means of various devices there is possible to ensure moving on a straight surface as well as overcoming height differences. Among such device the designed lifting seat is included (Figs. 1 and 2). Lift seats (or stair lifts) are devices, which are intended mainly for people permanently suffering from troubles of musculoskeletal system [1]. Safe and effective transportation of a person to individual stations is the main purpose of a lifting seat. But, it is allowed to occupy by its dimensions and positioning as less space as possible to avoid being an obstacle on a staircase. From the design of a device it is obvious that a person using it has to be partially mobile to get on and get off it. Currently produced devices are not suitable for manipulation with persons, who are entirely dependent on a wheelchair [3].

Such a handling machine is usually made of more kind of material to reach suitable mechanical properties of particular components in combination with required lifetime and acceptable price. There are most often used combination of standard steel, high strength steel, light metals, mainly such as aluminium alloys, plastics etc. [20, 21, 26]. Power transmission of a lifting seat is ensured by mesh of a gear wheel (a pinion) and a rack mounted on a guidance. Operation of the lifting seat is possible also in a case of blackout, because a battery is used as a power source charged during the stand-by regime in the end position of a track. Due to space effectiveness, a seat, armrests and footrests are tilted. The latest types have the automatic process of tilting and they dispose of a remote control [13]. The drive-train is composed of an electric motor, a gearbox and a gear wheel, which is in the mesh with a rack.

2. Formulation of the Driving Electric Motor Power Depending on a Transported Person Weight

During solution of this project, geometrical quantities as well as force quantities, which influence the value of the needed power of the driving electric motor, have been determined and mathematically described. There has been found
out, that from all resistances influencing the needed power of the used motor just the transported person weight is the most variable quantity. From this point of view there is necessary to consider different conditions in the contact of the driving wheel and the track [8, 9, 15, 16, 23]. Coefficients related with passive resistances depend on material choice as well as geometry of used components. Rolling wheels of the seat are mounted on pins, in which the friction is generated. Value of this resistance is determined by the normal force transmitted by the wheel, friction coefficient between the pin surface and material of the wheel, and the friction circle of radius [7, 11]. Therefore theirs values are constant while the structure of the device is not changed. Certain parameters are subjected to standards, hence the speed of a lifting seat is usually about 0.1 ms\(^{-1}\) regardless of a producer.

From information described above results, that at the same design of a lifting seat the needed power of a driving motor varies only with the person weight and the climbing angle of a track. In the calculation of the power, two variables rise, namely the force \(G\) as the gravity of the seat and the force \(Q\) as the gravity of a person. Dependences of resistance torques are graphically illustrated in Fig. 3 and particular values are listed in Table 1. Variables mean the following: \(m_c\) – weight of a transported person; \(Q\) – gravitational force resulting from \(m_c\); \(M_{ob}\) – torque of pin friction; \(M_{oav}, M_{oak}\) – torques of rolling friction of contact pairs; \(M_s\) – torque resulting from climbing; \(\Sigma M_i\) – sum of all resistance torques.

3. Determination of the Power Depending on the Climbing Angle of a Track

The climbing angle \(\alpha\) is a quantity changing individually for every track. The change of this angle is from 0° for straight track section up to maximum climbing angle, which can be maximum of 52° from the structural point of view. However, it should be noted, the shape of a track depends on a staircase design. This ultimately means that the maximum climbing angle on a track does not reach the limit value of 52°. According to the inclination, staircases are classified in several categories, namely: ramp (\(\alpha = 10°–20°\)), mild (\(\alpha = 20°–25°\)), standard (\(\alpha = 25°–35°\)), steep (\(\alpha = 35°–45°\)), ladder (\(\alpha = 45°–58°\)).

Generally, the inclination of a main staircase in a villa or in a family house is in the range of 20° – 30°, which is a favourable value also from the physical difficulty point of view for getting on it. As it is supposed, from all resistances acting on the lifting seat the gradient resistance is dominant, there will be determined analytically (Table 2) as well as graphically (Fig. 4) waveforms of moments and needed power for the loads, which corresponds to the maximal load capacity of \(m_c = 130\) kg.

![Fig. 3 Dependence of the driving motor power on a person weight at the constant climbing angle of \(\alpha = 52°\)](image)

Table 1

<table>
<thead>
<tr>
<th>(m_c) [kg]</th>
<th>(Q) [N]</th>
<th>(M_{ob}) [N·mm]</th>
<th>(M_{oav}) [N·mm]</th>
<th>(M_{oak}) [N·mm]</th>
<th>(M_s) [N·mm]</th>
<th>(\Sigma M_i) [N·mm]</th>
<th>(P) [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>52</td>
<td>510.1</td>
<td>368.9</td>
<td>313.0</td>
<td>1,198.1</td>
<td>28,016.8</td>
<td>29,896.9</td>
<td>148.2</td>
</tr>
<tr>
<td>58</td>
<td>569.0</td>
<td>393.5</td>
<td>334.0</td>
<td>1,264.1</td>
<td>29,559.1</td>
<td>31,550.7</td>
<td>156.4</td>
</tr>
<tr>
<td>64</td>
<td>627.8</td>
<td>418.2</td>
<td>354.9</td>
<td>1,330.0</td>
<td>31,101.3</td>
<td>33,204.7</td>
<td>164.6</td>
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<tr>
<td>70</td>
<td>686.7</td>
<td>442.9</td>
<td>375.9</td>
<td>1,396.0</td>
<td>32,643.5</td>
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<tr>
<td>76</td>
<td>745.6</td>
<td>467.6</td>
<td>396.8</td>
<td>1,462.0</td>
<td>34,185.7</td>
<td>36,552.0</td>
<td>181.0</td>
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<tr>
<td>82</td>
<td>804.4</td>
<td>492.3</td>
<td>417.8</td>
<td>1,527.9</td>
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<td>38,165.8</td>
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<td>88</td>
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<tr>
<td>94</td>
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<td>38,812.3</td>
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<tr>
<td>100</td>
<td>981.0</td>
<td>566.3</td>
<td>480.6</td>
<td>1,725.8</td>
<td>40,354.5</td>
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<tr>
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<td>543.4</td>
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<td>45,981.2</td>
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<td>124</td>
<td>1,216.4</td>
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<td>564.4</td>
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<td>46,523.4</td>
<td>49,742.3</td>
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<td>689.7</td>
<td>585.3</td>
<td>2,055.5</td>
<td>48,065.6</td>
<td>51,396.1</td>
<td>254.7</td>
</tr>
</tbody>
</table>
4. Choice of an Electric Motor

The resulting value of the driving electric motor power, which is designed for nominal parameters, is in compliance with the performed calculation \( P_c = 256.67 \, \text{W} \). An electric motor, which will drive this device, has to have the nearest higher power according to standardised parameters to ensure the operation of the device without the danger resulting from constant overloading. Therefore, the drive-train is designed for the TTH-442-15 electric motor (Fig. 5) with the nominal power of \( P_n = 270 \, \text{W} \), supply voltage of \( U = 24 \, \text{V} \), electric current of \( I = 16 \, \text{A} \), torque of \( M_n = 1.4 \, \text{Nm} \), RPM of \( n = 1,800 \, \text{min}^{-1} \) and the mass of \( m = 5.5 \, \text{kg} \). The used gearbox is marked as CM40 with the gear ratio of \( i = 60 \). It is the worm gearbox. The entire assembly of the drive-train is shown in Figs. 5 and 6.
Transmission of the torque from the electric motor to the system is ensured by two shaft keys (DIN 6885 A). Keys are positioned in the one direction in a row. The strength analysis of this shaft is also the objective of this article. In this part of the shaft is created a thread M8, into which a screw is screwed after mounting the gearbox with a special washer ensuring safety of the joint. In the middle part of the shaft is created the space for a flange, a cover of the seat, a holder, needle bearings and a plastic scroll. From the other side of the shaft the pinion (gear wheel) is mounted. Between the pinion and the shaft the DIN 6885 A the key is placed, which transmits the torque. For the minimum possible length of the key, the slot is placed specially in such a manner, that it interferes into the side cylinder of the shaft. The screw is screwed also in this part of the shaft.

5. Numerical Calculation of the Safety ratio of the Shaft Structure

As we have estimated the needed power of the drive electric motor, we can determine the boundary conditions of the loads for the designed shaft. In order to analyse distribution of stresses in the structure of the designed shaft and evaluation of its dimensioning, the three-dimensional model of the shaft has been created (Fig. 8). For it, we have used the Inventor software package. After that, we have input it to the FE program. The numerical calculation of stresses in the shaft structure has been carried out by means of the finite element method, which is common used method for standard analyses of structures of technical parts, assemblies and also whole constructions [5, 6, 25]. In our research we have used the Ansys software package. In the computational model surfaces of the shaft have been divided in such a way, that they simulate surfaces under the pinion, the plastic scroll and the gearbox (Fig. 7).

In addition, another surface has been modelled by dividing the facing place into two halves, which lean against the gearbox. The greater radius of this surface has been reduced to 15.0 mm, which corresponds to the radius of the contact part of the gearbox. On such prepared surface there were possible to simulate the contact of the shaft and the gearbox. All these acts were carried out in the Geometry module.

Material properties have corresponded with the 16MnCr5 steel (STN 14 220), which the yield strength $R_y$ is of 550 MPa and the ultimate strength $R_m$ is 550 MPa.

Subsequently, in the Model module the mesh of the model was defined (Fig. 9). The mesh was formed by elements of 2 mm and it has consisted of 53,684 nodes and 31,234 elements. After shaft meshing, joints were assigned between surfaces of the gearbox and the shaft. Then, degrees of freedom were defined. On surfaces under bearings, under the
plastic scroll and under the pinion, torques and forces were applied. After calculation, equivalent stresses in compliance with the HMH hypothesis were evaluated.

From performed numerical calculations of stresses in the loaded shaft we have identify, that the maximum stress in the structure is of $\sigma_{\text{max}} = 463.42$ MPa. In comparison with mechanical properties of the used material, the safety ratio in the most exposed section is of $k = 1.187$. The safety condition is met.

Based on numerical calculations we have found out that the maximal calculated stress in the original designed shaft is located in the locality of the cross-section variation and they are under the yield of strength of the used material (Fig. 10). Therefore, we have approached to optimization of the shaft design in order to save quantity of used material and thus also saving production cost. Subject of the optimization process has consisted in the change of diameters in the least loaded parts of the shaft. The number of shaft keys connecting the gearbox with the shaft was reduced only to the one. Moreover, the number of shaft keys was reduced in the location of the connection of the shaft with the pinion. The subsequent numerical calculation of the optimised shaft was performed under the same boundary conditions as the previous analysed case. Values and directions of the acting torques and forces were remained the same as well. The distribution of stresses in the optimised shaft we can see in Fig. 11. We identify, the maximum stress is located in the cross-section variation again, but, values of stresses are safety under the yield of strength of the used steel.

The future research will be focused to analyse effects resulting from the structure dynamics. For these purposes, advanced dynamical model has to be developed in MBS software [12]. Solutionists will make an effort for creating a computational model of the solved lifting seat as a multibody model [10, 22] even including flexible model, which will aid to identify the most loaded elements of the mechanical system and further optimise them. By means of further simulations and analyses it will be possible to find out values of accelerations in individual components of the lifting seat. Accelerations are main dynamical outputs [4, 19, 24], based on which we are able to analyse other dynamical effects influencing comfort [17, 18] during operation of the seat (acceleration, deceleration, climbing, kneeling, moving along a curved track on a sharped staircase).

6. Conclusion

The submitted article brings the summary of the problem focused on the design of a handling machine for disabled persons. There is a lifting seat intended for the civil sector. In the article, the calculation task of the needed power of a driving electric motor. It has been determined of $P_c = 256.67$ W. Based on these findings there was possible to choose a specific driving electric motor and a gearbox. Summary graphs present the dependence of the instant value of the motor power on a climbing angle of a track. Subsequently, after determination of the motor geometry there was possible to design a counter shaft of the pinion and to perform its numerical dimensional calculation. The analysis has proven its suitability for proposed operational conditions, but the possibility of its optimisation was identified in order to save amount of material used for its production. Therefore we have performed design modifications. They have consisted in design change in the location of key slots. The number of key slots was reduced only to the one (DIN 6885 AA 6x6x28), and this slot was positioned to the middle the cylindrical surface. The numerical analysis of the optimised shaft has proven that the modified shaft design is able to meet requirements of the required operational conditions hereby to save production costs.

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References

Application of Exergetic Analysis for LNG Regasification Process Optimisation and Redesign: Case Study of FSRU

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Abstract

Today the world energy market is in great transition and the demand for clean energy such as liquefied natural gas (LNG), which is increasing rapidly. Offshore large-scale terminals as Floating Storage Regasification Unit (FSRU) type are becoming commercially competitive and effective alternative for the areas where onshore gas supply infrastructure is not feasible. LNG production consumes energy (around 850 MJ per ton) and it is stored in the form of “cold energy” which is dumped into seawater or the atmosphere during LNG regasification process despite reusing as extra energy source in many processes. In this research work, mathematical model is performed to determine influence of LNG composition and regasification process parameters to quantity of released LNG cold energy in a large scale FSRU type terminal. It was determined that the potential of LNG cold energy at FSRU could vary from 20 to 25 MWh depending on LNG regasification flow rate, pressure, BOG recondensation as well as composition of LNG.

KEY WORDS: liquefied natural gas, FSRU, exergetic analysis, regasification, released energy utilisation

1. Introduction

According to market prediction, the World demand for natural gas will increase about 2.1% yearly to 2030 and a higher proportion for Asian countries [1]. Natural gas accounts quarter of global energy demand, of which 9.8% is supplied as LNG [2]. LNG is the main transfer form of long-range for water and short range for land transportation [3].

The herein used term “cold energy” represents to the sum of the amount of heat used to evaporate LNG and the amount of heat used to set the final parameter pressure and temperature at the exit of the FSRU.

Generated “cold energy” causes energy waste and pollution of environment [4], higher prices of natural gas and reduces efficiency of the primary energy source [5]. The utilisation of LNG cold energy could be direct (e.g., cold energy power generation [3, 4-6, 8-10, 11, 12, 15-18], cryogenic air separation [3, 8-10, 11-13], refrigerated warehouse [5, 8, 10, 14, 16]) and indirect (e.g., cryogenic comminution [8, 14] and the treatment of filthy water [8, 13, 15-17]) [9].

The cold-exergy analysis is the main method of cold-energy utilisation system design. Exergy analysis could identify exergy losses in different regasification equipment in order to improve thermodynamic efficiency [7].

The aim of this research work is to compare five LNG regasification cases with different technological parameters including thermodynamical and exergy analyses by considering LNG “cold energy” utilisation options in large scale FSRU type terminal.

2. Methodology

2.1. LNG Regasification Process Flow Diagram

The LNG line in Fig. 1 starts at the cargo tank at -160°C. The following buster pump (2) send it with an approximately 10 MPa pressure through the BOG recondenser (3) to the LNG vaporiser (4). The heating propane gas rise its temperature from -160 to -10°C. The natural gas trim heater (5) heats the gas to a send out temperature of +5 °C and pressure of 3.4–6.5 MPa.

The heating media is propane circulated by the pump (7) with constant speed in a closed loop (inlet pressure about 0.2 MPa, outlet 1.1 MPa). The liquid propane from the buffer tank (8) is evaporated by seawater in the preheater (6). After trimming the NG to its send out value, the propane is mixed with cold propane and again heated by seawater in the vaporiser (9). It transports the earned heat to the LNG vaporiser where its condensate with heat release from 0 to -5°C. Then it flows back to the tank.

Sea water is used as heating source by means of propane for LNG regasification. The minimum sea water inlet temperature to heat exchanger is determined at 13°C and if the sea water temperature is below this temperature, then seawater is preheated and circulated in a close loop.
2.2. Basic Process Performance

Mathematical modelling is performed to calculate absorbed cold energy and maximum work (exergy) from LNG to by seawater heated propane and to determine the best thermodynamic properties of the process varying different LNG flow rates and pressure.

For determination of energy and exergy of the system, two methods were chosen – the work (exergy) and energy:

1. The Peng-Robinson (P-R) equation based on following assumptions comparing with other mathematical models [3, 21]:
   - The heat transfer between the environment and the system is not feasible.
   - Heat exchangers are the counter-flow type and adiabatic.
   - The isentropic efficiency of pumps, turbines and compressors is equal 0.9.

2. The calculation of the thermodynamic parameters of working fluids (propane, methane, and seawater) and exergy of flows is carried out by database program REFPROP version 9.0. The exergy analysis conditions are set to reference conditions ($T_0 = 15^\circ C$ (288.15 K) and $p_0 = 0.101$ MPa (g)).

The mathematical model is performed in five different regasification cases in order to compare energy results and verify the most suitable case for exergy analysis (Table 1). Criteria of regasification cases are selected according to technological procedures and physical parameters to verify LNG cold energy release.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow of LNG, kg·h⁻¹</td>
<td>120000</td>
<td>102000</td>
<td>105000</td>
<td>50000</td>
<td>190000</td>
</tr>
<tr>
<td>BOG recondensation</td>
<td>no</td>
<td>with BOG circulation</td>
<td>no</td>
<td>partly</td>
<td>partly</td>
</tr>
<tr>
<td>Composition of LNG, %</td>
<td>methane – 86; ethane – 8; propane – 4; i-butane – 1; n-butane – 1</td>
<td>methane – 100</td>
<td>methane – 96; nitrogen – 4</td>
<td>methane – 86; ethane – 8; propane – 4; i-butane – 1; n-butane – 1</td>
<td>methane – 86; ethane – 8; propane – 4; i-butane – 1; n-butane – 1</td>
</tr>
<tr>
<td>Pressure, MPa(g)</td>
<td>3.5</td>
<td>6.5</td>
<td>6.5</td>
<td>6.5</td>
<td>5.5</td>
</tr>
</tbody>
</table>

LNG properties were calculated by standard ISO 6976:1995 “Natural Gas – Calculation of Calorific Values, Density, Relative Density and Wobbe Index from Composition” and Klosek-McKinley method [22].

3. Results and Discussions

Table 2 represents the physical parameters of LNG (mixture of mass, volume, density, individual gas constant) of the rich LNG with methane content is 86% and lean LNG with methane content is higher than 90%.

The Case 3 represents LNG with high methane (96%) and nitrogen amount (4%). Nitrogen is an inert component which reduces gross heating value [22]. High amount of nitrogen has effect of BOG generation and it could make LNG unmarketable [5]. The density is the indicator of LNG composition which determines what quality of LNG suppliers are stored in FSRU.
The estimated physical properties are used for energy and exergy calculations. The Case 1 with the highest regasification flow has the lowest pressure drop comparing with other cases. The final mass enthalpy at natural gas outlet is 2.3 times higher than in Case 4 with lowest flow. Case 2 and 3 with the similar pressure conditions at every flow point of regasification have different temperature. The reason is that the Case 3 is with large amount nitrogen of LNG, which boiling point is higher than methane and rich minus 196°C. The final mass enthalpy is slightly lower in Case 3 (131.17 MWh) than in Case 2 (136.52 MWh), because of the large amount of nitrogen comparing with other cases.

<table>
<thead>
<tr>
<th>Case</th>
<th>$M$</th>
<th>$V$</th>
<th>$V_{mix}$</th>
<th>$K_1$</th>
<th>$K_2$</th>
<th>$\rho_{LNG}$</th>
<th>$R_g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>kg·kmol$^{-1}$</td>
<td>L·mol$^{-1}$</td>
<td>L·mol$^{-1}$</td>
<td>L·mol$^{-1}$</td>
<td>L·mol$^{-1}$</td>
<td>kJ·(kmol·K)$^{-1}$</td>
<td>L·mol$^{-1}$</td>
</tr>
<tr>
<td>Case 1 *</td>
<td>19.1290</td>
<td>0.0400</td>
<td>0.0398</td>
<td>0.00718</td>
<td>0.00129</td>
<td>480.26</td>
<td>0.435</td>
</tr>
<tr>
<td>Case 2</td>
<td>16.0000</td>
<td>0.0400</td>
<td>0.0380</td>
<td>0.00001</td>
<td>0.00032</td>
<td>423.42</td>
<td>0.520</td>
</tr>
<tr>
<td>Case 3</td>
<td>16.4220</td>
<td>0.0360</td>
<td>0.0352</td>
<td>-2.66·10$^{-5}$</td>
<td>1.07·10$^{-5}$</td>
<td>432.40</td>
<td>0.506</td>
</tr>
</tbody>
</table>

*The composition of LNG is the same as in Case 4 and Case 5; $M$ – molecular mass of mixture (kg·kmol$^{-1}$); $V$ (without correction) – molar volume of LNG at the reference temperature (L·mol$^{-1}$); $V_{mix}$ – molar volume of mixture (L·mol$^{-1}$); $K_1$, $K_2$ – volume correction factors (L·mol$^{-1}$); $\rho_{LNG}$ – LNG density by reference temperature (L·mol$^{-1}$); $R_g$ – individual gas constant kJ·(kmol·K)$^{-1}$.

To evaluate released cold energy of LNG and verify this process optimisation, the propane closed loop thermodynamic properties are observed and analysed.

Case 4 with lowest circulating propane flow (100 000 kg·h$^{-1}$) is directly transferred by propane pump to propane preheater and the propane flow doesn’t change in all LNG regasification process. Furthermore, in other cases, after propane pressurisation by Propane pump, the part of propane flow is sent back to propane tank, as well as part is sent to Propane vaporiser for mixing and the rest flow is sent to propane preheater.

The maximum flow of propane (287 212 kg·h$^{-1}$) is circulated in Case 1, in which is the highest LNG regasification demand. This is 2.8 times higher than in Case 4. Initial flow of propane is 220 000 kg·h$^{-1}$ in Case 2, flow is 250 000 kg·h$^{-1}$ in case 3 and 270 000 kg·h$^{-1}$ in Case 5. Comparing these cases, small differences between flows estimate different mass enthalpy values, which depend on pressure and temperatures changes. For example, initial mass enthalpy is 183.78 MWh in Case 2, 198.51 MWh in Case 3 and 214.78 MWh in Case 5.

The higher impact of mass enthalpy changes has more positive effect for LNG cold energy recovering after LNG regasification. Propane preheating is important thermodynamic process due to the fact propane might be heated the temperature which is suitable to rise up natural gas temperate from -5 to +5°C in NG Trim heater according to transmission system requirements. Entering propane to preheater, it is heated by seawater approximately from minus 15°C to 11°C in all cases. After natural gas heating propane is mixed with cold flow and is sent to Propane vaporiser. This mixing process is not accepted in the Case 4 due to the low LNG regasification demand. The output mass enthalpy of Case 1 is 2.8 times higher than in Case 4. Furthermore, in other cases, the output mass enthalpy absorbed from seawater is quite similar comparing with Case 1.

When LNG is sent by booster pump to LNG vaporisation unit, the maximum power consumption is exceeded in Case 1 and 2 (0.74 MWh) in which are highest energy demand to regasify LNG. The maximum power consumption is 0.85 MWh according to technical specification has booster pump. The minimum power consumption is exceeded 0.57 MWh in Case 4 which is the minimum LNG regasification flow.

Regasification with BOG recondensation (Case 2, Case 4, and Case 5) requires lower power energy demand to regasify LNG due to the reason, recondensation process warm up cold LNG. For instance, comparing Case 1 (120 000 kg·h$^{-1}$) and Case 5 (190 000 kg·h$^{-1}$) with highest LNG regasification flow, the energy demand is higher in Case 1 than in Case 5 because of this case the partly BOG recondensation is fulfilled.

When propane is sent by propane pump to propane preheater, the maximum power consumption exceeds in Case 1 (0.16 MWh) and Case 5 (0.15 MWh). It is 0.20 MWh according to the technical specification of Propane pump. The minimum power consumption is exceeded 0.11 MWh in Case 4 in which is the minimum LNG regasification demand. Moreover, the power consumption is 0.13 MWh in Case 2 and 0.14 MWh in Case 3. The maximum absorbed heat is estimated in Case 1 (4.02 MWh) and Case 5 (3.84 MWh) in propane preheater. The minimum absorbed heat is estimated in Case 4 (1.56 MWh), which is 2.5 times less comparing with Case 1 and is 2.4 times less comparing with Case 5. This heat, absorbed by propane, is released to LNG in NG trim heater. Propane vaporiser, as the most energy consumption unit in closed propane loop, is affected by propane mixing before vaporisation. In addition, the heat absorption LNG vaporisation is equal to the heat of the propane from seawater in propane evaporator. The maximum heat absorbed is 20.50 MWh by propane from seawater in propane vaporiser. The minimum heat absorbed amount (7.16 MWh) is in the Case 4.

Released LNG cold energy is determined comparing LNG mass enthalpy input and output values of whole regasification system. The maximum value of 24.78 MWh is estimated in Case 5. Comparing results of released LNG cold energy, the huge amount is released in Case 3 than in Case 2 due to the reason of nitrogen content of LNG. The difference between these cases is 1.15 MWh. The minimum amount of released LNG cold energy is in Case 4. The difference between minimum and maximum released LNG cold energy values are 2.15 MWh. The LNG cold energy average of all these cases is 22.34 MWh. Hereby, the mean value of all these cases characterises that released LNG cold energy (22.34 MWh) could be reused in more feasible way.
To evaluate drawbacks of regasification system at FSRU the exergy analysis has to be performed. The exergy analysis includes calculation of input, output and loss of the system, efficiency under the reference conditions.

The exergy is investigated in the system as the physical (thermo-mechanical) exergy [19] (rejecting kinetic and potential energy changes, the flow exergy of natural gas at any stat; chemical exergy is not considered). The Case 2 was selected for the further analysis, because of the maximum amount of methane as well as flow rate is enough high to release LNG cold energy. The reference state for exergy calculations is set up $T_0 = 15^\circ C$ and $p_0 = 0.101$ MPa (g). The estimated values of exergy analyse calculated every flow in regasification system (Figs. 2 and 3) to determine the losses in the regasification system in exergy balance.

![Fig. 2 The values of LNG exergy flow in regasification system](image1)

![Fig. 3 The values of propane exergy flow in regasification system](image2)

Fig. 2 represents LNG exergy flows. LNG is transferred by Booster pump to the BOG recondensation unit and the exergy decreases from 47.40 MWh to 47.11 MWh. The exergy change is 0.29 MWh in this subsystem. Slope of the figure indicates the highest exergy flow changes between LNG input flow from BOG recondenser to LNG vaporiser as well as natural gas flow from LNG vaporiser to NG trim heater. It was investigated, that changes influence natural gas production from LNG and it consumes 12.68 MWh. The further natural gas heating consumes 0.54 MWh, which is estimated as a difference between natural gas flow from LNG vaporiser to NG trim heater as well as natural gas flow from NG trim heater to natural metering system.

Fig. 3 illustrates propane exergy flows. The slope between P2 and P5 represent propane work before propane heating and exergy decreases from 22.31 MWh to 18.56 MWh. During propane preheating process which represent exergy flow P5 and P6, the changes are not visible. The slope which increases from exergy flow P7 and P8 represents mixing propane cold exergy flow from propane tank and propane exergy flow after natural gas heating in NG trim heater. Therefore, exergy flow changes are positive and increase 4.70 MWh. The exergy changes could be seen during propane vaporisation process which indicates P8 and P9 flows. The exergy increases 9% from 23.06 MWh and 21.04 MWh and its difference is 2.02 MWh.

![Fig. 4 The values of seawater exergy flow in regasification system](image3)

Fig. 4 The values of seawater exergy flow in regasification system: SW2 – seawater inlet to the regasification system from heaters; SW5 – seawater flow to propane evaporator; SW6 – seawater output flow from propane evaporator; SW7 – seawater flow to propane preheater; SW8 – seawater flow output flow from propane preheater
Seawater exergy is illustrated in Fig. 4. Exergy flow is divided in two sections when seawater is sent to propane preheater as well as to propane vaporiser. The intensive exergy flow is in propane vaporiser due to the heat transfer. It was investigated, that all analysed sections (propane vaporiser, propane preheater) exergy increases due to the absorbed cold energy.

Table 3 shows the exergy input and output of regasification subsystem. The exergy input is 47.40 MWh and exergy output is 47.11 MWh when Booster pump performs works. The part of thermal exergy transfers to pressure exergy in booster pump, as LNG is pressurised and the temperature decreases. Furthermore, the minimum exergy input (47.11 MWh) and exergy output (46.65 MWh) are calculated in BOG recondenser because condensation of BOG process doesn’t extremely influence LNG temperature and pressure.

Table 3

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Exergy input (MWh)</th>
<th>Exergy output (MWh)</th>
<th>Losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster pump</td>
<td>47.40</td>
<td>47.11</td>
<td>1</td>
</tr>
<tr>
<td>BOG recondenser</td>
<td>47.11</td>
<td>46.65</td>
<td>1</td>
</tr>
<tr>
<td>LNG vaporiser</td>
<td>65.00</td>
<td>52.32</td>
<td>20</td>
</tr>
<tr>
<td>NG trim heater</td>
<td>52.32</td>
<td>51.78</td>
<td>1</td>
</tr>
<tr>
<td>Propane preheater</td>
<td>37.44</td>
<td>32.72</td>
<td>13</td>
</tr>
<tr>
<td>Propane vaporiser</td>
<td>75.99</td>
<td>74.06</td>
<td>3</td>
</tr>
</tbody>
</table>

It could be seen the highest exergy input (75.99 MWh) and exergy output (74.06 MWh) is in Propane vaporiser, but the exergy losses (12.67 MWh) are not as considerable amount as in the LNG vaporiser (12.67 MWh). The effect of high exergy demand could be caused because of high seawater flow and propane precooling before propane vaporisation process. The precooling could be done to decrease system work and propane temperature after natural gas heating in the NG trim heater. In addition, the large exergy input (65.00 MWh) and exergy output (52.32 MWh) are in the LNG vaporiser in which is high heat transfer between LNG and propane flows. Moreover, the losses in this subsystem are high enough comparing with other subsystem in the regasification process.

The exergy losses in FRSU regasification process are calculated. Assumption of high losses in propane evaporator is rejected because exergy loses estimated value is less than 3%. It was determined, that other exergy losses do not exceed more than 1%. These exergy losses could be caused for the irreversibility of regasification process [3]. It could be seen, that the highest losses are in LNG vaporiser which are more than 19% and in Propane preheater, which are more than 13%. The main reason is that the loss of irreversible of heat transfer is high enough because of thermal difference between heat and cold fluids well as the phase is not stable [20].

Calculation of energy balance and exergy analysis verified the generated LNG cold energy of the regasification system at FRSU could be utilised using cold energy technologies and its integrating in LNG regasification process at receiving terminals.

4. Conclusions

It was calculated that the potential of LNG cold energy is up to 25 MWh at FSRU when LNG flow rich 190,000 kg h⁻¹, regasification pressure is 5.5 MPa (g), partly BOG recondensation is performed and methane content of LNG is 80% (Case 5). LNG cold energy decreases 18%, when LNG flow is 41% lower (Case 4) than in Case 5. Moreover, LNG cold energy is 9% lower in Case 1 than in Case 5, because of partly BOG recondensation which has effect of LNG chilling in Case 5. Furthermore, LNG cold energy is 2.3% higher in Case 3 with 4% nitrogen and 96% of methane than in Case 2 with pure methane, because of low nitrogen boiling temperature (-196 °C) which could produce more LNG cold energy.

It was determined that the maximum exergy input of the regasification system at FSRU is 75.99 MWh in Propane vaporiser and the minimum is 37.44 MWh in Propane preheater. Meanwhile, exergy input is estimated 47.40 MWh in Booster pump, 47.11 MWh in BOG recondenser, 52.32 MWh in NG trim heater as well as 65.00 MWh in LNG vaporiser.

To increase energy efficiency of whole regasification process, it is recommended to use cascade LNG cold energy utilisation by combining thermodynamic cycles with LNG cold energy utilisation for industry chain. A sustainable use of cold energy would have environmental and economic advantages. However, innovative technologies would have to be developed in order to extract, store, transport and ultimately make the intangible cooling energy from the LNG as loss free as possible.

References


Development and Modeling of a Battery System for Commercial Electric Bicycles

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Abstract

The development of a battery system appropriate for electric bicycles is the subject of this paper. Oriented to be implemented as a plug-and-play equipment in existing electric bicycles or as part of a conversion kit, the analyzed battery system can successfully support electric and electric power assisted bicycles providing simultaneously real time information about critical powertrain parameters like battery and cell voltages, currents, temperatures and battery state of charge (SoC). A series of on the road experiments are used to evaluate the performance of the battery system. Additionally, the overall powertrain of the bicycle is modeled in order to compare the real world performance with simulation results.

KEY WORDS: Electric bicycles, energy storage system, battery modeling

1. Introduction

The intrusion of vehicle electrification in the world of the so-called human powered vehicles like bicycles and various types of tricycles was inevitable. The initial power assistance offered to the riders has become autonomous electric traction but at the same time the safe, speed limited, due to the restricted power a human can or is willing to provide, vehicles have become more demanding in terms of power delivery, operation monitoring and driving range [1, 2]. From the architectural point of view, the electric bicycle significantly differs from other types of electric vehicles since it is not in general a purely electric vehicle. It actually is a hybrid electric vehicle, the second source of traction power delivered to the wheels by the rider (human). Although pure electric traction is possible in electric bicycles, the most interesting case is that of the pedelec, that is the electrically power assisted bicycle. This is considered to be hybrid electric vehicle of parallel configuration where human power and electricity can at the same time contribute to bicycle traction.

Initial batteries used for transforming conventional human powered vehicles into electric ones have been found in many cases inadequate regarding power delivery, power density, operation range, life, even safety [2]. That is the reason why they are considered to be the most critical structure of the electrical powertrain. On the other hand, lack of international standards regarding electric vehicle batteries also affect the market of electric bicycles and allow a great deal of freedom to manufacturers in order to develop high performance products.

The battery system presented in the next section, has been developed in order to meet the requirements of modern human powered vehicles, and not only support electric power assistance. It is also meant to be free of the aforementioned deficiencies and to allow detailed and continuous monitoring of critical parameters like cell temperature, electric current, cell and battery voltages as well as real time estimation of the battery state of charge. High energy, high power cells are utilized in order to assure good range when traction power is purely electric and good performance in increased load situations (hill climbing, acceleration). The developed battery system, continuously balanced and monitored, has been undergone a series of on road experiments empowering an electric bicycle in order to prove its efficiency. The resulted system has also been simulated by means of a first order equivalent circuit. The rest of the powertrain has been simulated with the aid of the traction equation. Comparison of the measurement and simulation results regarding battery voltage and state of charge present adequate convergence.
2. Energy Storage System Development

The overall battery system is composed of the battery cells stack, a passive battery management system (BMS) to ensure cell balancing during charging and discharging, a temperature measurement circuit, a controller, monitoring battery operation, and a display. As it is developed to provide electric power to human powered vehicles, it was initially selected to be adjusted to the electric bicycle of Fig. 1, supporting 5 levels of electrical assistance for the rider and meeting the requirements of current European legislation [3], that is not exceeding the speed of 25 km/h. Assuming a bicycle rider of 85-115 kg and taking into account the fact that, on a typical asphalt flat road, 50Wh provide a range of 10 km, bicycle autonomy was selected to be around the average value of 50 km [2]. The degrees of freedom in the design are totally focused on the battery system, which determines bicycle autonomy, assuming it is moving only on electric power, and all monitoring parameters. Thus, the battery was designed in order to have nominal capacity around 14 Ah and nominal voltage 36V, equal to the nominal voltage of the electric motor selected for the bicycle.

The cell types selected for the battery pack are the Panasonic NCR18650PF Li-ion 18650 cells [4], having as nominal specifications 3.6 V voltage, 2900 mAh capacity, 1C discharge rate and 3.5C maximum continuous discharge rate. In order for the overall battery to provide 36V voltage and about 14 Ah capacity (14.5 to be precise), fifty cells were connected in a 10s5p structure. This kind of structure is able to provide 14.5 A nominal discharge current and 50.75 A maximum continuous current to the motor, values that are considered adequate for the operation of the electric motor selected. The battery cell pack was cold welded by means of aluminum foils and enclosed in a 3D printed case made of biological Polylactic Acid (PLA) filament, appropriately designed so as to fulfill all technical and space limitations. Together with the battery itself, the temperature measurement circuit as well as the BMS were installed in the PLA enclosure, thus forming the complete battery pack (green structure of Fig. 2).

The measuring and monitoring system records the crucial measures connected to the battery, that is cell voltage for all battery cells, overall battery voltage, battery discharging and charging current, temperature per cell and ambient temperature are measured instantaneously, allowing complete monitoring of battery’s state of operation. These values are utilized for the calculation of the instantaneous State of Charge (SoC) which appears on the indication display located on the steering wheel of the bicycle as shown in Fig. 2 and Fig. 4.

The monitoring system was based on three sensor circuits, measuring voltage, temperature and electric current. For the monitoring of the voltage of each cell as well as of the overall battery pack, the circuit of Figs. 3 and 5 was developed based on the microcontroller ATTINY 85 and optocoupler in order to isolate the processor (Arduino Nano) from the rest of the circuitry. Cell temperature was performed by means of ten digital temperature sensors Dallas DS18B20 directly connected to bicycle’s main controller, an Arduino MEGA one (Fig. 4). Finally, an ACS 712 current sensor connected in series with negative pole of the battery provided the instantaneous value of electric current. Current measurement is exploited not only to assure protection of the battery pack but also in order to allow instantaneous battery SoC estimation. The latter is considered to be a crucial parameter for the rider as well as for the comparison with simulation data.
Instantaneous SoC calculation is based on a Coulomb counting procedure combined with an initial SoC estimation through a piecewise relationship with the battery Open Circuit Voltage (OCV) \[5\]. Particularly, each time the battery is about to deliver power to the motor after a non-operational time interval, the OCV is measured and corresponded to a SoC value, that is assumed to be the initial SoC, SoC\(_0\). The electric charge, \(dQ(t)\), leaving the battery pack during the discharging procedure is measured by the Coulomb counting procedure as described by the following equation and approximated by the summation of elementary charges \(i_k\delta t\):

\[
dQ(t) = \int_0^t i(t)dt = \sum i_k \delta t, \tag{1}
\]

where \(i_k\) is assumed to be constant in the time interval \(\delta t\). Therefore, the repetitive measurement of electric current leaving the battery is enough to allow the update of the battery SoC value according to

\[
\text{SoC}(t) = \text{SoC}(t_0) - \frac{dQ(t)}{Q_{\text{nom}}}, \tag{2}
\]

where \(Q_{\text{nom}}\) is the nominal capacity of the battery pack. Apparently, during charging procedure the sign in front of the fracture becomes positive.

The instantaneous SoC is recorded together with all other measured values on a memory disc during measurement phases, and depicted on the bicycle information display (Fig. 4). Also, together with the instantaneous values of battery pack voltage, it is utilized for comparison with simulation data.

3. Measurements and Simulation

The performance of the battery system was evaluated through a series of measurement tests conducted on the electric bicycle with the aid of the special measuring device that was consisted of an appropriately developed PCB circuit of Fig. 2 and a data acquisition software. As described in the previous section, the overall measuring system was attached to the bicycle during the tests allowing the measurement and recording of voltages, currents and temperatures measured by the bicycle monitoring system as well as SoC calculated as previously described.

The experiments performed were divided into two types. The first type aimed in testing bicycle performance under various loads caused either by the overall weight of the bicycle and rider either by the speed profiles of the bicycle. The bicycle was ridden by four different riders, weighting 55.8 kg, 72.1 kg, 85 kg and 114.1 kg with the bicycle, covering four times a rectangular, closed 750 m long, pathway. The circuit, having overall length 3 km, was covered at four different constant speeds. Thus, 16 different bicycle load profiles were created. Fig. 6 presents the variation of battery state of charge and voltage for the heavier and light rider and bicycle speed at 10 km/h and 15 km/h. Battery voltage presents very slight alterations as the battery SoC diminishes with time, as demanded. The voltages drops observed at short stops are connected to the high current the motor requires every time it restarts. Similar figures can be contacted for all load profiles.

Additionally, a range test of the bicycle was performed on a straight and flat road with an average rider at a relatively constant maximum speed (25 km/h) without pedaling. Two bicycle-rider weights were selected, at 85 kg and 114.1 kg. In both cases the bicycle was ridden for 50 km for a total time of about 2 h. The battery energy consumed was 76.8% and 80.14% respectively without voltage reduction below critical levels (2.5 V), allowing the safe assumption that the bicycle range is 50 km. As depicted in Fig. 7, where the variation of battery SoC and voltage with time is shown for the case of a heavy rider over a two hour riding, voltage ranges from 41.5 V maximum to 32 V minimum which as the SoC ranges from 89.3% to 9.16%. Taking into account that the battery consists of 10 cells in series, no cell voltage drops below 3.2 V and each of them as well as the overall battery remain in “healthy” operational level.

Fig. 6 Battery SoC and voltage vs speed and rider weight       Fig. 7 Battery SoC and voltage during range testing
Additionally to the experimental measurements performed on the developed battery pack, a simulation model was utilized in order to validate battery’s performance. The battery model was developed in MATLAB®, Simulink® (Fig. 8) and on the battery equivalent circuit theory. Specifically, a first order equivalent circuit is assumed for the modeling of the battery where battery internal resistance and a parallel RC term in series with the open circuit voltage (OCV) are the degrees of freedom. The OCV is a SoC dependent voltage source. Also, temperature dependence is included in the model in the form of look-up tables providing the values of resistances and capacitance of the model. The battery is placed as the source of the powertrain which is completed with bicycle electric motor. The dynamic behavior of the bicycle is included in the model by means of the following equation that defines the mechanical power, $P$, required by the motor with respect to the road slope, $\theta$, the bicycle and rider’s mass, $m$, bicycle’s aerodynamic drag coefficient, $C_b$, and frontal area, $A$, rolling resistance coefficient, $f$, and bicycle speed, $v$.

$$P = m v + m f g \cos \theta + m g \sin \theta + 0.5 C_b \rho Av^3$$  \hspace{1cm} (3)

All terms in the aforementioned equation can be estimated for each of the experiments performed and inserted in the model. The simulation model has appeared to be quite in accordance with the experimental results as far as the battery SoC concerns. In Fig. 9, an indicative comparison of the SoC and voltage measurement performed for the cases of 15 km/h speed by the lighter rider with those resulted from the corresponding simulation are presented. The relative error does not exceed 2% for both cases except excessive voltage drops which seem to be much more intense for the measurement data. It must be mentioned herein that errors occurred are the outcome of inaccuracies produced by both the SoC estimation algorithm (Coulomb counting) followed during the measurement procedure as well as model inaccuracies like the utilization of first order equivalent circuit and non optimized data for the estimation of battery model degrees of freedom through lookup tables.

![Fig. 8 Simulation model of the e-bike powertrain](image1)

![Fig. 9 Comparison of measurements and simulation](image2)

4. Conclusions

An energy storage system appropriate for commercial electrically assisted human powered vehicles is presented in this paper. The battery system is composed of all the essential elements required to provide power assistance to the rider and at the same time measure critical parameters, like battery and cell voltages, electric current, cell temperatures and estimate instant state of charge. A series of measurements are performed by means of a bicycle on which the system is installed. The system is validated by comparison with an appropriately developed simulation model. Although the results are proved to be good, an apparent extension of this work would be the extraction of more load profiles across a wider temperature range, thus creating a database that could be used in order to optimize utilized battery simulation model. Simultaneously, Coulomb counting SoC measurement can be replaced with a more sophisticated algorithm.

References

Influence of the use of Bioethanol Additive on Waste Cooking Oil Methyl Ester on the Parameters of the CI Engine and Emissions of Toxic Exhaust Components

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Abstract

Biodiesel could substitute petroleum-based diesel fuel as an alternative source of energy. In order to be viable, a biofuel should be environmentally friendly, economical, provide a net energy gain and should be possible to produce in large quantities without reducing food supplies. The purpose of this article is to research such an alternative to fuel a Diesel engine. The main focus is on the influence of the addition of bioethanol in 10, 20 and 30% volume on work parameters and emission exhaust obtained in the combustion of waste cooking oil methyl ester in the IC engine. The addition of bioethanol to WCOME positively affected the properties of the fuel by lowering its viscosity, density and the temperature of blocking the cold filter. The aim of this article was to describe a study run on a Perkins engine showing the components of the exhaust gas and work parameters obtained by this engine.

KEY WORDS: waste cooking oil methyl ester, bioethanol, exhaust components

Nomenclature

WCOME – waste cooking oil methyl ester; M1 – the mixture of 10% of bioethanol and 90% of waste cooking oil methyl ester; M2 – the mixture of 20% of bioethanol and 80% of waste cooking oil methyl ester; M3 – the mixture of 30% of bioethanol and 70% of waste cooking oil methyl ester; SFC – specific fuel consumption; BSFC – break specific fuel consumption; NOX – nitric oxides; PM – particulate matter; CO – carbon monoxide; CO2 – carbon dioxide; THC – hydrocarbons.

1. Introduction

The desire and need to have a clean, healthy and green environment have currently raised the issue of searching for alternative solutions to obtain and provide energy. Moreover, advanced internal combustion engines must be characterized by high requirements for the fuel economy, low emissions and high boost pressure [32]. The development of mechanization and industrialization has led to increasing use of fossil fuels and further its harmful emissions [1-6]. The harmful impact of the internal combustion engines on the environment could be reduced, for example, through the proper adjustment of the air delivery system [6, 30]. On the other hand, researchers and scientists have started to look for an alternative source of energy on a scale to compete with fossil fuels, but not contest with agriculture and the environment [31]. Biodiesel, which can be made of various renewable sources, is gaining worldwide acceptance as a partial solution to the widespread problem because as its low smoke emission as biodiesel contains 10 per cent of oxygen and therefore it is environmentally friendly. Biodiesel can be produced from either vegetable oil, including edible oil, or animal fat [7-10].

In general, different proportions of biodiesel are mixed with fossil fuels for use in diesel engines that are recognized for power generation and are a source of power that provides higher efficiency and strength in the field of transport. One of the biodiesel sources is waste cooking oil methyl ester (WCOME) [11-13]. The fact that the waste cooking oil is being reused is not the only advantage important to the environment and society, it is also considered as one of the cheapest biodiesel feedstocks [14-18]. Unfortunately, there are some disadvantages as well. Comparing to the other fossil fuels, the waste cooking oil is characterized by higher viscosity, therefore its direct use is limited in internal combustion (IC) engines. This can have an impact on the fuel automatization and can cause a reduction in engine performance, because of higher viscosity leads to the formation of larger droplets, worse vaporization and narrower spray angle [19-23]. Moreover, it can also lead to toxic gases emission increase.

In order to reduce the viscosity of waste cooking oil various chemical processes can be performed. One of the processes which reduce the viscosity to the acceptable in diesel engines level can be adding bioethanol to the waste cooking oil [24, 25].

From the chemical point of view bioethanol is odorless ethyl alcohol produced in the process of alcoholic
fermentation - most often from rye, corn, sugar beet, and potatoes, as well as straw and grass plants [26-28]. Ethanol production takes place in distilleries, and its yield depends on the used plant. Due to the enzymes contained in yeast, the sugar is converted into alcohol and carbon dioxide. The ethanol contained in the fuel is dehydrated to less than 0.02% water content. In this research, the water content in bioethanol is 0.01%. Bioethanol can be added to gasoline or be a fuel itself [29].

The research investigates the measurement of concentrations of toxic components when burning selected mixtures of in a four-stroke four-cylinder engine.

2. Fuel Description

The aim of the study was to investigate the influence of bioethanol addition to WCOME on concentrations and emissions of toxic exhaust components. In order to conduct the research used cooking oil (WCO - waste cooking oil) from a food court was collected, filtered and esterifies to get WCOME. The second component was bioethanol produced from biomass by the hydrolysis and sugar fermentation process. The parameters of WCOME and bioethanol are presented in Table 1. Four types of fuel total were taken into consideration. Firstly, only WCOME biodiesel was investigated. Then suitable concentrations of bioethanol were added in order to obtain three different types of fuel.

### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>WCOME</th>
<th>Bioethanol</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cetane Number</td>
<td></td>
<td>51</td>
<td>8</td>
<td>PN-EN ISO 5165</td>
</tr>
<tr>
<td>Calorific Value</td>
<td>[MJ/kg]</td>
<td>37,8</td>
<td>28</td>
<td>PN ISO 1928</td>
</tr>
<tr>
<td>Density in 15°C</td>
<td>[kg/m³]</td>
<td>887</td>
<td>796</td>
<td>PN-EN ISO 12185</td>
</tr>
<tr>
<td>Kinematic viscosity in ~40°C</td>
<td>[mm²/s]</td>
<td>5,29</td>
<td>0,92</td>
<td>PN-EN ISO 3104</td>
</tr>
<tr>
<td>Surface Tension in (20°C)</td>
<td>[N/m]</td>
<td>3,57·10⁻²</td>
<td>-</td>
<td>PN-C-04809</td>
</tr>
<tr>
<td>Flash Point</td>
<td>[°C]</td>
<td>168</td>
<td>-</td>
<td>PN-EN ISO 2719</td>
</tr>
<tr>
<td>Cloud point</td>
<td>[°C]</td>
<td>-2</td>
<td>-</td>
<td>PN ISO 3015</td>
</tr>
<tr>
<td>The temperature of blocking the cold filter (CFPP)</td>
<td>[°C]</td>
<td>-7</td>
<td>-</td>
<td>PN-EN 116</td>
</tr>
<tr>
<td>Average elementary composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- C [%]</td>
<td></td>
<td>76,8</td>
<td>52,2</td>
<td></td>
</tr>
<tr>
<td>- H</td>
<td></td>
<td>12,2</td>
<td>13,6</td>
<td></td>
</tr>
<tr>
<td>- O</td>
<td></td>
<td>10</td>
<td>34,2</td>
<td></td>
</tr>
<tr>
<td>Sulfur content</td>
<td>[mg/kg]</td>
<td>8,05</td>
<td>-</td>
<td>PN-EN ISO 20846</td>
</tr>
<tr>
<td>Water content</td>
<td>[mg/kg]</td>
<td>111</td>
<td>-</td>
<td>PN-EN ISO 12937</td>
</tr>
<tr>
<td>The content of solid impurities</td>
<td>[mg/kg]</td>
<td>17</td>
<td>-</td>
<td>PN-EN 12662</td>
</tr>
</tbody>
</table>

The research was conducted on four types of fuel. The first fuel was pure WCOME. The second type of fuel was obtained by adding 10% of bioethanol to 90% of WCOME named as M1. The third type of fuel was obtained by adding 20% of bioethanol to 80% of WCOME defined as M2. The fourth type of fuel was obtained by adding 30% of bioethanol to 70% of WCOME referred to as M3. The measurements parameters of the fuel mixtures are presented in Table 2 below.

To start the combustion process it is necessary to produce a certain amount of fuel pairs with appropriate parameters, which is determined by the evaporation temperature of 10%-20% volume. The addition of bioethanol positively affects the properties of fuel M1, M2, M3.

### Table 2

<table>
<thead>
<tr>
<th>No</th>
<th>Parameters</th>
<th>Unit</th>
<th>WCOME</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>Test method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Flashpoint</td>
<td>[°C]</td>
<td>171</td>
<td>33</td>
<td>32</td>
<td>27</td>
<td>PN-EN ISO 2719</td>
</tr>
<tr>
<td>2.</td>
<td>Cloud point</td>
<td>[°C]</td>
<td>-2</td>
<td>-2</td>
<td>-3</td>
<td>-3</td>
<td>PN ISO 3015</td>
</tr>
<tr>
<td>3.</td>
<td>Pour point</td>
<td>[°C]</td>
<td>-7</td>
<td>-13</td>
<td>-14</td>
<td>-15</td>
<td>PN-EN 23015</td>
</tr>
<tr>
<td>4.</td>
<td>Density in 15 °C</td>
<td>[kg/m³]</td>
<td>883</td>
<td>874,3</td>
<td>866,1</td>
<td>856,6</td>
<td>PN-EN 12185</td>
</tr>
<tr>
<td>5.</td>
<td>Kinematic viscosity in 40 °C</td>
<td>[mm²/s]</td>
<td>5,26</td>
<td>3,58</td>
<td>2,96</td>
<td>2,56</td>
<td>PN-EN ISO 3104</td>
</tr>
</tbody>
</table>

The test setup

The fuel tests were performed with a 4.4l, four-cylinder, four-stroke, water-cooled, 19,3:1 compression ratio, direct injection Diesel engine Perkins 1104C-44. The maximum torque was 400 N·m at 1400 rpm (ISO/TR14396), and the maximum engine power was 74 kW at 2200 rpm (ISO/TR14396). The engine was not new but adapted to combustion biofuel B100.
Fig. 1 The test rig: 1 – Perkins 1104-C44 engine; 2 – SCHENCK W450 eddy-current brake; 3 – crank position sensor; 4 – AVL GM 13P piezoelectric pressure sensor; 5 – amplifier; 6 – AVL Indi Smart system; 7 – smoke meter Horiba Mexa 1230 PM; 8 – AVL CEB II Exhaust gas analyzer with calibration gases; 9 – data acquisition system based on a PC

The engine torque and speed, fuel consumption, the concentration of total hydrocarbons, nitric oxides, carbon monoxide, particulates and cylinder pressure were possible to measure because the engine was attached to a test rig equipped with measurement devices.

The AVL CEB II (number eight in Fig. 1) gas analyzer was used to measure the concentration of toxic exhaust components. The analyzer measures the concentrations of toxic components of exhaust fumes using the following methods:

- carbon monoxide and carbon dioxide using the NDIR (Non-Dispersive Infra-Red) method;
- oxygen paramagnetic using the PMD (Paramagnetic Detector) method;
- hydrocarbons using the FID (Flame Ionization Detector) method;
- nitrogen oxides using the CLD (Chemiluminescence Detector) method.

Smoke meter Horiba Mexa 1230 PM (number 7 in Fig. 1) is designed to measure the concentration of gas components diesel compression ignition internal combustion engines. The flue gas collected by the analyzer may be both, directly from the outlet installation as well as after dilution in the tunnel measurement. The soot concentration measurement is carried out by measurement of the amount of transported electrical charge, by charged soot particles in the electric field. Soluble organic fraction (SOF) are measured with two FID detectors as a difference of their signals for the test gases at 47°C and 191°C. The measuring ranges of the MEXA-1230 PM analyzer are as follows:

- soot: 0-15 / 75/150 mg / m³;
- soluble organic fraction (SOF): 0-150 mg / m³;
- total PM particulate matter: 0-300 mg / m³.

The error used in empirical studies of the AVL sensor is equal to the element of the sum of squares of linearity errors and temperature drift:

$$\delta_c = \sqrt{\delta_{\text{cl}}^2 + \delta_{\text{ct}}^2},$$

where $\delta_{\text{cl}} = 0.15\%$ – relative linearity of the sensor; $\delta_{\text{ct}} = 0.13\%$ – drift resulting from temperature changes. The relative error of the piezoelectric pressure sensor is $\delta_c = 0.2\%$.

The error of the load amplifier consists of relative linearity error and error related to the amplifier's noise.

$$\delta_n = \sqrt{\delta_{\text{al}}^2 + \delta_{\text{an}}^2},$$

where $\delta_{\text{al}} = 0.1\%$ – relative amplifier linearity error; $\delta_{\text{an}} = 0.1\%$ – relative error resulting from the noise of the amplifier. The relative error of the load amplifier is $\delta_n = 0.14\%$.

The error of the A / C converter used in the measuring system has a source in its resolution and measuring range.

$$\delta_{\text{ac}} = \frac{\theta}{\text{range}} \cdot 100\%,$$

where $\theta$ is the quantization interval of the [V] converter, which can be determined as:

$$\theta = \frac{\text{range}}{2^n}.$$
where range – the scope of converter processing A/C for KPCI-3110 amounting ±10 [V]; \( r \) – transducer resolution – 12 bit. The error of the A/C converter used in the measuring system is \( \delta_{\text{ac}} = 0.024\% \).

In conclusion, the relative error of the working medium pressure in the combustion chamber can be determined by the following equation:

\[
\delta = \sqrt{\delta_r^2 + \delta_{\text{ac}}^2 + \delta_v^2}
\]  

(5)

The relative error of pressure is \( \delta = 0.25\% \).

The absolute value of this error, related to the maximum measuring range used in the AVL sensor tests of 25 MPa, is \( \Delta p_c = 0.0625 \) MPa.

The procedure

The measurement of toxic exhaust components was carried out in accordance with the ISO8178 standard. The engine qualified as C1 category in agreement with the above-mentioned standards. The points in which research was conducted along with the weighting factor are included in Fig. 2.

![Fig. 2 Weighting factors dependent on engine speed and load in the ISO 8178 C1 test](image)

To establish maximum engine performance and the number of toxic components of exhaust emissions an engine speed curve was performed.

Results

Fig. 3 shows the average torque value of the WCOME, M1, M2 and M3 fuel mixture at the change of rotation speed. Higher torque was produced by the WCOME fuel than all other test fuels, at the same time M3 fuel were generated almost 20% less torque.

![Fig. 3 The torque generated by the engine with the WCOME, M1, M2 and M3 fuel mixture at the change of rotation speed](image)

Moreover Fig. 4 demonstrates the average brake power value of the WCOME, M1, M2 and M3 fuel mixture at the change of rotation speed. Again, higher power was produced by the WCOME fuel than all other test fuels, at the same time M3 fuel were generated nearly 20% less power.
Fig. 4 The brake power generated by the engine with WCOME, M1, M2 and M3 fuel mixture at the change of rotation speed

It can be noticed that an increase in the volume of bioethanol in the M1, M2, and M3 fuel being tested results in a reduction of the average torque, and power achieved by the engine approximately 6 ÷ 7% by every 10% addition of biocomponent.

The specific fuel consumption is shown on Fig. 5 and can be observed the fluctuation of SFC parameter, but changes of this factor acquire average approximately 10%.

Fig. 5 The specific fuel consumption of the WCOME, M1, M2 and M3 fuel mixture at the change of rotation speed

Fig. 6 a and b show the nitric oxides emitted by the WCOME, M1, M2 and M3 fuel mixture at 1400 rpm, and 2200 rpm. With the increase in the amount of bioethanol, the concentration of nitric oxides decreases, also the change of this parameter achieved approximately 24% for 1400 rpm, and 27% for 2200 rpm by maximum torque. At the point of minimum torque, alteration of concentration factor is roughly 15%.

Fig. 6 Nitric oxides concentration of the WCOME, M1, M2 and M3 fuel mixture at : a - 1400 rpm; b - 2200 rpm

Fig. 7 a and b display the carbon monoxide emitted by the WCOME, M1, M2 and M3 fuel mixture at 1400 rpm, and 2200 rpm. At the point of minimum torque at 1400 rpm, the concentration of carbon monoxide increase rapidly for fuel M3, and difference of CO concentration between WCOME and M3 fuel reach almost 241%. The change of this parameter for M1 and M2 fuel achieved only 33% for the first one and approximately 83% for the second. At the speed 2200 rpm it can be observed that the concentration of carbon monoxide for the lowest value of torque is almost 327% higher for M3 than WCOME fuel, likewise M1 and M2, but the difference in concentration is only 43% in the first case and 171% in second. At both speed, and the point of maximum torque the concentration of carbon monoxide for all
fuels is almost the same, only in one point can be observed the difference between M3 and WCOME fuel, which obtains 28%.

Almost the same situation is shown on Fig. 8 in reference to hydrocarbons concentration. At the point of minimum torque at 1400 rpm, the concentration of THC increase rapidly for fuel M3, and the difference of this parameter between WCOME and M3 fuel reach almost 241%. The change of this parameter for M1 and M2 fuel achieved only 38% for the first one and approximately 89% for the second. At the speed 2200 rpm it can be observed that the concentration of hydrocarbons for the lowest value of torque is almost 597% higher for M3 than WCOME fuel, likewise M1 and M2, but the difference in concentration is only 86% in the first case and 213% in second. At both speed, and the point of maximum torque the concentration of hydrocarbons for all fuels is almost the same, only in one point at the speed 2200 rpm, can be observed the difference between M3 and WCOME fuel, which obtains 134%.

Fig. 9 a and b indicate the particle matter emitted by the WCOME, M1, M2 and M3 fuel mixture at 1400 rpm and 2200 rpm. The bioethanol content causes a general reduction in the concentration of particulate matter. However, increasing its content from 20% to 30% does not affect the significant decrease in the PM value. The major differences can be observed for the point of the maximal moment at 1400 rpm and 2200 rpm, where we can notice a fourfold increase in PM between M3 and WCOME fuel.
According to appropriate weights, torque values for appropriate speeds in accordance with test C1 shown in Fig. 2. The results of CO, THC, NOX, PM emission test C1 ISO 8178 are shown in Fig. 10.

As can be inferred, CO and HC emissions are the lowest for pure WCOME fuel and increase with the amount of bioethanol, while PM emission decreases. The reduction of NOX emissions is low, which is related to the growth in fuel consumption as the number of bioethanol increases.

3. Conclusions

The following conclusions can be made on the basis of the analyses carried out:
- addition of bioethanol reduces torque, power (Figs. 3-4);
- concentration and emission of particulate matter and nitric oxides decreases with the addition of bioethanol (Figs. 6, 9, 10);
- addition of bioethanol increases fuel consumption, carbon monoxide and hydrocarbon concentrations and emissions (Figs. 5, 7, 8).

The differences described above in the test results are caused by different physicochemical properties of the tested mixtures (Table 2). Two parameters are particularly important here: density and viscosity of fuel, which significantly influence the course of the combustion process. This process has an influence on the obtained engine operating parameters as well as concentrations and emissions of exhaust gases components. In general, from the presented fuels, the most prospective seems to be a fuel with a 20% addition of bioethanol to WCOME (M2).

References


Technological Limits for the Use of Automated Guided Vehicles in Intralogistic Systems

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Abstract

The use of Automated Guided Vehicles in intralogistic systems has increased in recent years. Material handling operations in warehousing and production are typical applications of AGVs. New navigation technologies extend their application potential. In real traffic, various limiting factors could reduce the work efficiency of AGV.

This paper analyses the limiting factors for using different AGV systems in intralogistics. If the AGV is used in existing interiors (e.g. warehouses, production halls), the application must often be adapted to given spatial layout. In this case, there is sometimes no possibility to avoid bottlenecks on the routes. Such possible bottlenecks are identified in this paper. Authors analyze their influence on traffic continuity and route capacity.

Described situation can also influence the operating costs, therefore the paper deals also with economic factors compared to use of conventional transport trucks.

KEY WORDS: AGV, intralogistics, material handling

1. Introduction

The possibilities for the use of AGV in intralogistic systems are currently quite wide. AGVs are used typically for transport of material in warehouses, picking systems, vehicle loading and unloading, the operation of production lines, etc. AGV are driverless programmable vehicles that are used in industrial applications using a communications and navigation system to transport materials around a production facility [1, 15, 12]. Such vehicles move along a predefined route to perform the required tasks without operator supervision [16, 14]. If the system is implemented as new, it is possible to design the buildings and space layout directly for the needs of the application. With an appropriately designed system, AGVs can significantly increase material handling efficiency, reduce physical work and thus labor costs.

However, if the system is applied in an existing layout, the options for customization may be limited. In this case, the AGV may not always be the ideal choice. In this work, we focused on the key factors that can influence the decision to implement an AGV in existing intralogistics systems.

A model situation in this paper can be used for:
- transport of material in the warehouse (from receiving to storage area, from storage area to dispatch area);
- transport of material in production (supplying production lines).

For the above-mentioned purposes, it is possible to use tow vehicles with carts, unit load vehicles and masted vehicles with handling attachment. These trucks belong to the category of cyclically operating devices that can also be fixed to a given track. They can replace mainly conventional trucks and tow vehicles. Because AGVs are non-driver vehicles, one of the main advantages lies in reducing labor costs.

2. Technological Limits for the Use of Various AGV Systems

AGVs, as well as other material handling equipment, have various operating limitations. In general, these limits can be divided into the following groups:
- limits given by the navigation system;
- limits given by the type of drive and the direction control of the AGV;
- limits given by AGV performance parameters;
- limits resulting from the environment in which the AGV moves.

Several technologies are used to navigate an AGV in a warehouse or in a production hall. Commonly used navigation system uses magnetic tape, which is glued to the floor to form a network of precisely defined paths. Sensors are located at the bottom of the AGV, which sense the direction of the magnetic field generated by the tape, and the AGV moves according to the direction in which the tape continues to move. The disadvantage of this method is the dependence on a predefined path. One of the most common handicaps in operation is the fact that the tape is torn off from the floor by moving other handling means in the same space as the AGV. Although AGV can overcome a short distance without a magnetic tape, if the tape is missing in the arc, it may cause AVG to stop. The limitation is also in the implementation of branching routes for different AGVs. For some AGVs, the given sections of the routes are common
The AGV must be able to evaluate the direction in which to turn. Another disadvantage is the fixed link to the defined track. If an obstacle occurs on the route, the AGV can detect it and stops. However, AGV cannot bypass it and therefore must wait until the obstacle is removed. This may in some cases take a relatively long time, and this delay may then cause problems in production. A similar AGV navigation technology is the guidance line, which is painted directly on the floor. In this case, the guide line is not impacted by accidental damages, but even the paint peeling off the floor over time. This drawback is eliminated in the technology using inductive cable located in the floor. In comparison to previous technologies, the disadvantage here is that it is very difficult to make changes to the route network. This requires construction works of the floor.

Laser triangulation technology eliminates some of the drawbacks of previous systems (eg, fixing to a given track). This technology detects the distance from objects in the warehouse or in the production hall. These distances are then compared with the forward created map of the space in which the AGV moves. The AGV is thus able to orient itself in the topological context in the warehouse or in the production hall. The advantage here is that the AGV is not rigidly bound to a single guideline and can thus bypass various obstacles occurring on the route.

The AGVs in interiors are usually electric, where the battery is used as a power source. Batteries must be recharged continuously (eg during AGV downtime) or simply replaced with a charged one in case of AGVs where the battery is adapted for this purpose. However, it is not possible to operate the AGV for any length of time. The actual charging time depends mainly on the type and capacity of the batteries used and on the charging method. If the AGV has its own loading platform and is not designed to pull other trucks (unit load vehicles), the radius of rotation can be minimized by means of a suitable combination of driven and steered wheels. In some cases, the AGV can rotate in place.

The driving speed is a limiting factor in terms of AGV performance. This is in most cases below 1 m/s. The reason why AGVs do not move at higher speeds, is it necessary to stop safely from an obstacle that may occur suddenly (eg a worker walks near a moving AGV). At higher speeds and at higher load weights, the stopping distance could be too long and could cause a crash. The AGV sensors have a limited range and only follow the near vicinity of the AGV. This does not allow them to predict the situation as man does. Man can register other moving objects while moving and evaluate whether there is any risk of collision. This shortcoming can be eliminated by choosing a suitable warehouse layout or production hall where workers’ access will be restricted to some areas.

### 3. Technological Limits in the Material Handling Problem

Material handling problem in intralogistics systems is characterized by these technological parameters:
- Subject of handling (characteristics of the transported material and transport unit);
- Quantity (eg, per cycle, per time);
- Handling direction (horizontal, vertical, combined);
- Route (default and destination, possible linking options);
- Way of manipulation (material handling equipment and technology);

The material flow is affected by many parameters, particularly [14x]:
- Handling equipment parameters (transport performance, capacity, speed...);
- Parameters of warehouse / production hall (total area and its arrangement, parameters of handling streets, type and parameters of related systems);
- Used information system.

The technological process of the material transport realized by trucks in the warehouse or production can be divided into the following stages:
- loading;
- driving from the place of loading to the place of unloading;
- unloading and, when appropriate, further loading;
- driving to the place of loading;
- unloading (only in the case of material transport from the place of unloading to the place of loading).

From the above-mentioned technological process, the total duration of one cycle can be derived at a given manipulated quantity, route and speed of the truck (Fig. 1).

$$t_c = t_{L1} + t_{D1} + t_{UL1} + t_{L2} + t_{D2} + t_{UL2}$$

where $t_c$ – total duration of one cycle [sec]; $t_{L1}$ – total duration of loading in the place A [sec]; $t_{D1}$ – duration of driving from the place A to the place B [sec]; $t_{UL1}$ – total duration of unloading in the place B [sec]; $t_{L2}$ – total duration of loading in the place B [sec]; $t_{D2}$ – duration of driving from the place B to the place A [sec]; $t_{UL2}$ – total duration of unloading in the place A [sec].

The required number of trucks can be determined from the total duration of one cycle and the number of cycles per observation period. If the result is a decimal number, the result is rounded up to integers. However, this means that when the truck is in use, it will be downtime to wait for loading / unloading.
Loading and unloading

Loading time depends on the volume of material in one batch and on the loading technology. In the case of tow vehicles and unit load vehicles, an external loading system using another handling device is required. The advantage of a masted vehicle with a fork is that it can load itself. On the other hand, the advantage of tow vehicles with carts is the higher capacity in one cycle.

An important parameter is also the possible change in transport requirements over time.

In warehouses, the material is unloaded / loaded from and into the trucks in receiving / shipping areas. Vehicle arrivals over time are not continuous and these areas must be equipped with enough storage capacity. Thus, the removal of material does not necessarily have to be continuous.

Production lines are typically characterized by continuous transport requirements and limited storage space. The production plan can be stable with constant requirements or variable, where the required volume of material can change over time. The use of the AGV is particularly useful in the case of a permanent production plan, where it is possible to plan circuits with minimal downtime.

In the case of a variable production schedule, the number of trucks depends on the maximum transport requirement that may occur at the place of loading. This achieves a continual removal and thus avoids the accumulation of material in the place of loading. When the transport requirements are lower, there is a risk of truck downtime. In this case, the conventional trucks that are not fixed to the given track are more flexible. If the cart is not used on the route, it can be used elsewhere.

An optimum condition would be achieved with continuous operation without downtime due to waiting for loading / unloading. In this case, other arriving truck would replace the truck leaving the loading place. In reality, this can only be achieved if the time of loading and unloading is identical and there is no downtime on the route.

The following situations may occur:

- The time of stay at the place of loading is longer than the time of stay at the place of unloading. In this case, there will be downtime at the place of loading, where the trucks will have to stand and wait for the departure of the previous truck after the end of loading.
- The time of stay at the place of loading is shorter than the time of stay at the place of unloading. In this case, downtime will occur at the place of unloading.

Driving time

The driving time of the trucks depends on their speed and the length of the route. The character of traffic and handling aisles may also be the technological limit. It is necessary to consider the type of traffic (mixed traffic with other handling devices and / or persons) and crossroads with other aisles.

The AGVs have a limited speed against conventional handling equipment for safety reasons, and therefore the driving time on the same route is longer.

It is also necessary to consider the charging time of the truck. The truck is standing at the time of charging and the total operating time can be increased. Conventional forklift trucks are charged at charging stations outside of the truck’s operating time, or a discharged battery is replaced with a charged one.

For AGVs, charging stations can be placed in loading and unloading areas and the truck can be charged during these operations. If the charging time during loading / unloading is enough for the operation of the truck, the operating time is not increased. On longer tracks, when the truck is moving for a longer time, it is sometimes necessary to place the charging stations on the route. The truck may stand on the route for charging and that resulting in downtime.

Capacity of handling aisles

When introducing new handling equipment, it is necessary to check the width of existing aisles in accordance with the given technology (according to the relevant technical standards). To ensure the continuity of the ride for more trucks on the route in one aisle, it is essential that the trucks can pass in the opposite direction. This means leading the route in a circular way that requires a two-way aisle, i.e. for two AGVs side by side. If the existing layout in the warehouse does not allow bidirectional traffic across the whole route, it is necessary to create place for passing. That can significantly reduce the capacity of the route.

For aisles that run through the storage area, it is also necessary to consider the solution of traffic at crossroads with other aisles. In this case, it is necessary to determine the rules for the traffic organization to avoid collisions of trucks. This is related to the possible further downtime (e.g. due to giving priority to driving, slowing down, etc.)

If there is a risk of loading and unloading downtime, a waiting place is necessary. Thus, when using a larger number of trucks, an existing space of corresponding length is the limiting factor.
4. Economical Limits

The increase in labor costs due to the expansion of the e-commerce market is a serious problem in logistic warehouses and intralogistics [7, 17]. In these warehouses, labor costs account for approximately 55% of order picking costs [2]. The most common order picking system is a manual picking system for parts where picking cars enter the stock selection warehouse [10]. The benefits of AGVs range from more efficient warehouse systems and inventory management, lower labor costs, increased safety and production to more flexible manufacturing systems. The second possibility is that AGVs can easily cope with changes in both product demand and labor [5]. AGV systems have been developed to achieve high scalability [3, 4, 13]. AGVs have a significant impact on warehouse management. They are widely used for the intelligent transport and distribution of materials in warehouses and production lines due to their high efficiency and low cost characteristics. Due to the large number of operations, AGVs offer a wide range of different technical and exploitation solutions and have a large estimate of the importance of factors in reducing physical handling costs money, therefore the key task is to eliminate or reduce as much as possible. In this way, some of the anticipated mechanical manipulations reduce labor costs for manual material handling. The high initial costs associated with inflexibility of navigable roads are becoming an obstacle to the use of AGVs. The choice of suitable material handling systems is particularly influenced by considering initial investment costs rather than operating costs and long-term effects.

The main drawbacks of the current AGV-based material handling system are the high initial costs. A number of researchers have addressed the general factors to be taken into account when deciding on high initial costs [6].

Higher control software costs and a range of required vehicles prevent extensive use. The forklift can be replaced economically for easy deployment of the AGVs. An economic time to use is allocated as five years for the forklift and eight years for the AGVs [14].

5. Conclusions

In general, the use of an AGV is suitable in production, which continuously produces a constant amount of products to be transported. In this case, the truck movement can be planned with minimal downtime. The disadvantage of AGVs compared to conventional trucks is their low average speed, which increases the number of vehicles required in the event of higher transport requirements. With the current technologies for AGV management and the safety of other entities that can move on the AGV’s route, it is not possible to consider a significant increase in their speed.

The benefits of the AGV can be fully exploited, especially in new fully automated enterprises. When applying the AGV to the existing warehouse / production system, it is necessary to consider the technological limits, which can ultimately significantly affect the economy of operation process.

References

Possibilities of Using Trends of Content Marketing Strategy According to Psychographic Segmentation of the Transport Company Customers

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Abstract

Content marketing has gained more attention from marketers around the world in recent years. Content is what controls today's media and marketing world, and content marketing is a way of building a customer relationship strategy. Nowadays, time is passing very fast, along with trends and innovations that affect the world around us. Trends do not circumvent content marketing as well. What worked a few years ago may nowadays not be enough to move the business forward in the coming years and to achieve sustainability. The ability to predict customer behavior based on trends allows you to customize the content strategy, even in a transport company. The aim of the paper is to summarize the basic trends of the content marketing strategy, such as native advertising, adblock, collaboration with micro influencers, video, voice search, virtual reality and augmented reality and their subsequent analysis in the context of the psychographic segmentation of the transport company customers based on the statistical evaluation of the marketing research data. For the purpose of this research, we used lifestyle generational market segmentation. Each generation represents a different set of unique expectations, experiences, generational history, lifestyles, values, and demographics that influence their buying behaviors.

KEY WORDS: trends, marketing strategy, psychographic segmentation, transport company

1. Introduction

The basic element of marketing has always been to communicate and promote products or services to customers with affection to believe they will choose to buy them. In the past, and nowadays as well, it is mostly about attracting customers' attention with mass advertising, often at several places at once. Using opinion by Meeraman [18], enterprises have to choose alternatives to attract the attention of customers. The first alternative is to buy expensive advertising, the second alternative is to reach and attract the attention through media and the third alternative is to create truly interesting, quality and valuable content. Marketing experts from all over the world are constantly observing trends in marketing, and content marketing is currently being included in current trends [1, 4]. Content marketing has relatively traditional concept and practices in online marketing because mass advertising gradually ceases to function [9, 22]. Content Marketing is a strategically oriented approach focused on creating and distributing interesting, quality and valuable content [26]. A very important step is that businesses are now aware that they need to adapt to trends in any area of marketing, with content marketing being one of them.

Trends do not circumvent content marketing as well. What worked a few years ago may nowadays not be enough to move the business forward in the coming years and to achieve sustainability. The ability to predict customer behavior based on trends allows you to customize the content strategy, even in a transport company [11, 14, 16, 27]. The aim of the paper is to summarize the basic trends of the content marketing strategy, such as advertising, adblock, content distribution, collaboration with micro influencers, video, voice search, virtual reality and augmented reality and their subsequent analysis in the context of the psychographic segmentation of the transport company customers based on the statistical evaluation of the marketing research data. For the purpose of this research, we used lifestyle generational market segmentation.

2. Literature Review

Content marketing has gained more attention from marketers around the world since 2007. Content is what controls today's media, marketing, and content marketing is a way of building a customer relationship strategy. The notion of content marketing is not unambiguous and world experts have not yet agreed on a unified definition. In general, content marketing is defined as the art of communicating with customers without selling anything to them because it is a form of unforced marketing.

Baltes according to Decker defined that content marketing creates or organizes non-product content [3]. It is an informational, educational or entertaining content and is published in the customer contact locations to get their attention, pull them closer to learning more about the business. Clark has defined that the content marketing lies in creating and sharing valuable free content to attract internet users, of which later may become regular customers [6].
Content Marketing Institute (2018) claims that content marketing is a strategic marketing approach focused on creating and distributing valuable, relevant, and consistent content to attract and retain a clearly defined audience – and, ultimately, to drive profitable customer action. Content marketing is thus a publication of information that supports brand authority and trust among potential customers. A way of building a strategy and relationship that should help to become a market leader without traditional, unobtrusive and selling techniques. Content marketing is a long-term strategy where the results are seen in a few months, in some cases even years of work. The company cannot ignore the trends in this area.

Kuna lists native advertising as the first content marketing trend [17]. The first banner ad on the Internet was created in 1994, when a person has been exposed to an average of 2,000 ads a day, which in 2017 was up to ten thousandth. If a company wants to succeed at a customer in such a large number of ads, it needs to be distinctly different and bring added value. The right way is the native advertising. By native advertising, an advertiser can build trust and later gain loyal customers.

Mokráňová ranks the adblock among the trends of content marketing [20]. The advertising we mentioned above attacks the Internet daily, so it's understandable that customers are annoyed and take software to ensure that they don't get ads [21]. In the last half of 2018, 615,000 unwanted advertisements have been blocked, and in 2019, even greater increases are expected. Reaching a target group without blocking can be done using content marketing and native advertising.

Holiday et al. includes collaboration with micro influencers into trends of content marketing [8]. In this context, it is not about joining a brand with celebrities, but with ordinary individuals (1,000 - 10,000 followers) who have significantly recorded results in social media. Businesses are looking for the best way to deliver content in a way that makes it more authentic and non-advertising. It is based on the idea that up to 99% of micro-influencers believe in products and services they promote and deliver seven times more engagement than other types of influencers.

Achen at al. argues that video is still an integral part of the long-term trend of content marketing [2]. Social networks in paid searches prefer videos because the amount of engagement is much higher. Up to 55% of internet users currently consume video content on a regular basis, and by 2020, it will be about 80%.

Voice Search is another trend. The growth rate of voice search usage (in the US) has accelerated dramatically in recent months. Already in May 2016, 20% of all searches were made by voice. By 2020, the share of voice and visual searches is projected to grow to at least 50% (in the US). This is over 200 billion of voice searches per month. Therefore, voice search will be as important as manual search for finding information on the internet in the future [24].

According to Čakloš, the latest trends include virtual reality and augmented reality, which represent new opportunities for content marketing as well as customer engagement [5]. Last year, active virtual reality users were around 90 million, and this year the number almost doubled, accounting for some 171 million active virtual reality users.

3. Methodology

The enterprise for which this analysis was conducted operates on the B2C market in the Slovak Republic in the transport sector. From the point of view of annual turnover, the enterprise is classified as a medium-sized enterprise and is also classified as a medium-sized enterprise from the point of view of number of employees. It has been operating since 1998. The company has a separate marketing department since 2005 with staff who have experience with traditional marketing and are also inspired by a useful and effective tool that resonates in the Slovak Republic. Workers strive to combine experience and strategic approach with a modern look at current customer behavior. Therefore, for several years they have been implementing content marketing and realizing that creating a content marketing strategy is a long-term process, so they are already interested in innovative forms within this issue. The company plans to follow these trends in the future and to observe the data from a chronological point of view. The analysis will be done in terms of psychographic customer segmentation.

Based on the delimitation of the theoretical backgrounds and the requirements of the surveyed enterprise, we identified a research problem as follows: To what extent the content marketing trends affect the customers of the surveyed enterprise segmented by psychographic segmentation. After confirming the existence of the segments showing greater influence on content marketing tools, the company plans to focus more on these customer groups because the management of the company is aware of the benefits of content marketing such as growth of metrics and KPIs without paid support.

Psychographic segmentation criteria divide consumers into different segments based on belonging to particular social classes, based on different lifestyles or types of personalities [13]. Their goal is to explain the differences in market manner based on the psychological and social predispositions of consumers. It seeks to uncover the reasons why some consumers with the same descriptive characteristics show different buying behavior. Lifestyle as one of the characteristics of market behavior can be tracked and analyzed from many different viewpoints, often in combination with other segmentation factors. For purpose of this research we used lifestyle generational market segmentation [19]. Understanding generation values and motivations has become essential because each generations is driven by unique ideas about the lifestyle to which it aspires [23]. Each generation represents a different set of unique expectations, experiences, generational history, lifestyles, values, and demographics that influence their buying behaviors. This information empowers you to craft a relevant message that draws a direct connection between individuals and how they relate to your brand. There are many studies that identify and analyze differences in consumer behavior according to the
customer generations. For the purposes of this contribution, respondents are segmented into six classifications by their
generational cohort: (Post-War Cohort - born: 1928-1945; The Baby Boomers - born: 1946-1954; Generation Jones -
1995-2012)

Based on the research problem identified in the first phase of the research, a method of selecting a suitable
sample, sample size, appropriate methods and survey tools was then established. The choice of the target group of
respondents is an important step for successful marketing research [10, 25]. It is necessary to decide who will be the
ultimate target entity. As the final respondents, we defined the customers of the analyzed enterprise, i.e. the stratified
available sample selection [15]. The size of the research sample was determined on the basis of a formula determined
by Chráska in accordance with Nowak [7]:

\[ n = \frac{t_{\alpha}^2 \cdot p(1-p)}{d^2}, \]  

(1)

where \( n \) is the minimum number of respondents, \( t_{\alpha} \) is the critical value of the normal distribution, \( p \) is the likely sample
proportion, expressed as a decimal, and \( d \) is the confidence interval, expressed as a decimal. The confidence level was
set at 95%. The critical value of the normal distribution at confidence level \( \alpha = 0.05 \) was 1.96. This is based on the fact,
that 95% of the area of the normal distribution is within 1.96 standard deviations of the mean. For those cases where the
likely sample proportion was not known, \( p \) was set at 50%. The confidence interval was set at 5%.

The confidence interval determines the margin of error we tolerate within the marketing research and the rate
is based on current trends in marketing research [12]. So the needed sample size is 384 customers of the monitored
business. In our case, we surveyed 700 respondents. The choice of method for data collection depends on the
information needs, as well as the budget, availability of resources and timetable. For the purposes of this research, we
chose the method of collecting data through a questionnaire, even though we are aware of its shortcomings as time
consuming and low returns.

4. Results

Using the first survey questions, we tried to answer the question about the advertising trend in content marketing.
We focused on comparing the customers' perception of native advertising versus classic forms of advertising.
Argumentatively, these topics are also related to another trend of the surveyed problem, and that is ad block. We asked
the respondents about the level of harassment and the degree of influence by both forms of advertising, with the help of
questions: Are you bothered by classic / native advertising? You are affected by classic / native advertising.
Respondents could answer these questions using a Likert scale ranging from 1 - strongly agree to 10 - strongly disagree.
We summarized the answers based on the selected psychographic segmentation. According to the survey, we can say
that customers of all generations show more resistance to traditional advertising, which means that they perceive native
advertising as less harassing, and the results also confirm that native advertising also affects respondents in their
purchases for all generations. By examining the differences in generations, we can confirm the fact that younger
generations have clearly higher values when observing the factor of harassment by traditional advertising and at the
same time show that native advertising convinces them much more in buying behavior. In essence, the results confirm
that some banner blindness across all generations has hit people, and they are increasingly immune against forms of
advertising. Native advertising is not at first glance the advertising. It blends with the environment in which it is
embedded. Therefore, native advertising itself attracts the attention of users with its attractive content (pull method) as
opposed to classic advertising that pushes the information to customers (push method).

As part of the research of content marketing trends in the surveyed company, we focused on identifying the share
of customers using ad block. Based on the answers, we can say that only 17% of customers use blocking ads. Blocking
Internet advertising is the domain of desktops where the percentage of users using ad blockers is 16 percent. It is 11
percent for tablets, 7 percent for mobile phones. In comparison to generations, this add-on in the web browser for
blocking ads is mainly used by the Y generation.

There are many types of content that can be used in content marketing. Customers look for different kinds of
information. Many authors, including surveys, put video in the foreground, even referring to it as the long-term trend of
content marketing. Therefore, one of the aspects examined in our survey was content types. Respondents had the
opportunity to choose the most popular types for them, such as articles (stories, tutorials, reviews, interviews, videos,
tutorials, reports, animated videos), infographics (flat design, news, comparisons, education), tips, how-to's, attractions,
interesting facts, guides, studies), applications (games, helpful tools, activity recorder, dictionary), email newsletter
(blog news, site news, links to interesting content), presentation (statistics, research, white papers, education, case
studies), webinar (courses, conferences, training, seminars), podcast (comments, reviews, audiobooks, records). According
to the overall survey results, the most favorite type of the content are articles on various topics. A particularly popular content type is the video that won the top among content types for the Y and Z generations. Respondents also include infographics for the forefront. These three content types ranked first in the cross-section of all
generations.
Another investigated content trend was influencer marketing, namely collaboration with micro influencers. In the past, the company has already analyzed the influence of influencer marketing in general, and the results have said that even though this form of content marketing does not bother the customers, nor does it affect them. Therefore, we wanted to find out by asking questions how it is with the perception of influencing and harassing by micro influencers.

By comparing the results, we can conclude that this form of marketing also does not give customers a sense of harassment, but the degree of influence shows much higher levels than overall influencer marketing, especially among younger generations. Even in comparison to the values of native and classic advertising. Micro influencer marketing is more influential than classical advertising, not only for younger generations. This can be due to the fact that micro influencers have authenticity obtained by ongoing interaction with their followers.

Voice search plays a huge role in nowadays content marketing. The number of voice searches will only grow, as evidenced by global surveys. However, the results of our survey point to the fact that this trend did not appeal to the customers of the surveyed company, as only 35% had used this tool in the past. This low value may be due to the fact that none of the voice assistants yet meaningfully support Czech or Slovak. It can be assumed that the growth rate of voice search in Slovakia will grow slower than in the US. As part of exploring the use of voice search among generations, the Y generation clearly leads (32.8%) and Baby Boomers are the least likely demographic with only 7 percent.

The latest explored trend of content marketing strategy was virtual reality. Customers of the surveyed company encountered such a type of promotion very rarely (12.6%). As the virtual reality in the Slovak Republic is used very limited, a low percentage of the occurrence of the trend was expected. For this reason, we asked our customers whether the form of promotion would also make them harassed or positively influenced to purchasing decisions. Respondents showed enormous interest in this trend in content marketing. Up to 89% said that this form of promotion does not bother them at all and even up to 75% assume that using virtual reality would convince them to purchase.

5. Conclusions

The aim of the paper was to summarize the basic trends of the content marketing strategy and subsequent analysis in the context of the psychographic segmentation of the transport company customers based on the statistical evaluation of the marketing research data. The research was realized because transport company management is aware of the importance of content marketing, which brings various benefits. The benefits include, in particular, supporting the growth of the entire business by providing many new opportunities to attract potential customers. Other benefits include gaining new customer information, valuable feedback, growing trust between the customer and the business. The advantage is also the multiplication of visibility on social networks, where valuable content will cause more traffic and potential customers become more interested in the business. Advantages include lowering advertising costs because the company only invests in content creation and promotion. The disadvantages include its time-consuming nature, as it will take several months since the content was created, in some cases several years before we see the results. Last but not least, the disadvantages of content marketing include flexibility. In content marketing, we need to think about the future, estimate trends and take the risk that the created content may not be attractive. For this reason, we investigated the research question in the survey. To what extent does the trend of content marketing affect the customers of the enterprise under review.

Of the trends examined, customers were most positively affected by native advertising. According to the survey, we can say that the customers of the surveyed company have confirmed the importance of native advertising, which is usually perceived by customers as particularly positive, also because it provides added value. It is not just about advertising the advertiser, but also about making to the reader a positive impression of native content and taking valuable information or having fun with it. In addition, native advertising gets directly to users through an editorial system that is independent of advertising systems. By doing so, ad blocky, although only a small proportion of customers use them, virtually have no chance of blocking it.

As mentioned, the native ad has clearly resonated with the content marketing trends we have followed in the survey. However, micro influencer marketing has also achieved very positive results, so the company should consider using this trend as there is no need for a high budget for this form of promotion. And lower budget improves ROI and you can cooperate with multiple influencers at once, which expands your reach audience.

Another recommendation based on research results is the use of virtual reality. Although virtual reality has only recently been made available to the wider public, interest in it has been developing very quickly. Also, the new Google Cardboard product has been of great interest. This is a low cost version of glasses for viewing virtual reality. The glasses are compatible with the Android and iOS operating systems and are made of cardboard and are affordable for a wide audience. Given the increasing demand of ordinary consumers for goggles for virtual reality, this product has great marketing potential. The glasses can be used as a valuable promotional gift that, in conjunction with your own virtual application (video), can inspire as the most effective marketing tool of the year.

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References


Stability of the Railroad Track Gauge with Railpad and Railpad-free Designs of Rail Fastening System

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Abstract

The structure of the railroad track, despite its simplicity, is related to the complex design structures, which experience the influence of various natural factors and the complex dynamic interaction with the moving vehicle. It is not a purely resilient structure, but a resilient-viscose and resilient-dissipate structure. The internal viscosity of the materials of the track’s upper structure and the strength of the viscous resistance in the ballast bed, in the ballast layer, are the source of energy dissipation, and hence the primary source of accumulation of residual deformations.

The intensity of accumulation of the residual deformations of the railroad track depends on many factors, in particular: the size of the gap between the wheels flanges and the working edge of the rail, the freight capacity of the section, the axle loads, the speed of the trains, the stiffness of the rail lengths, and others. The intensity of the change in the track gauge and the possibility of rails slipping is significantly influenced by the design of rail fastenings.

In order to evaluate the behaviour of the rail fastenings of the fishplate and fishplate-free design in conditions of combined traffic (the combination of passenger and freight transportation), experimental research has been carried out under operating conditions. On the basis of experimental researches, regularities have been revealed between the rail fastening design, the intensity of accumulation of residual deformations correspondingly to the railroad track gauge and the operating conditions.

KEY WORDS: rail fastening system, track gauge, railpad-free and railpad designs, reliability, random value, vehicle, reinforced concrete sleepers.

1. Introduction

With the gradual transition of the railroad track to the reinforced concrete sub-rail base (which increases the weight of the track’s upper structure and its spatial rigidity), increasing the weight of the vehicle un-sprung mass, and insufficient resilience of the spring suspension leads to an increase in the vibration characteristics of the impact of the moving vehicle on the track, which causes a rather specific spectrum of accumulation of residual deformations and complication of the work of the intermediate rail fastening unit and may ultimately cause a phenomenon such as a derailing of rolling stock [1].

Until 1996-97 Ukrainian railways on main lines with reinforced concrete sleepers used only railpad rail fastening units of KB-type with a rigid clip and two-turn spring-packing. The railpad-free fastening units of old designs of ZhB-type and ZhBR-type for reinforced concrete sleepers were used very rarely and only on tracks with low intensity of traffic. A far wider use was experienced by railpad-free fasteners with the appearance of elastic rod clips after 1996-97. The introduction of such fasteners in Ukraine began with the use of Polish elastic fastening units of type SB-3. After 2000 on the home railroads railpad-free fastening units of the KPP-type began to be widely used.

The introduction of modern railpad-free designs of rail fastening units with elastic spring-packing on reinforced concrete sleepers which are not worse than those of railpad design is an objective necessity, based, first of all, on the economic inexpediency of using a typical railpad design of fastening of KB-type in high-speed sections and in areas with moderate freight capacity. However, at the same time, the introduction of elastic railpad-free designs of rail fastening units, which are low metal-consuming and low-maintenance, on such railway sections requires the necessary scientific substantiation regarding the efficiency of its operation under modern and prospective operating conditions on the railways of Ukraine.

The reliability of the entire railroad track largely depends on the reliable connection of the rail with the base, which in future determines the safety of the train running. Breakdown of the reliable connection of the rail with the base leads to a dislocating of the track gauge and the sliding of rail lengths [2].

Changing the railroad track gauge during operation is caused by the action of the lateral forces that arise when the wheel and rail length interact. Even at perfectly equal straight sections of the railroad track when wheel-sets rolling along the rails, there are their lateral displacements, that is, there is a twisting motion of a wheel-set and the whole vehicle.
2. Methods and Course of Research

Residual deformations of the railroad track can be accumulated for quite a long time, intensively or can be displayed immediately in the form of significant deviations from the design provisions. In parallel with this process, there is a process of accumulation of damage in the material elements of the track’s upper structure, which leads to the fatigue of the material and its destruction [3]. In many cases, such deviations can be forecasted.

A significant influence on the level of dynamic forces, and hence on the rate of accumulation of residual deformations and damage in the elements of the structure have the conditions of contact interaction of the track and rolling stock.

To date, in determining the influence of various operational factors on the nature of the accumulation of damage the most widely used methods are those of mathematical modelling [4-7], which is associated with the impossibility to fix the damage to the structure material in its entire section.

In turn, in determining the influence of various operational factors on the nature of behaviour and accumulation of residual deformations in the geometry of railroad track elements, it is more appropriate to use the data obtained as a result of operational [8,9] or laboratory studies [10-12], which is related to the complexity of the structure of the track. Although with the development of computer modelling methods, studies related to this problem appear in particular through the finite element method [13-15].

The authors of this article used the methods of statistical analysis during the research since the most objective information about the reliability of an element or the whole structure can be obtained on the basis of the use of statistical data on failures received during the operation. Without information on failures, it is impossible to determine reliability indicators, to identify deficiencies in the track structure and in its maintenance, to determine the impact on the reliability of operating conditions and on this basis to take measures to further improve the reliability of the track.

After stacking the research structures, they are supervised for their operation and accumulation of failures.

In most cases, it is impossible to obtain information about all the elements forming a general population - a set of values of the features of all objects of the given type (Ng), so random sample No is used, that is, part of the general population consisting of elements that are randomly selected from all of the same types of elements lying in the rail of this network of railways. The more Ng → No, the more substantiated judgments can be made on the basis of a sample of the general population. The sample gives the most comprehensive information about the general population only when the survey results that form the sample are independent. The sample must necessarily be representative, that is, in such a way that all the main features of the general population from which the sample is obtained are represented approximately in the same proportion or with the same frequency with which the given feature occurs in this general population.

Thus, the method of using the sample consists in the fact that from the general population a sample is taken in the scope No << Ng and the indicators are determined, taken as approximate values of the corresponding characteristics of the general population. The degree of approximation of observation results to real values is determined by the sample size No and evaluated by the relative error δ and the reliable probability of the β values considered. The relative error δ characterizes the degree of accuracy of the determination of the mean value. It is counted as:

$$\delta = \frac{t_B - T_{cep}}{T_{cep}} = \frac{|t_H - T_{cep}|}{T_{cep}},$$  
(1)

where $t_B$ – the upper safe limit; $T_{cep}$ – the average value of the parameter under consideration; $t_H$ – the lower safe limit.

If the range of $t_B$...$t_H$ is set, one cannot exclude receiving a result that is outside this range. Therefore, the probability of obtaining the result in the indicated limits β is also indicated.

For solving practical engineering problems, $\beta = 0.8 ... 0.9$ is used. if the sudden failure of the element has no grave consequences (human sacrifices, essential material expenses for eliminating the failure or trains idle hours), and $\beta = 0.91 ... 0.99$, if the failure can have the indicated consequences.

Reliability of the provision of parameters of the railroad track (gauge, creep, the position of rails in the layout, profiles, and level) in most cases is ensured by the reliability of the behaviour of rail fastening units. The deviations intensity in the interaction of the rail with the base depends on the nature of the interaction of the elements of the rail lengths with each other and with the ballast layer under the action of the moving load.

The principal basis for running track facilities is not the elimination of failures, but their prevention, that is, the implementation of preventive work in due time. Proceeding from this, the main indicator of the reliability of the system of rails interaction with the base will be the probability of failure-free operation $P(t)$, that is, the probability that in a given interval of time $t \leq T$ (or within the limits of working hours in million tons of gross load), there is no system failure. The value $P(t)$ can be within range $0 \leq P(t) \leq 1$.

The probability of irreversible work $P(t)$ and the probability of failure $F(t)$ form a complete plane of events:

$$P(t) + F(t) = 1.$$  
(2)
Setting the value of $T$ we can provide the required probability for each object $P(t)$ as the parameters are interconnected by a functional dependence:

$$P(t) = \int_{t-T}^{t} f(t) \, dt,$$

where $f(t)$ – the probability density for the service life (working out) of an object according to the given output parameter.

Distribution functions – integral $F(t)$ and density $f(t)$ – completely characterize a random variable. To solve many problems it is sufficient to know the values of only a few moments of random variables.

To establish the regularities between the design of the rail fastening unit, the intensity of accumulation of residual deformations along the railroad track gauge and operational conditions, experimental researches have been conducted directly in the track with railpad rail fastening unit of KB-type and with railpad-free fastening unit of the KPP-type. Operational and constructive characteristics of selected sections of the railroad are shown in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>№</th>
<th>Location of the section</th>
<th>Set speed (passenger / freight), km/h</th>
<th>Series of driving locomotives</th>
<th>Track layout</th>
<th>Type of fastening unit</th>
<th>Sleeper density pcs/km</th>
<th>Freight capacity / Carried tonnage (million tonnes Gross km/km per year) / (million tons gross / km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fastiv-Koziatyn 1008KM</td>
<td>100/70</td>
<td>ChS 4 / VL 80</td>
<td>straightforward</td>
<td>KPP</td>
<td>1840</td>
<td>62.6/61.8</td>
</tr>
<tr>
<td>2</td>
<td>Fastiv-Koziatyn 1008KM</td>
<td>100/70</td>
<td>ChS 4 / VL 80</td>
<td>straightforward</td>
<td>KB-65</td>
<td>1840</td>
<td>62.6/61.8</td>
</tr>
</tbody>
</table>

Operational studies on the effect of the design of an intermediate rail fastening unit on the railroad track behaviour as a whole were based on the analysis of the results of roadside checks with track-testing cars for the year of operation.

Since the reliability indicators of the rail fastening unit for ensuring the stability of the track gauge are random variables, their mathematical models should show how these indicators are distributed, depending on the carried tonnage. Such models are the laws of the distribution of random variables. Any relation, which establishes the dependency between the possible values of the random variable and their corresponding probabilities, is called the law of the distribution of a random variable. A complete description of the reliability of objects with a continuous nature of work is the law of time distribution of fail-safe work.

Different continuous distributions used in probability theory can be used as theoretical laws of the distribution of work-to-failure ratio.

The deviation of the track gauge from the designed position can be described by the normal distribution (Gaussian distribution), that is, the random variable (deviation) has the probability density of the following form:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}.$$  

This law is applied in cases where there are processes in which failures arise as a result of the influence of several equal factors. Fig. 1 shows the normal law of the distribution of deviations of the railroad track gauge in the case of a railpad-free design of the rail fastening unit of the KPP-type.

The main parameters that characterize the normal law of probability distribution are: mathematical expectation, mod, variance, and mean square deviation of Eqs. (5)-(8).

$$M(X) = \int_{a}^{b} x \cdot f(x) \, dx;$$  

$$f(M_o) = \text{max};$$  

$$D(X) = \int_{a}^{b} (x-M(X))^2 \cdot f(x) \, dx;$$  

$$\sigma(X) = \sqrt{D(X)}.$$
From the experimental researches, the following dependences of the change of the railroad track gauge during operation with railpad rail fastening unit and with railpad-free fastening unit (Figs. 2 and 3) were obtained.

Fig. 1 Normal law of the distribution of deviations of the railroad track gauge with the rail fastening unit of the KPP-type.

Fig. 2 Average square deviation of the railroad track gauge.

Fig. 3 Mathematical expectation of the probability distribution of the railroad track gauge.
3. Conclusions

1. The intensity of the breaking of the railroad track gauge depends to a large extent on the design of the intermediate rail fastening unit and the strength of its structural elements.
2. From the results of operational studies it turns out that the greatest stability of the railroad track gauge is provided at the sites with the use of the intermediate rail fastening unit of the KPP-type, where the intensity of the change in the railroad track gauge is 0.13 and 0.14 mm per 1 million tons of gross cargo.
3. The greatest intensity of the change in the railroad track gauge was observed at the sites of the use of the KB-type rail fastening unit.
4. From the conducted researches it is clear that in the case of a railpad-free design of the rail fastening unit of the KPP-type, the geometric deviations of the parameters of the rail track have a smaller amplitude compared with the fastening of the KB-type in the case of freight capacity to 60 million tons gross km / km per year. Therefore, under such operating conditions, the most rationally is to use the railpad-free design of the rail fastening unit of the KPP-type.

References


Financial and Operational Leasing as an Alternative Source of Financing Vehicles in the Czech Republic

A. Bieliková, J. Hakalová, Y. Pšenková

Abstract

The paper deals with the definition and analysis of financial and operational leasing as one of the possible alternatives of financing vehicles in the Czech Republic. In the introduction, the paper specifies the definition and characteristics of these types of leasing in terms of the current legislation in the Czech Republic, followed by the definition of the accounting view of financial and operational leasing under the current Czech legislation and International Financial Reporting Standards (IFRS). The paper also deals with the tax aspect from the perspective of both income and value added tax, again under the existing Czech legislation. In conclusion of the paper, the advantages and disadvantages of the above-mentioned forms of financing are presented, including the current practise in the use of financial and operational leasing of vehicles in the Czech Republic.

KEY WORDS: financial leasing, operational leasing, financing, income tax, value added tax, vehicles

1. Introduction

Leasing is a modern form of rental in which a lessee leases a movable investment (machinery, vehicles) or an immovable investment (land, buildings) in return for a fixed payment of an agreed rental including interest [8]. It can be one of the options to acquire tangible or intangible assets for business purposes. Apart from a bank loan, a company can finance intangible and tangible fixed assets also through leasing. In recent years, it has been used as a special form of financing, especially when financing a car [3]. From a legal point of view, Jarinkovičová characterizes a leasing as “a trilateral legal relationship between a supplier, a lessor and a lessee, in which the lessor buys property from the supplier and provides it to the lessee for value. The lessor is the owner of the property” [5]. From a financial point of view, Fekete describes the leasing as “a special, alternative form of financing long-term needs of lessees with foreign capital which differs from bank loans and other forms of foreign capital primarily by the fact that the creditor/lessor becomes the owner of the goods” [2].

Leasing is easier to finance and provides operational flexibility, although it costs more in the long run. The benefits of leasing are particularly important to firms with financial constraints and high uncertainty [12]. Leasing is not explicitly defined in the Czech private law, even after the amendment of the Civil Code, which has been in force since 1 January 2014. The private law is applicable to leasing transactions primarily in its general provisions. An innominate (unnamed) contract is drawn up with the objective of ultimately transferring the ownership of the leasing contract subject after its termination. The leasing establishes a legal relationship between two entities, namely the lessor and the user of the leasing subject (the lessee). The rights and obligations of the contracting parties are governed primarily by provisions drawn up in particular leasing contracts. The leasing provider is obligated to provide the lessee with the leasing subject for use for a specified period of time in return for the agreed payment, and at the same time, it is determined how the subject of the leasing contract will be dealt with after the expiration of the leasing term. The service provider is owner of the leasing subject for the duration of the contract, and the user of the leasing is only entitled to use the subject for a specified period of time. The most important aspect for assessing the type of a leasing is the resolution of ownership after the end of the leasing contract. Based on this criterion, there are two basic types of leasing - financial and operational leasing [4]. The popularity of operational leasing, which allows more efficient management of business costs than financial leasing, has been growing recently. Compared to other forms of vehicle financing, operational leasing is the most frequently used one in case of vehicle purchase, which is also shown by the year-on-year growth of almost 5% at the expense of financial leasing and business loans. According to the statistics of the Czech Leasing and Finance Association (CLFA), the share of financial leasing in the total number of newly concluded contracts among entrepreneurs was less than 3.5 percent last year. The previously popular financial tool was almost forced from the market by traditional bank loans. On the other hand, the leasing of cars through operational leasing is becoming increasingly popular.

2. Definition of Financial and Operational Leasing

As mentioned above, neither financial nor operational leasing is defined in the Czech private law. But since the
financial leasing is significant in terms of accounting and taxes, a separate definition of financial leasing has been included in the Act No. 586/1992 Sb., on Income Tax since 2015. For the purpose of income taxes, a financial leasing is understood as a transfer of a thing, except for a thing that is an intangible asset, by the owner to be used by the user in exchange for consideration if it is agreed at the time of concluding the contract that after the agreed period the owner will transfer the right of ownership to the user of the thing at the purchase price or free of charge, or the right of the user for a transfer is agreed. On the date of the transfer of ownership, the purchase price is not higher than the net book value calculated from the entry price recorded with the owner which the subject of the financial leasing would have had in case of straight-line depreciation without increasing the depreciation during the first year, except when the thing was already depreciated at the amount of 100% of the entry price. At the time of concluding the contract, it is also agreed on that for the duration of the financial leasing, the right to use the leasing subject, obligations related to its keeping and risks associated with its use will be transferred to the user, and that the minimum term of the financial leasing is met.

The term of a financial leasing is calculated from the date when the subject of the financial leasing was left to the user in a condition fit for normal use. The minimum term of a financial leasing is the minimum depreciation period of tangible assets specified in section 30 of the Act on Income Tax or the depreciation period pursuant to section 30a) or 30b) of the Act on Income Tax at the time of concluding the contract. This period is reduced by 6 months for tangible assets included in depreciation group 2 through 6 in accordance with the Annex 1 to the Act on Income Tax. The provisions on leases of the Act on Income Tax do not apply to a financial leasing. For the purpose of income tax, a financial leasing is treated as a lease from the moment when the financial leasing contract is concluded, unless the financial leasing is prematurely terminated in which case the ownership is not transferred to the user after the agreed period. If the user leaves the subject of the financial leasing to another person to be used in exchange for consideration under a contract, such contract is considered a lease agreement for the purpose of income taxes.

Operational leasing is also called operating leasing, short-term or medium-term leasing. It is a type of financial service, which is a foreign source of funding. It is basically a short-term lease, in which a lessee returns the property to a lessor after the lease term expires. There is no contractual claim to the possible transfer of ownership of the subject of the leasing contract to the lessee. The minimum and maximum leasing term is not regulated by law, and as a rule, the leasing term for an operational leasing is usually shorter than the economic life of the leased thing. The purpose of an operational leasing is a temporary use of a thing in exchange for consideration without transferring majority of the risks and benefits associated with the ownership of the subject of the leasing contract to the lessee, without any contractual right to the possible ownership transfer to the lessee. The lessor usually provides service and maintenance of the thing and carries most of the risks and benefits associated with the ownership of the leasing contract subject. If the company sells the thing to another company and leases it immediately, it is the case of sale and leaseback [6]. In case of financial problem, the lessee must return the subject to the lessor and negotiate a settlement [1]. Table 1 shows a comparison of financial and operational leasing from different perspectives.

Table 1

<table>
<thead>
<tr>
<th>Leasing type</th>
<th>Leasing term</th>
<th>Asset’s useful life</th>
<th>Ownership risks</th>
<th>Maintenance of the leased subject</th>
<th>Ownership right after termination of leasing</th>
<th>Termination by notice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial leasing</td>
<td>Long-term</td>
<td>Usually corresponds with the length of the concluded leasing contract</td>
<td>On the user’s side</td>
<td>Provided by the user or lessor under the terms of the contract</td>
<td>The user becomes an owner after a purchase</td>
<td>Possible only for the lessor</td>
</tr>
<tr>
<td>Operational leasing</td>
<td>Short-term, medium-term</td>
<td>Significantly longer than the leasing term</td>
<td>On the lessee’s side</td>
<td>Paid and ensured by the lessor</td>
<td>The lessor remains the owner</td>
<td>Possible for both the lessor and the lessee</td>
</tr>
</tbody>
</table>

3. Accounting View of Financial and Operational Leasing

As already mentioned, two types of leasing are recognized in the Czech Republic – a financial leasing and operational leasing. Both forms differ in the way of treating ownership rights after the leasing contract is terminated. If the leasing contract includes a pre-emption right, this type of leasing is referred to as a financial leasing. If a thing remains in the ownership of a leasing company after the leasing contract is terminated, this type of leasing is referred to as an operational leasing. The duration of such leasing is usually shorter than the useful life and depreciation period. The financial leasing is a form of a lease in which the lessee gradually repays the goods to the lessor. In case of financial leasing, the lessee borrows a thing for its entire useful life. The contract pre-regulates the transfer of ownership rights to the subject of the leasing contract after the expiration of the leasing term. In terms of accounting, the use of a car is recorded in off-balance sheet accounts (accounting group 75-79 Leased assets) and the instalments are recognized as purchased services to current costs, which must be treated on an accruals basis according to the Act on Income Tax, while the leasing term must be at least 60 months, and when the leasing contract is terminated, the property must be classified as a business asset. The Act also states that in case of tangible movable assets included in the depreciation group 2 or 3 (such as cars), the leasing term can be reduced by up to six months. The operational leasing allows efficient management of business costs, and its popularity continues to grow, not only for economic reasons. Compared to other forms of vehicle financing, it is becoming increasingly popular in comparison to business loans and financial leasing. Companies will pay
only the part of the car's acquisition cost which wears out during its use without affecting the capital needed. The monthly instalments include estimated service, insurance, and many other services. The advantage of operational leasing lies in more effective recognition of car running costs in accounts compared to accounting depreciation of assets. The concluded contract includes the scope of the service plan, and future costs are part of the instalments, which mainly eliminates one-time expenses in the future and stabilizes cash flows.

4. Tax View of Financial and Operational Leasing

In terms of income taxes, a financial leasing in the Czech Republic is regulated in section 21d) of the Act No. 586/1992 Sb., on Income Taxes, as amended [13]. For income tax purposes, a financial leasing is understood as a transfer of tangible assets by the owner to the user to be used under specified conditions. This means that a financial leasing must involve a transfer of a tangible asset and not a transfer of an intangible asset. If the transferred asset is not an asset specified in section 26 (2) of the Act on Income Tax, it is not a financial leasing [13]. An amendment to the Act on Income Tax implemented by the Act No. 170/2017 Sb [15]. clarified that a financial leasing for that purpose only applies to tangible assets which are depreciated and not to assets that are not tangible as well as to assets not depreciated under this Act. The amendment added a subsection 6 to the section 21 of the Act on Income Tax, under which the following transfers are not a financial leasing:

- transfer of tangible assets excluded from depreciation;
- transfer of intangible assets;
- transfer of movable or immovable property which is not a thing within the meaning of the Act (neither tangible nor intangible).

The financial leasing must therefore be made in exchange for consideration; if a tangible asset is transferred free of charge, it is not considered to be a financial leasing. Under the amendment to the Act on Income Tax, a financial leasing needs to meet the following attributes:

- the user's right to transfer ownership of the property;
- corresponding relationship between the purchase price and the tax net book value;
- transfer of corresponding rights and obligations to the user;
- minimum term of a financial leasing.

The first condition is to transfer the ownership right to the user. One of the two options must be agreed upon the creation of the contract, namely that after the expiration of the agreed leasing term, the owner of the subject of the financial leasing contract transfers the ownership right to it for a purchase price or free of charge to the user of the subject or that the user is entitled to such transfer. The transfer can be made for both the purchase price or free of charge. The second condition is the corresponding relation between the purchase price for which the leased subject will be transferred to the user and the tax net book value. In order to meet the conditions of a financial leasing, the purchase price may not be higher than the tax net book value. Tax net book value is the price calculated from the acquisition cost recorded with the owner, with a straight-line depreciation method without increasing the depreciation in its first year. If it is agreed at the time of concluding the contract that certain rights and obligations will be transferred to the user for the duration of the financial leasing, then it is considered to be a financial leasing. This should remove any doubts as to whether the concluded contract is a financial leasing or an operational one (a lease). In addition to being able to use the subject of the leasing contract for own activities, the user is also obliged to maintain, repair and finance current operating expenses and bears the responsibility for risks associated with the subject of the leasing contract such as damage or theft. It is therefore another attribute defining a financial leasing. The last condition is to meet the minimum duration of a financial leasing. The term of a financial leasing is calculated from the date when the subject of the financial leasing was left to the user in a condition fit for normal use. If the subject of a financial leasing is transferred to the user before concluding the leasing contract, the term will be counted from the date of concluding such contract. The Act on Income Tax defines the instalments of a financial leasing as a payment which is a tax expense (cost), provided that the subject of the leasing contract is included in a business asset after the leasing contract is terminated. For taxpayers who keep tax records, this payment is an expance only in proportion to the agreed period for the relevant tax period (it is set in calendar months, even for each month started). For taxpayers who keep their accounts, the payment for a financial leasing is accrued in accordance with the accounting legislation [15]. In terms of the value added tax, the financial leasing is regulated by the Act No. 235/2004 Sb., on Value Added Tax [14].

Under this Act, a financial leasing is considered to be a specific method of delivering goods under a contract containing an arrangement for the future transfer of ownership of the goods used to the user. When delivering goods pursuant to section 13 (3) (d) of the Act on Value Added Tax, the tax base is the total payment which the user is obliged to pay to the lessor without the tax for the taxable event under a financial leasing contract. If the user of goods is a VAT payer and uses the goods in his/her economic activities for the purpose of performing transactions, the user is entitled to deduct the tax from the moment when the goods were provided for use under a financial leasing contract. Tangible assets that are acquired by a taxable person through a financial leasing are treated as fixed assets of the user from the moment when they are transferred for use under the contract, which affects the right to claim the tax deduction for tangible assets acquired through a financial leasing [14]. From a tax perspective, an operational leasing is often more advantageous to entrepreneurs than a business loan or a financial leasing. An operational leasing is considered to be a service, and with the current tax legislation under the Act on Income Tax, it is possible to apply the entire payment for an operational leasing as an tax deductible costs. If the operating lease is terminated with the sale of the subject of the leasing contract
to the lessee, it is necessary to test the purchase price; if the purchase price is greater than or equal to the tax net book value calculated using the straight-line tax depreciation from the acquisition cost of the asset recorded with the lessor, then the instalments remain tax deductible. Otherwise, all payments are deemed as tax non-deductible.

5. Current State, Advantages and Disadvantages

According to a survey conducted by the Czech Leasing and Finance Association (CLFA), a financial leasing is used by less and less people to purchase a car. In 2017, the use of a financial leasing by entrepreneurs amounted only to 3.5% of the total number of newly concluded contracts. The figure is even lower for private individuals: only 0.3%. The previously popular financial tool was replaced by traditional bank loans. They are particularly popular among ordinary people as they account for more than two-thirds of all car purchases on credit. Last year, entrepreneurs chose a loan in two cases out of five. It turns out that especially for companies and entrepreneurs, it is mobility and not car ownership that is important. And that the advantages of renting cars for a company often prevail. More than half of entrepreneurs purchased a car through an operational leasing in 2017, see Fig. 1. This is 7.5 percent more than in 2016 [10]. As for households, the share amounted only to one third, see Fig. 2.

![Fig. 1 Share of products for financing new cars for businesses in 2018 by the number of newly concluded contracts of CLFA's members [9]](image1)

![Fig. 2 Share of products for financing new cars for households in 2018 by the number of newly concluded contracts of CLFA's members [9]](image2)

Operational leasing is offered by a large number of companies in the Czech Republic; ranging from car dealers, through specialized services to banking institutions, there is a diverse range of services available. An important aspect should not be only the price, but also the length of the operational leasing, the mileage, services included in the leasing, or whether it includes car insurance and with what co-payment (excess). Operational leasing can also be provided with or without services. In case of a "full service" product, all services associated with running a car are already included in the price. The most popular option is still a variant without any services [11]. Considerable benefits of operational leasing include immediate mobility, affordability, efficient and optimal cost management, full outsourcing of services, the ability to make faster use of smart applications and other tools from the category of electronic solutions available in new cars, as well as the immediate tax aspect of instalments. The disadvantages lie mainly in the fact that the subject of the contract remains the property of the lessor. The advantages of financial leasing include especially the option of instalments timing, which positively affects cash flows, and the fact that the subject of the leasing is immediately available. The disadvantages include the fact that the instalment is usually increased by a relatively high margin, the lessee becomes the owner of the thing only after the termination of a leasing contract, i.e., after a certain wear time; if the thing is lost, the leasing contract
Table 2

<table>
<thead>
<tr>
<th>Company name in the Czech Republic</th>
<th>Amount in million CZK</th>
</tr>
</thead>
<tbody>
<tr>
<td>ŠkoFIN s.r.o.</td>
<td>14,986.02</td>
</tr>
<tr>
<td>UniCredit Leasing CZ, a.s. */</td>
<td>9,556.96</td>
</tr>
<tr>
<td>s Autoleasing, a.s.</td>
<td>5,380.96</td>
</tr>
<tr>
<td>ČSOB Leasing, a.s.</td>
<td>5,276.88</td>
</tr>
<tr>
<td>ESSOX, s.r.o.</td>
<td>5,236.58</td>
</tr>
<tr>
<td>MONETA Auto, s.r.o.</td>
<td>4,352.68</td>
</tr>
<tr>
<td>LeasePlan Česká republika, s.r.o.</td>
<td>4,116.05</td>
</tr>
<tr>
<td>ALD Automotive s.r.o.</td>
<td>4,107.17</td>
</tr>
<tr>
<td>Mercedes Benz Financial Services Česká republika s.r.o.</td>
<td>3,884.85</td>
</tr>
<tr>
<td>Raiffeisen-Leasing, s.r.o.</td>
<td>2,738.27</td>
</tr>
</tbody>
</table>

Source: Czech Leasing and Finance Association (CLFA), 2018

6. Conclusions

As already mentioned in the paper, both financial and operational leasing are a frequent foreign source of financing in case of households or companies. However, when buying a car, it is necessary to carefully consider specific conditions and circumstances and to assess the advantages and disadvantages of the chosen method of financing. According to the managers of the European leasing companies, the first half of 2019 will be favourable for their businesses, but the prevailing optimism regarding the further development of the market has slightly decreased (CLFA, 2019). While there was an 1.9% increase in the category of household financing through a financial or operational leasing in 2019, the business financing showed a year-on-year decrease by 2.1%. This was mainly due to a decline in sales of new passenger cars. Some clients have even shifted their interest to the used car market, but according to the CLFA, this phenomenon seems to be temporary. Czech companies are increasingly discovering the benefits of operational leasing for financing the purchase of vehicles into their fleet and its subsequent management. This product certainly has a great potential and will be more widely used in the future than the once popular option of financial leasing. Most companies, however, finance and will continue to finance the acquisition of new cars through a loan, which is particularly beneficial for small businesses and entrepreneurs. In the Czech Republic, operational leasing certainly has the best years ahead of itself. Its current share is only over 10 percent. The current situation on the Czech leasing market, however, clearly shows the growing share of this form of transport vehicle financing. In 2019, more than half of all newly concluded contracts among businesses were an operational leasing.

References

Train Commercial Speed Versus Maximum Line Speed – Central-European Experience

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Abstract

Railway infrastructure quality is the precondition for services provided by rail passenger and freight operators. One of the key characteristics of the rail infrastructure is the maximum line speed, being the crucial factor determining quality and competitiveness of the offer and demand for transport. It is extremely important, to assess, to what extent the maximum line speed is utilised by trains. The main objective of the study performed at Instytut Kolejnictwa was to identify factors influencing real utilisation of the maximum line speed on conventional railway lines in a few countries in Central-Eastern Europe. As far as infrastructure is concerned, the most important factor seems to be differentiation of the maximum speed along the line. This differentiation is taken into account through the harmonic weighted mean. Among the rolling stock aspects, the essential factors are type of traction (electric, diesel), type of train formation (loco-hauled, EMU, DMU), power-to-weight ratio and percentage of powered axles. The infrastructure data and rolling stock data for intercity train services from various Central-European countries (including Lithuania, Latvia, Estonia, Belarus and Poland) have been collected. The best utilisation of maximum line speed is in the case of long sections passed without intermediate stops, at which the influence of acceleration and braking is relatively minor. The utilisation of maximum speed is negatively influenced by significant differentiation of the speed profile (frequent and large changes of speed along the line). The most effective utilisation of line capabilities is in the case of electric motor units (EMUs) and diesel motor units (DMUs) with distributed power and high power-to-weight ratio.

KEY WORDS: infrastructure, operation, maximum line speed, commercial speed, speed profile, power output

1. Introduction

Railway infrastructure quality is the precondition for services provided by rail passenger and freight operators. One of the key characteristics of the rail infrastructure is the maximum line speed, being the crucial factor determining quality and competitiveness of the offer and demand for transport. It is extremely important, to assess, to what extent the maximum line speed is utilised by trains.

The issue of train speed was the subject of numerous publications, practically since the beginning of railway as a transport mode. Start-to-stop average speed was commonly used for presentation of the fastest train services in professional journals before World War II. Good example was the series of articles “British Express Train Services” in the Railway Magazine [6]. Similar analyses were also compiled for express train services in other European countries [7]. It is noteworthy that the start-to-stop train speeds are the basis for train classification in the World Speed Survey, published bi-annually in Railway Gazette International until now [2].

The factors influencing commercial train speed and line capacity are discussed in the paper by Ramunas et al [8]. The main parameter determining line capacity is the difference in train speeds. When the difference between the highest and the lowest train speed is increased, then the available line capacity decreases. Depending on operational conditions, the impact of the train load and the characteristics of the locomotive on the journey time, can be very significant, especially in case of heavy freight trains operated on line with long gradients (Fig. 1).

![Fig. 1 A diagram showing movement of trains with different acceleration indicators in short and long districts [8]](image)

It is noteworthy that not only the speed and capacity are the only measures characterising functioning of railway
transport. Good example can be found in the paper by Wróbel, which is related to the integration of timetables for passenger trains in Poland co-financed by competent authorities in the frame-work of Public Service Contracts (PSC) [11]. The examples of parameters used for this particular assessment were: number of connections in the directions specified in the Transport Plan, average waiting time and average connection time for stations and for individual directions [3].

The work of Vaičiūnas investigates a possibility of using the traditional multi-criteria assessment methods to evaluate how significance of a railway line is distributed for the countries it crosses. Two examples of railway lines are analysed: the Rail Baltica (Poland, Lithuania, Latvia and Estonia) and the container train Viking route (Lithuania, Belarus and Ukraine) [10].

Interesting examples of evaluation of railway transport system can be found in the reports of the European Court of Audit (ECA).

In 2016 ECA evaluated rail freight transport across Europe [16]. The poor performance of rail freight transport in terms of volume and modal share in the EU is not helped by the average commercial speed of freight trains. On some international routes freight trains run at an average speed of only around 18 km/h. This is due to weak cooperation between the national infrastructure managers. In Central and Eastern European Member States, the average speed is between 20 and 30 km/h. The analysis o ECA showed, however, that the situation is significantly better in some freight corridors, where the average is speed is around 50 km/h. This values is closer to the average speed of trucks (around 60 km/h), [16].

In 2018 the results of comprehensive performance audit on the long-term strategic planning of high-speed lines in the EU and their cost-efficiency were published. [12]. The analysis covered (inter alia) the speed on the audited high-speed lines and indicated that, on average along the course of a line, trains run at only around 45% of the line’s design speed (in European conditions usually at the level of 300 km/h). Only two lines operate at average (commercial) speeds of more than 200 km/h, and no lines operate at an average speed above 250 km/h. The lowest speed yield on a completed high-speed line is on the Madrid-León high-speed line (39% of design speed). The cross-border Figueres – Perpignan section also only operates at 36% of its design speed, because it accommodates mixed traffic. Average speed so far below the design speed indicates that an upgraded conventional line would have been enough to achieve the objectives set, at a much lower cost [12].

The relation between the maximum speed on particular railway line and the commercial speed of the trains has been investigated in the paper by Massel [5]. However that research was restricted to the high speed train services in selected European countries and to the services operated with high-speed rolling stock in Poland (EIP trains).

2. The Scope of the Study

The main objective of the study performed at Instytut Kolejnictwa was to identify factors influencing real utilisation of the maximum line speed on conventional railway lines in a few countries in Central-Eastern Europe.

As far as infrastructure is concerned, the most important factor seems to be differentiation of the maximum speed along the line. To characterise them it is necessary to adopt some statistical measures. One of these measures should be the highest maximum speed on analyzed section. This value is very important, because in fact it determines the requirements for rolling stock making the full use from the infrastructure capabilities.

The differentiation of the maximum speed along the line has significant influence on journey time and, consequently, on line capacity. It is taken into account with the harmonic weighted mean $V_{0\text{max}}$, calculated according to the formula (1) [5]:

$$V_{0\text{max}} = \frac{\sum_{i=1}^{n} l_i}{\sum_{i=1}^{n} \frac{l_i}{V_{\text{max}}^i}}, \quad (1)$$

where $V_{i\text{max}}$ is maximum speed on section of track $i$, and $l_i$ is the length of section $i$. This formula has a very clear physical interpretation. Harmonic weighted mean is a quotient of the total length of the line (or the network) and the sum of theoretical journey times on particular sections with the constant speed. The example showing relation between actual speed profile and weighted mean value is presented in Fig. 2.

As the parameter characterising the utilisation of the maximum line speed, the speed utilisation ratio $I_s$ has been defined. It can be easily calculated according to the formula (2):

$$I_s = \frac{V_s}{V_{0\text{max}}}, \quad (2)$$

where $V_s$ is the start-to-stop average speed of the train on particular section and $V_{0\text{max}}$ is the weighted average maximum line speed on the same section.

There is a diversity of passenger rolling stock operated on the European railways. Some trains are operated as sets of conventional passenger cars hauled with electric or diesel locomotives (loco-hauled trains). However the trains
composed of Electric Motor Units (EMUs) or Diesel Motor Units (DMUs) are getting more and more popularity. From operational point of view, the train performance is very important. It is characterised with the maximum speed, but also with the values of train acceleration and deceleration. The higher these values are, the lower are the time losses for acceleration and braking of the train. The most important factors influencing train performance are the power output and arrangement of powered axles. Useful (and frequently used) characteristics for them seem to be power-to-weight ratio and percentage of powered axles.

---

Fig. 2 Example of speed profile: Vilnius – Kaišiadorys section of Vilnius – Klaipeda main line

<table>
<thead>
<tr>
<th>Country</th>
<th>Train type</th>
<th>Train weight [t]</th>
<th>Power output [kW]</th>
<th>Max.speed [km/h]</th>
<th>No of axles</th>
<th>No of powered axles</th>
<th>Power-to-weight ratio</th>
<th>% of powered axles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithuania</td>
<td>ER9M</td>
<td>196</td>
<td>1600</td>
<td>130</td>
<td>8</td>
<td>4</td>
<td>8.2</td>
<td>0.500</td>
</tr>
<tr>
<td>Belarus</td>
<td>EP8 (ЭП8)</td>
<td>132</td>
<td>2000</td>
<td>160</td>
<td>10</td>
<td>4</td>
<td>15.1</td>
<td>0.400</td>
</tr>
<tr>
<td>Belarus</td>
<td>EP9 (ЭП9)</td>
<td>260</td>
<td>3000</td>
<td>160</td>
<td>18</td>
<td>6</td>
<td>11.5</td>
<td>0.333</td>
</tr>
<tr>
<td>Lithuania</td>
<td>EJ575</td>
<td>164</td>
<td>2000</td>
<td>160</td>
<td>12</td>
<td>4</td>
<td>12.2</td>
<td>0.333</td>
</tr>
<tr>
<td>Ukraine</td>
<td>HRCS2</td>
<td>461</td>
<td>6000</td>
<td>160</td>
<td>36</td>
<td>24</td>
<td>13.0</td>
<td>0.667</td>
</tr>
<tr>
<td>Poland</td>
<td>ED160</td>
<td>281</td>
<td>2000</td>
<td>160</td>
<td>20</td>
<td>4</td>
<td>7.1</td>
<td>0.200</td>
</tr>
<tr>
<td>Poland</td>
<td>ED161</td>
<td>282</td>
<td>2400</td>
<td>160</td>
<td>20</td>
<td>6</td>
<td>8.5</td>
<td>0.300</td>
</tr>
<tr>
<td>Belarus</td>
<td>TEP70+5 couches</td>
<td>460</td>
<td>2944</td>
<td>160</td>
<td>24</td>
<td>4</td>
<td>6.4</td>
<td>0.167</td>
</tr>
<tr>
<td>Latvia</td>
<td>DR1AM</td>
<td>135</td>
<td>736</td>
<td>120</td>
<td>12</td>
<td>2</td>
<td>5.5</td>
<td>0.167</td>
</tr>
<tr>
<td>Estonia</td>
<td>DR1B</td>
<td>135</td>
<td>736</td>
<td>120</td>
<td>12</td>
<td>2</td>
<td>5.5</td>
<td>0.167</td>
</tr>
<tr>
<td>Belarus</td>
<td>DP3 (PESA)</td>
<td>144</td>
<td>1154</td>
<td>140</td>
<td>12</td>
<td>4</td>
<td>8.0</td>
<td>0.333</td>
</tr>
<tr>
<td>Lithuania</td>
<td>730ML (PESA)</td>
<td>151</td>
<td>1154</td>
<td>140</td>
<td>12</td>
<td>4</td>
<td>7.7</td>
<td>0.333</td>
</tr>
<tr>
<td>Estonia</td>
<td>2400 (Stadler)</td>
<td>176</td>
<td>1342</td>
<td>160</td>
<td>12</td>
<td>4</td>
<td>7.6</td>
<td>0.333</td>
</tr>
<tr>
<td>Estonia</td>
<td>2300 (Stadler)</td>
<td>148</td>
<td>1342</td>
<td>160</td>
<td>10</td>
<td>4</td>
<td>9.1</td>
<td>0.400</td>
</tr>
<tr>
<td>Estonia</td>
<td>2200 (Stadler)</td>
<td>124</td>
<td>1342</td>
<td>160</td>
<td>8</td>
<td>4</td>
<td>10.8</td>
<td>0.500</td>
</tr>
</tbody>
</table>

The infrastructure data and rolling stock data for intercity train services from various Central-Eastern European countries (including Lithuania, Latvia, Estonia, Belarus and Poland) have been collected (Table 1).

3. Results

To identify factors influencing real utilisation of the maximum line speed, several cases from different countries, and related to different operational conditions can be presented.

Case I – conventional trains operated with diesel locomotives in Belarus

Group of sections of railway lines in Western Belarus has been selected for analysis. All these sections are not electrified, with single track only:
- Luniniec – Zhabinka,
• Lida – Mosty,
• Mosty – Grodno (Hrodna),
• Baranovich – Vaukavysk.

The maximum speed for analysed sections is in the range between 70 and 120 km/h. The best maximum speeds are in force on Lida – Mosty and Mosty – Hrodna sections.

The start-stop runs of long-distance passenger trains on lines in question according to the timetable of Belarusian Railway valid from 1 June 2014 have been listed in Table 2. All trains were hauled with TEP70 diesel locomotive. Some of them were composed of just 4 or 5 cars, while the others could carry up to 18 cars.

Table 2
Selected runs of passenger trains operated with diesel locomotives on Belarus railway network in 2014/2015 timetable

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Distance (l) [km]</th>
<th>Harmonic mean ($V_{\text{mean}}$) [km/h]</th>
<th>Maximum speed ($V_{\text{max}}$) [km/h]</th>
<th>Time (t) [min]</th>
<th>Start-to-stop average speed ($V_s$) [km/h]</th>
<th>Speed utilization ratio $I_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luninets</td>
<td>Pinsk</td>
<td>58.4</td>
<td>99.4</td>
<td>120</td>
<td>48</td>
<td>73.0</td>
<td>0.735</td>
</tr>
<tr>
<td>Pinsk</td>
<td>Yanov-Poleskiy</td>
<td>36.9</td>
<td>99.2</td>
<td>100</td>
<td>30</td>
<td>73.8</td>
<td>0.744</td>
</tr>
<tr>
<td>Yanov-Poleskiy</td>
<td>Drahichyn-Horad</td>
<td>28.0</td>
<td>100.0</td>
<td>100</td>
<td>23</td>
<td>73.0</td>
<td>0.730</td>
</tr>
<tr>
<td>Drahichyn-Horad</td>
<td>Kobryn</td>
<td>55.8</td>
<td>107.7</td>
<td>120</td>
<td>41</td>
<td>81.7</td>
<td>0.758</td>
</tr>
<tr>
<td>Kobryn</td>
<td>Zhabinka</td>
<td>22.9</td>
<td>95.7</td>
<td>120</td>
<td>22</td>
<td>62.5</td>
<td>0.652</td>
</tr>
<tr>
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<td>Kobryn</td>
<td>22.9</td>
<td>95.7</td>
<td>120</td>
<td>24</td>
<td>57.2</td>
<td>0.598</td>
</tr>
<tr>
<td>Kobryn</td>
<td>Drahichyn-Horad</td>
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<td>107.7</td>
<td>120</td>
<td>30</td>
<td>67.0</td>
<td>0.622</td>
</tr>
<tr>
<td>Drahichyn-Horad</td>
<td>Yanov-Poleskiy</td>
<td>28.0</td>
<td>100.0</td>
<td>100</td>
<td>26</td>
<td>64.6</td>
<td>0.646</td>
</tr>
<tr>
<td>Yanov-Poleskiy</td>
<td>Pinsk</td>
<td>36.9</td>
<td>99.2</td>
<td>100</td>
<td>32</td>
<td>69.2</td>
<td>0.697</td>
</tr>
<tr>
<td>Pinsk</td>
<td>Luninets</td>
<td>58.4</td>
<td>99.4</td>
<td>120</td>
<td>50</td>
<td>70.1</td>
<td>0.705</td>
</tr>
<tr>
<td>Lida</td>
<td>Rozhanka</td>
<td>50.7</td>
<td>114.1</td>
<td>120</td>
<td>33</td>
<td>92.2</td>
<td>0.808</td>
</tr>
<tr>
<td>Rozhanka</td>
<td>Mosty</td>
<td>22.8</td>
<td>111.5</td>
<td>120</td>
<td>17</td>
<td>80.5</td>
<td>0.722</td>
</tr>
<tr>
<td>Mosty</td>
<td>Skidel</td>
<td>28.4</td>
<td>112.5</td>
<td>120</td>
<td>20</td>
<td>85.2</td>
<td>0.757</td>
</tr>
<tr>
<td>Skidel</td>
<td>Grodno</td>
<td>29.7</td>
<td>86.0</td>
<td>120</td>
<td>29</td>
<td>61.4</td>
<td>0.714</td>
</tr>
<tr>
<td>Grodno</td>
<td>Skidel</td>
<td>29.7</td>
<td>86.0</td>
<td>120</td>
<td>28</td>
<td>63.6</td>
<td>0.740</td>
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<tr>
<td>Skidel</td>
<td>Mosty</td>
<td>28.4</td>
<td>112.5</td>
<td>120</td>
<td>20</td>
<td>85.2</td>
<td>0.757</td>
</tr>
<tr>
<td>Mosty</td>
<td>Rozhanka</td>
<td>22.8</td>
<td>111.5</td>
<td>120</td>
<td>17</td>
<td>80.5</td>
<td>0.722</td>
</tr>
<tr>
<td>Rozhanka</td>
<td>Lida</td>
<td>50.7</td>
<td>114.1</td>
<td>120</td>
<td>33</td>
<td>92.2</td>
<td>0.808</td>
</tr>
<tr>
<td>Baranavichy-Pol.</td>
<td>Slonim</td>
<td>55.0</td>
<td>72.6</td>
<td>100</td>
<td>56</td>
<td>58.9</td>
<td>0.812</td>
</tr>
<tr>
<td>Slonim</td>
<td>Zelva</td>
<td>42.5</td>
<td>78.5</td>
<td>120</td>
<td>45</td>
<td>56.7</td>
<td>0.722</td>
</tr>
<tr>
<td>Zelva</td>
<td>Vaukavysk-Horad</td>
<td>25.9</td>
<td>101.8</td>
<td>120</td>
<td>27</td>
<td>57.6</td>
<td>0.565</td>
</tr>
<tr>
<td>Vaukavysk-Horad</td>
<td>Slonim</td>
<td>25.9</td>
<td>101.8</td>
<td>120</td>
<td>25</td>
<td>62.2</td>
<td>0.610</td>
</tr>
<tr>
<td>Slonim</td>
<td>Baranavichy-Pol.</td>
<td>55.0</td>
<td>72.6</td>
<td>100</td>
<td>59</td>
<td>55.9</td>
<td>0.771</td>
</tr>
</tbody>
</table>

The highest start-to-stop average ($V_s = 92.2$ km/h) was in the case of runs on Lida – Rozhanka section (in both directions), on which the maximum speed is 120 km/h, apart from Lida junction. The train in question (629/630 Minsk – Grodno) is relatively light, as its standard composition consists of 5 cars. The average speed utilisation ratio $I_s$ for all analysed BCz sections is, however, relatively low (0.715), mainly to due to the considerable weight of several trains, even in relation to the quite high power of TEP70 locomotive (2944 kW).

Case II – two types of diesel rolling stock on main line in Lithuania

All start-to-stop sections covered with long-distance trains on Vilnius – Klaipėda railway line have been selected for analysis. This line is not electrified (apart from Vilnius – Kaisiadorys section). There are two tracks on some parts of the line, mainly between Vilnius and Šiauliai, while the practically entire line between Šiauliai (Kužiai) and Klaipėda has only one track.

The maximum speed is generally 120 km/h on open sections (between stations) and 100 km/h through the stations, with some local restrictions due to track geometry (usually on curves with small radiuses).

Traditionally the Vilnius – Klaipėda fast trains were operated with conventional rolling stock – the sets of passenger cars hauled with TEP70 diesel locomotives [14]. The start-to-stop runs of these trains according to the LG timetable, valid for 2008/2009 period have been listed in Table 3.

In 2008/2009 period the highest values of speed utilisation ratio $I_s$ (0.904) was observed for Kėdainiai – Radviliškis section, for which the start-to-stop average equaled to 99.1 km/h. Another section with very good utilization of line parameters was the line stretch between Šiauliai and Telšiai (0.858). The average value of $I_s$ for all analysed sections was 0.778, i.e. better than in case of before mentioned sections from Belarus.

At present the Vilnius – Klaipėda fast trains are operated with 730M diesel motor units, manufactured by Pesa. These trains are usually composed of 2 three-car DMUs. The start-to-stop runs of trains according to the LG timetable, valid for 2018/2019 period have been listed in Table 4.

The maximum speeds on Vilnius – Klaipėda main line remained in principle the same, as they were 10 years
ago. However it is visible, that implementation of new rolling stock resulted in certain improvement of start-to-stop average speeds between consecutive stops. The mean value of speed utilization ratio $I_s$ equals to 0.842 and is significantly higher than in case of loco-hauled trains in 2008 (0.778). The best performance can be observed in the case of express service, running without stops on intermediate stations between Vilnius and Šiauliai. For this particular run the $I_s$ value is 0.915.

Table 3

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Distance ($l$) [km]</th>
<th>Harmonic mean ($V_{max}$) [km/h]</th>
<th>Maximum speed ($V_{max}$) [km/h]</th>
<th>Time ($t$) [min]</th>
<th>Start-to-stop average speed ($V_o$) [km/h]</th>
<th>Speed utilization ratio $I_s$</th>
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Table 4

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<th>Maximum speed ($V_{max}$) [km/h]</th>
<th>Time ($t$) [min]</th>
<th>Start-to-stop average speed ($V_o$) [km/h]</th>
<th>Speed utilization ratio $I_s$</th>
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<td>0.852</td>
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<td>99.2</td>
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<td>17</td>
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</table>

Case III – two types of diesel rolling stock on main line in Estonia

The analysis covered start-to-stop runs on Tallin – Tartu route. The only electrified section is located in Tallin suburban zone. The remaining part of the line is not electrified. The Tallin – Tapa section (77 km) has two tracks, while the rest of the line (between Tapa and Tartu) is equipped with single track only. The maximum speed is generally 120 km/h, with just a few local restrictions due to geometry of tracks.

Until 2013-2014 the passenger services on Tallin – Tartu line were operated with old generation DR1B DMUs (Fig. 3), dating from the Soviet times. The list of runs made with this kind of rolling stock is presented in Table 5.
Table 5
Selected runs of passenger trains operated DR1B DMUs on Estonian railway network in 2013 timetable

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Distance (l) [km]</th>
<th>Harmonic mean ( (V_{\text{max}}) ) [km/h]</th>
<th>Maximum speed (( V_{\text{max}} )) [km/h]</th>
<th>Time (( t )) [min]</th>
<th>Start-to-stop average speed (( V_s )) [km/h]</th>
<th>Speed utilization ratio ( I_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulemiste</td>
<td>Tapa</td>
<td>69.5</td>
<td>118.3</td>
<td>120</td>
<td>40</td>
<td>104.3</td>
<td>0.881</td>
</tr>
<tr>
<td>Tapa</td>
<td>Tamsalu</td>
<td>14.9</td>
<td>106.7</td>
<td>120</td>
<td>11</td>
<td>81.3</td>
<td>0.762</td>
</tr>
<tr>
<td>Tamsalu</td>
<td>Jogeva</td>
<td>50.2</td>
<td>119.6</td>
<td>120</td>
<td>28</td>
<td>107.6</td>
<td>0.900</td>
</tr>
<tr>
<td>Jogeva</td>
<td>Tartu</td>
<td>47.4</td>
<td>112.2</td>
<td>120</td>
<td>27</td>
<td>105.3</td>
<td>0.939</td>
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<td>Jogeva</td>
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<td>112.2</td>
<td>120</td>
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<td>0.874</td>
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<td>Tamsalu</td>
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<td>120</td>
<td>40</td>
<td>104.3</td>
<td>0.881</td>
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</tbody>
</table>

Since 2014 all passenger train services in Estonia are operated with modern FLIRT DMUs (designated as 2200, 2300 and 2400 series) (Fig. 3) [9]. The start-to-stop runs of these trains according to the Elron timetable, valid since April 2019 have been listed in Table 6.

Fig. 3 Two generations of diesel motor units in Estonia serving Tallinn – Tartu route: DR1 (2013) and Flirt DMU in 2018

The new generation diesel trains have very good accelerating abilities of 0.85 m/s². However, their top speed of 160 km/h is not utilised in day-to-day operation, because the 120 km/h maximum line speed is still in force on Estonian railway network. Nevertheless, the admirable accelerating makes the drivers capable to catch up even significant leeway’s between two stops [17].

The average speed utilisation ratio \( I_s \) for Tallinn – Tartu route has been increased from 0.751 to 0.862. The highest start-to-stop average speed significantly exceeds 100 km/h (as in the case of Jogeva – Tamsalu section, in both directions).

Table 6
Selected runs of passenger trains operated FLIRT DMUs on Estonian railway network in 2019 timetable

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Distance (l) [km]</th>
<th>Harmonic mean ( (V_{\text{max}}) ) [km/h]</th>
<th>Maximum speed (( V_{\text{max}} )) [km/h]</th>
<th>Time (( t )) [min]</th>
<th>Start-to-stop average speed (( V_s )) [km/h]</th>
<th>Speed utilization ratio ( I_s )</th>
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<tr>
<td>Ulemiste</td>
<td>Tapa</td>
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<td>40</td>
<td>104.3</td>
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<td>104.3</td>
<td>0.881</td>
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</table>

Case IV – modern electric motor units on Minsk – Brest main line in Belarus

The railway line section between Minsk and Brest forms the part of international corridor linking Moscow with Poland and the Western Europe. The section is 344.6 km long and equipped with two tracks. Traditionally the maximum speeds allowed on the line reflected its importance. According to the data from the year 2013, the maximum speed of 140 km/h is in force on several open sections, and even through some intermediate stations. The speed profile is, however, not uniform, there are numerous curves, on which the speed is limited to 90-100 km/h, mainly between Minsk and Baranavičy.

Since the year 2012, several regional and interregional trains in Belarus are operated with the new generation of electric motor units EP8 series, manufactured by Stadler. The start-to-stop runs of trains served with these EMUs according to the timetable valid from 1 June 2014 have been presented in Table 7.
Table 7

Selected runs of electric motor units on Belarussian railway network in 2014/2015 timetable

<table>
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<th>From</th>
<th>To</th>
<th>Distance ((d)) [km]</th>
<th>Harmonic mean ((V_{\text{max}})) [km/h]</th>
<th>Maximum speed ((V_{\text{max}})) [km/h]</th>
<th>Time ((t)) [min]</th>
<th>Start-to-stop average speed ((V_s)) [km/h]</th>
<th>Speed utilization ratio (I_s)</th>
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<td>Minsk-Centr</td>
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<td>Zhabinka</td>
<td>25.7</td>
<td>115.2</td>
<td>140</td>
<td>18</td>
<td>85.7</td>
<td>0.744</td>
</tr>
<tr>
<td>Zhabinka</td>
<td>Arančycy</td>
<td>46.7</td>
<td>138.8</td>
<td>140</td>
<td>22</td>
<td>127.4</td>
<td>0.918</td>
</tr>
<tr>
<td>Arančycy</td>
<td>Byaroza</td>
<td>32.1</td>
<td>135.1</td>
<td>140</td>
<td>16</td>
<td>120.4</td>
<td>0.891</td>
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<tr>
<td>Byaroza</td>
<td>Ivatsevichy</td>
<td>31.5</td>
<td>134.6</td>
<td>140</td>
<td>17</td>
<td>111.2</td>
<td>0.826</td>
</tr>
<tr>
<td>Ivatsevichy</td>
<td>Baranavichy-Pol.</td>
<td>70.3</td>
<td>115.8</td>
<td>140</td>
<td>46</td>
<td>91.7</td>
<td>0.792</td>
</tr>
<tr>
<td>Baranavichy-Pol.</td>
<td>Stowbtsy</td>
<td>66.5</td>
<td>121.2</td>
<td>140</td>
<td>38</td>
<td>105.0</td>
<td>0.867</td>
</tr>
<tr>
<td>Stowbtsy</td>
<td>Kojdanava</td>
<td>37.3</td>
<td>116.6</td>
<td>140</td>
<td>24</td>
<td>93.3</td>
<td>0.799</td>
</tr>
<tr>
<td>Kojdanava</td>
<td>Minsk-Centr</td>
<td>37.8</td>
<td>90.8</td>
<td>100</td>
<td>31</td>
<td>73.2</td>
<td>0.806</td>
</tr>
</tbody>
</table>

The utilisation of maximum speed is quite good, the average value of \(I_s\) is 0.830. The highest start-to-stop average speed (127.4 km/h) was achieved on Zhabinka – Oranchicy (Arančycy) section, for which running at practically constant speed of 140 km/h was possible. This is also the section with the best speed utilisation ratio of 0.918.

The express trains (branded as Interregional Business Class Trains), running non-stop between Minsk and Brest could achieve the average speed of 106 km/h, despite non-uniformity of speed profile on significant part of the line close to Minsk. It is noteworthy, that four years later, in 2018/2019 timetable, the journey time of mentioned trains was reduced from 3 hours 15 minutes to 3 hours 10 minutes (the average speed is 108.8 km/h).

4. Utilisation of Maximum Speed and Acceleration of Passenger Traffic

Novelty on the Central-Eastern European railways is the gradual replacement of overnight trains (composed of couchete and sleeping cars) by EMUs operated as daytime trains. The best examples can be shown in Belarus and Ukraine.

In Belarus such restructuring of passenger offer was possible after electrification of selected lines of BC network and simultaneous raising the maximum speed up to 140 km/h. The central location of the capital city of Minsk, at the intersection of main railway lines in Belarus, makes it very easy to start new daytime connections [1].

Similarly, in the year 2012, the fast daytime Intercity services were implemented on several routes in Ukraine. Some of these trains are operated with modern electric motor units manufactured by Hyundai and Skoda. They serve routes linking Kyiv with major regional centres as Lviv, Dnipro, Kharkiv.

Fig. 4 The express train from Homel to Minsk served with double Flirt EMU

It should be noted, that the importance of electrification of railways has grown recently [4]. After long time of stagnation, numerous electrification projects have recently been undertaken in several countries in Europe and overseas. The most recent examples of completed electrifications are the Minsk – Homel railway line in Belarus (Fig. 4) and the electrified international link between Lithuania and Belarus [15].

The best intercity services from various countries in Central-Eastern Europe operated with electric traction (Fig. 5) are presented in Table 8.
Examples of fast intercity services operated with electric motor units in 2018/2019 timetable

<table>
<thead>
<tr>
<th>Country</th>
<th>From</th>
<th>to</th>
<th>Distance [km]</th>
<th>Journey time [hh:min]</th>
<th>Commercial speed [km/h]</th>
<th>Max. speed [km/h]</th>
<th>Stops</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belarus</td>
<td>Minsk</td>
<td>Homel</td>
<td>300.2</td>
<td>2:54</td>
<td>103.4</td>
<td>140</td>
<td>0</td>
<td>EP³⁶°</td>
</tr>
<tr>
<td>Belarus</td>
<td>Homel</td>
<td>Minsk</td>
<td>300.2</td>
<td>2:54</td>
<td>103.4</td>
<td>140</td>
<td>0</td>
<td>EP³⁶°</td>
</tr>
<tr>
<td>Belarus</td>
<td>Minsk</td>
<td>Brest</td>
<td>344.6</td>
<td>3:10</td>
<td>108.8</td>
<td>140</td>
<td>0</td>
<td>E³⁶°</td>
</tr>
<tr>
<td>Belarus</td>
<td>Brest</td>
<td>Minsk</td>
<td>344.6</td>
<td>3:10</td>
<td>108.8</td>
<td>140</td>
<td>0</td>
<td>E³⁶°</td>
</tr>
<tr>
<td>Lithuania</td>
<td>Vilnius</td>
<td>Kaunas</td>
<td>104.3</td>
<td>1:06</td>
<td>94.8</td>
<td>120</td>
<td>1</td>
<td>E³⁵⁷⁵</td>
</tr>
<tr>
<td>Lithuania</td>
<td>Kaunas</td>
<td>Vilnius</td>
<td>104.3</td>
<td>1:02</td>
<td>100.9</td>
<td>120</td>
<td>1</td>
<td>E³⁵⁷⁵</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Kyiv</td>
<td>Lviv</td>
<td>572.0</td>
<td>5:09</td>
<td>111.1</td>
<td>160</td>
<td>2</td>
<td>HRCS²</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Lviv</td>
<td>Kyiv</td>
<td>572.0</td>
<td>5:07</td>
<td>111.8</td>
<td>160</td>
<td>2</td>
<td>HRCS²</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Kyiv</td>
<td>Kharkiv</td>
<td>485.0</td>
<td>4:45</td>
<td>102.1</td>
<td>160</td>
<td>3</td>
<td>HRCS²</td>
</tr>
<tr>
<td>Ukraine</td>
<td>Kharkiv</td>
<td>Kyiv</td>
<td>485.0</td>
<td>4:45</td>
<td>102.1</td>
<td>160</td>
<td>3</td>
<td>HRCS²</td>
</tr>
</tbody>
</table>

Implementation of modern diesel motor units can lead to significant journey time reductions. These reductions are particularly large in relation to journey times achieved with traditional sets of cars hauled with diesel locomotives. For example the journey time for the loco-hauled G-category train operating between Klaipeda and Vilnius (376 km) was 4 hours 30 minutes (2010/2011 timetable). At present (2018/2019 timetable) the G-category train operated with 730M class DMU needs 4 hours 12 minutes to cover the same route, with the stops on 8 intermediate stations, as 8 years ago. It is noteworthy that the maximum train speeds allowed on the line remained generally the same as they were in the year 2010. Therefore the 18 minutes of journey time improvement can be attributed to better utilisation of the permitted speeds by modern rolling stock, mainly thanks to better acceleration.

Replacement of old generation of DMUs with the new ones can also bring significant improvement, not only in terms of passenger comfort, but also in travel time. Good example is the case from Estonian railways. In 2013 the Tartu – Tallin main line was served with old DR1B diesel motor units and the shortest journey time was 2 hours 13 minutes. Just one year later, after implementation of modern DMUs, the journey time at that route was reduced to 1 hour 57 minutes (with unchanged stopping pattern) (Table 9).

Examples of fast intercity services operated with diesel motor units

<table>
<thead>
<tr>
<th>Country</th>
<th>From</th>
<th>To</th>
<th>Distance [km]</th>
<th>Journey time [hh:min]</th>
<th>Commercial speed [km/h]</th>
<th>Max. speed [km/h]</th>
<th>Stops</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belarus</td>
<td>Minsk</td>
<td>Hrodna</td>
<td>337.0</td>
<td>4:08</td>
<td>81.5</td>
<td>120</td>
<td>3</td>
<td>DP-3</td>
</tr>
<tr>
<td>Belarus</td>
<td>Hrodna</td>
<td>Minsk</td>
<td>337.0</td>
<td>4:03</td>
<td>83.2</td>
<td>120</td>
<td>3</td>
<td>DP-3</td>
</tr>
<tr>
<td>Estonia</td>
<td>Tallin</td>
<td>Tartu</td>
<td>190.0</td>
<td>1:55</td>
<td>99.1</td>
<td>120</td>
<td>5</td>
<td>FLIRT</td>
</tr>
<tr>
<td>Estonia</td>
<td>Tartu</td>
<td>Tallin</td>
<td>190.0</td>
<td>1:57</td>
<td>97.4</td>
<td>120</td>
<td>5</td>
<td>FLIRT</td>
</tr>
<tr>
<td>Estonia</td>
<td>Tallin</td>
<td>Narva</td>
<td>209.6</td>
<td>2:14</td>
<td>93.9</td>
<td>120</td>
<td>6</td>
<td>FLIRT</td>
</tr>
<tr>
<td>Estonia</td>
<td>Narva</td>
<td>Tallin</td>
<td>209.6</td>
<td>2:14</td>
<td>93.9</td>
<td>120</td>
<td>6</td>
<td>FLIRT</td>
</tr>
<tr>
<td>Latvia</td>
<td>Riga</td>
<td>Daugavpils</td>
<td>217.8</td>
<td>2:39</td>
<td>82.2</td>
<td>120</td>
<td>5</td>
<td>DR1AC</td>
</tr>
<tr>
<td>Latvia</td>
<td>Daugavpils</td>
<td>Riga</td>
<td>217.8</td>
<td>2:42</td>
<td>80.7</td>
<td>120</td>
<td>6</td>
<td>DR1AC</td>
</tr>
<tr>
<td>Lithuania</td>
<td>Vilnius</td>
<td>Klaipeda</td>
<td>376.2</td>
<td>3:48</td>
<td>99.0</td>
<td>120</td>
<td>1</td>
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<tr>
<td>Lithuania</td>
<td>Klaipeda</td>
<td>Vilnius</td>
<td>376.2</td>
<td>3:58</td>
<td>94.8</td>
<td>120</td>
<td>3</td>
<td>730ML</td>
</tr>
</tbody>
</table>

5. Conclusions

Railway infrastructure is the long-standing asset, which is very difficult to change. Significant improvements of its components (tracks, turnouts, bridges, overhead catenary lines, signalling systems) usually require huge capital investment. Therefore, it is absolutely crucial to make best possible use of existing infrastructure. In particular it is
necessary to utilise the permitted speeds with the aim to offer the best possible journey times to the public. The results of research conducted in IK show, that the most effective utilisation of line capabilities can be achieved in the case of motor units (EMUs and DMUs) with distributed power and high power-to-weight ratio. They confirm the previous studies concerning the utilisation of the maximum speed on the Polish railway network, in particular by EIP trains of PKP Intercity [5].

The railways from Central and Eastern European countries are struggling to offer better passenger service, which could be competitive to travel by car or by bus. Several accelerated passenger train services have been recently implemented in Estonia, Lithuania, Belarus and Ukraine. Some of these trains are operated with electric traction, while the others make use of diesel traction.

References

The Impact of the Dynamics of a Train Ride in a Curve and its Effect on a Superstructure

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Abstract

This article analyses a ride of railway vehicles in a curve and their effect on a superstructure. In a specific example we demonstrate negative dynamic forces affecting a railway track, and we assess the ride of a railway tractive vehicle using an electronic recording device MIREL RM 1 in a tractive vehicle.

KEY WORDS: digital trace, railway transport accident, investigation, recording device MIREL RM 1

1. Introduction

In context of other modes of transport, the railway transport is (thanks to its position) a significant subject in the transport market; under the conditions of the Slovak Republic it represents approx. 18.4% of the total volume of goods transportation and each transport interruption causes problems for carriers to meet delivery times for their customers. A keeper of a railway infrastructure has a primary task - to care for the superstructure so the safety and reliability of railway transport is not reduced due to collinear forces which arise in the process of transport on rails. Dynamic forces, which arise, vanish or change their point of application, size and direction in the contact point between a wheel and a rail in the movement of a railway tractive vehicle, feature a provable effect on the superstructure. An insufficient care for the superstructure may result in negative operational states which may lead to a transport accident [3, 4].

2. Description of an Arose Accident Event on a Railway Track

In order to analyse an accident event it is necessary to note that it has been evaluated using digital traces which comprise any information carrying a value of evidence which is stored, transferred or otherwise kept in a digital form. This technology was used in this example, too [1, 10].

In real life the railway police service clarifies and also deals with accidents qualified as offences according to the Act No. 513/2009 Coll. on Railroads, Act No. 514/2009 Coll. on the Transport on Railroads, Act No. 372/1990 Coll. on Offences with their subject matters stated in § 108 Paragraph 1 Article a to g of the Act No. 513/2009 Coll. on Railroads, as well as in § 42 Paragraph 1 Article a to k of the Act No. 514/2009 Coll. on the Transport on Railroads [2].

It is also due to these procedures of proving the guilt and drawing the criminal liability against a particular person why outputs of a registration device - speedometer MIREL RM 1 are used. It is a device constructed for the application in railway tractive vehicles of all tractions. Its basic unit functionally ensures all operational functions of the registration speedometer MIREL RM 1:

- Measurement and filtration of pulses from a pulse speed sensor;
- Speed calculation;
- Calculation of run distance;
- Evaluation of the movement direction;
- Archiving of required quantities;
- Scanning of binary and analogue inputs;
- Controlling of binary and analogue outputs;
- Communication with indicating and identifying units in cabs;
- Communication with connected cooperating devices of HDV;
- Auto-diagnostics;
- Indication on the front panel [2].

An accident event requires performing an analysis and evidence of an emergency event on a single track in order to find out the reason for derailment of the rail car 812.052-9 during the ride of the passenger train Os 6611 of ZSSK company which happened on February 14, 2007 at 15:37 in the passing point Zlatno on 28.637 km.

The rail car 812 is a modernised two-axle railway tractive vehicle with a rear-axle drive. Technical parameters can be found in Table 1. The automatisation method of gearing, braking and controlling of the engine and gear box interoperation is provided with the electronic controlling system MIREL 812. The cabinet of the rail car has two cabs for a train driver. The compartment for passengers is soundproof and heated with an independent heating device. The rail car is intended for a light passenger transport with maximum two connecting rail cars, class 011, and for a long ride with a maximum speed [8, 9].
3. Analysis of the Os 6611 Train Ride on the Basis of the Analysis of Attachment 1 to Attachment 4

At the head of the train there is the first railway tractive vehicle HDV 1, 812.062-8, which is followed with an attached vehicle 011.883-6, and behind it there is the second railway tractive vehicle HDV 2, 812.052-9, which was derailed on the 28.637 km in the passing point Zlatno on a single track Utekáč stop - Lučenec.

An illustrative arrangement of Os 6611 train from February 14, 2007 is in Fig. 1:

The riding technique of the first railway tractive vehicle HDV 1: Fig. 3 and Fig. 4 represent the start of HDV 1 and its stop. The driver was alert; he was operating the Alert button. After the start he was reducing the speed while passing the curve from the max. speed 38 km.h⁻¹ down to stopping the train using a straight brake.

The riding technique of the second railway tractive vehicle HDV 2: Fig. 5 and Fig. 6 represent the ride of HDV 2. This vehicle was in a banking mode, it was not remotely controlled from HDV 1. This HDV 2 was derailed at 15:37:28 which is read through the activity of the straight brake, and it was completely stopped at 15:37:34, i.e. 6 seconds after activating the straight brake. The driver was applying the straight brake from the speed 28 km.h⁻¹ at the time of putting on the brake at 15:37:28.

HDV 2 stopped pushing - it stopped working as a banking locomotive at 15:37:24, i.e. 4 seconds before applying the straight brake. The vehicles were stopped after 6 seconds. It was 15:37:34.

This vehicle served only as an attached rail car, i.e. without a driving traction power, from 15:37:24 to the time of derailment, i.e. to 15:37:34. It definitely did not push the connecting vehicle at the time of derailment. This statement is supported with the course of traction characteristics at the traction gear box TrPr in the Attachment 4 - green line.

Based on the analysis of the recording device of both tractive vehicles HDV 1 and HDV 2 it is reasonable to claim that the riding technique was standard, no way special or otherwise affected with an incorrect function of both HDVs’ operation. The reason for the driving axle of HDV 2 to leave rails was not a wrong riding technique of the driver. The only possible answer to the derailment matter is the state when HDV 2 stopped working as a pusher HDV and began to behave as a connecting vehicle - a hauled one. Just due to a possible dynamic impact in the joint of individual rail cars of
a train the effect of the pulling force of HDV 1 represents the factor which caused the following: both the connecting vehicle and HDV 2 were pushed to the inner side of the rail in a curve with the pulling force. The effect of this collinear force, which can be divided into a straight direction and radial direction in the train ride from the vector point of view, is as follows. This radial component of the force pushed on the inner rail in the curve of the track and since rails were not mounted tightly enough on sleepers, there happened their radial shift which caused the outer wheel of the front axle of HDV 2 to fall inside between the rails. The graphical representation of the incident can be seen in Fig. 2.

It was not possible to verify the radial shift on the derailment site since no measurement was performed, however, results of measuring the gauge and the versed track there on the accident site qualify us for such a conclusion [8, 9].

The legend of the decomposition of the driving traction force:

![Fig. 2 Vector Decomposition of the Driving Traction Force onto Vehicles [8, 9]](image)

4. Analysis of a Mismatch of Time and Kilometrical Differences according to the MIREL RM 1

**HDV 1, 812.062-8, railway tractive vehicle**

The tachometer - speedometer of the vehicle provided this data:

- HDV 1 started to move at: 15:36:34 (Note: 15th h., 36th min., 34th s.)
- HDV 1 stopped at: 15:37:19
- Running time of HDV 1: 26 s + 19 s = 45 seconds of running

According to data on the tachometer:

- at the beginning of the ride there was the data: 13,391.176 km
- at the end of the ride, at the stop time: 13,391.426 km

HDV 1 ran the distance: 13,391.426 – 13,391.176 = 0.250 km = 250 m

**HDV 2, 812.052-9, railway tractive vehicle (as a tractive vehicle as well as a banking locomotive)**

The tachometer - speedometer of the vehicle provided this data:

- HDV 2 started to move at: 15:36:48 (Note: 15th h., 36th min., 48th s.)
- HDV 2 stopped at: 15:37:34
- Running time of HDV 2: 12 s + 34 s = 46 seconds of running

According to data on the tachometer:

- at the beginning of the ride there was the data: 58,713.634 km
- at the end of the ride, at the stop time: 58,713.869 km

HDV 2 ran the distance: 58,713.869 – 58,713.634 = 0.235 km = 235 m

**Evaluation of the mismatch:**

- The difference in running times: HDV 1 was running for 45 seconds
  HDV 2 was running for 46 seconds
- The difference in time shown on measuring instruments MIREL is 1 second which may be caused with the degree of accuracy these instruments measure data with. There was an accord of both vehicles riding, they were joint and were running like a train.
- The difference in the run distance: HDV 1 ran the distance 250 m
  HDV 2 ran the distance 235 m
The difference in the run distance on a 250 m long railroad is 15 m (250 m - 235 m = 15 m).

This difference can be explained through a demonstration of two prerequisites for such a disproportion:

Firstly, the setting of the run distance must be configured after each modification of the diameter of the driving wheel in the driving axle while its lathe-turning on a wheel lathe machine in a railway depot. If this setting was not configured precisely enough, the instrument could have showed different values, when the distance 250 m allows for the difference of many meters; however, this prerequisite explains it only partially.

The second prerequisite using which we justify this difference as possible and precise enough is the fact that HDV 1 was in the mode of a railway tractive vehicle in this train, and due to the ride in a curve as well as the ride in a straight direction it could have led to slipping of the driving axle in HDV 1. Then this value does not seem to be unreasonably big.

Since HDV 2 was not active during the entire train run till its derailment, i.e. it did not generate a traction force, it was not possible for the driving axle of the second vehicle to slip for such a long time, and it was only hauled in the train...
on the given railroad. Based on the analysis of the electronic device this HDV 2 was active for 28.8 seconds. Since the overall running time of the train is found via the analysis of the electronic device Mirel and it has the value of 46 seconds then HDV 2 served as a hauled vehicle for 17.2 s, i.e. there occurred no slipping of the driving axle, which seems to be a more probable reason for the difference in the run distance of both HDVs. The slipping phenomenon of a driving wheel - axle on a rail is a natural phenomenon in the operation of adhesive railways when the traction force is transferred only with a force called adhesion, i.e. a contact force between the wheel and the rail. We must not forget that the accident happened in the afternoon in February, thus there could have been ice as well as snow and/or water in the contact point of the wheel and the rail; in such a case the coefficient of adhesion is much smaller than in case the contact point of the wheel and the rail is dry and clean. Since the adhesion coefficient is proportional to the size of the force being transferred in the contact point of a wheel and a rail, it explains this difference quite precisely and satisfactorily [5].

Fig. 5 Attachment 3 Railway tractive vehicle 812 052-9 - start: speed of the driving vehicle \( v = 1 \text{ km.h}^{-1} \) indicated in blue. The position of a vertical line in the figure between 15:36:00 and 15:37:00. Connecting railway tractive vehicle which was derailed - start [8, 9]

Fig. 6 Attachment 4 Driving vehicle 812 052-9 - The connecting railway tractive vehicle had the brake applied at the time of turning the straight brake on - it only ran as a connected vehicle without any driving force - as a hauled vehicle - see traction gear box (TrPr) was not engaged [8, 9]
5. Conclusion

The analysis unambiguously proved that the maintenance of the railway track was not performed in accordance with the regulation "The Head's of Infrastructure Department Measure No. 2/2004 to the Inspection of the Superstructure and Substructure State", which was issued under the No. 75/2004-O 430/Ot on December 14, 2004, which could have removed shortcomings found out in a subsequent inspection of the track, and it was required to replace 1,590 pieces of damaged sleepers on that accident site [6, 7].

The first HDV is affected with a radial force only and this is the force which emerges in the point of joint of the connecting vehicle to this HDV 1, i.e. a force at the end of HDV 1 in the joint point with the connecting vehicle at a coupling - drawbar. All other vehicles, active or hauled ones, or sham ones, are always affected with two components of these radial forces, namely forces by the vehicle in front of the given vehicle, and by the vehicle behind it. In case of HDV 2 there was only the effect of the connecting vehicle in front of it. This force component caused the sheering of the rail and the over-fall of the front axle of HDV 2 with its left wheel in-between the rails, and with its right wheel leaping onto the upper surface of the rail, and the following derailment of the entire front axle of HDV 2.

In accordance with the representation in Fig. 2 we can claim that due to the termination of the pulling force effect on HDV 2 when this pulling force acts on the left rail, its inner part, and the rail itself with its curvature creates the resistance during the ride of HDV 2, there happens a change of the pulling force effect onto HDV 2 in that moment when it stops pushing and its impact on the superstructure changes. The change happens because afterwards there begins the effect of the drawbar pull of HDV 2 by the pulling force of HDV 1 and the front axle begins to push on the inner edge of the upper surface of the rail a while after HDV 2's traction gear box turns off. This will change the force thrust-drift ratios on the inner rail. And this phenomenon was also observed on the superstructure where accident experts detected an over-fall of the left wheel of the axle on the outer rail inside in-between rails.

This radial motion of the front axle was possible only thanks to the fact that the rails allowed it, i.e. they could have been shifted radially in a value which enabled the over-fall of the wheel inside between the rails. Thus, the reason is a loosed rail on the site of derailment due to a weak anchoring at a sleeper. This can be considered a crucial moment why the derailment happened exactly there and did not occur in case of other trains. Apparently this phenomenon was caused with the dynamic component in the traction effect. If the rail was mounted tightly enough, then there would be no derailment.

This proof can clearly be seen in the Attachment 4, where the time interval between the moment when the traction gear box stopped acting and the traction force in case of HDV 2 was generated - HDV was pushing a connecting vehicle in front of it, and the moment the continuous brake of HDV 2 was turned on, was 4.4 s according to this figure. At this time there happened a change of forces effects on rails from the left rail in the direction of the running to the right rail. If the cause of the derailment was the riding technique of HDV 2, then thanks to its traction force it would climb up the outer rail in the curve, and not the inner rail, as it happened here and as it has been proved.

References:

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Assessment and Modelling of Transport Demand in Public Passenger Bus Transport

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Abstract

The article is focused on assessment of a priori as well as posterior transport demand after public passenger bus transport. This is a prior input for planning and realization of public transport. Basic requirements of individual subjects participating on public passenger transport are defined. Mobility management and marketing approach define basic problems needed to be solved. There are basic methods of transport modelling able to be applied within demand assessment presented in the article. A part of assessment process is presented by the case study focused on trip generation in agglomeration of Hradec Králové and Pardubice in the Czech Republic.

KEY WORDS: mobility management, sustainable mobility, transport demand, transport demand modelling, transport services, transport surveying.

1. Introduction

Surveying of a priori as well as posterior transport demand is one of initial steps by planning and realizing of public passenger transport. A priori demand after transport is related to all potential passengers. Passengers using public transport are representing posterior demand. There are requirements on transport of students to schools and on transport of employees to work. Requirements on transport to doctors, offices and for shopping, culture or sport are typical as well. The transport authority can be also considered as a customer of transport operators although this point of view is not common. The transport authority signs a contract for the provision of passenger transport services with individual transport operators. The transport authority provides compensations for a service in public intent. The Ministry of Transport is also an important customer. This ministry provides compensation of loss for pupils’ and students’ fare discounts (75% of standard fare in the case of the Czech Republic). Total value of this compensation is about CZK 500,000,000 per month. The organisation authority on an integrated transport system (transport association) belongs to important customers of transport operator if the integrated transport system is operated.

2. Various Points of View on Transport Demand in Public Passenger Transport

Transport demand is depended on several factors. The proposal of integrated system of decision-making and general methodology for improvement of public transport planning in countryside areas are mentioned by [1]. Transport demand in the areas surrounding the city of Pilsen in the Czech Republic is solved by [2]. Experience with relation of social and economic sustainability of transport regarding accessibility of public transport in countryside areas is mentioned by [3] for the case of the Czech Republic. Social aspect of transport demand is often related to ensuring of barrier-free accessibility for people with reduced mobility. The article [4] is focused on this issue in detail. Socio-economical point of view on transport demand is presented by [5] for the case of countryside area of Gemer located in the Slovak Republic. Transport needs, rules of transport market organisation, required level of transport services as well as funding of transport are mentioned by [6] for Koszalin (Poland). Analysis of public transport and assessment of future transport demand in the city of Zadar (Croatia) are characterized by [7]. The proposal of model focused on transport demand prognosis (expressed by number of passengers) using transport data from previous time periods is mentioned by [8]. Aspects of the role of railway within public passenger transport system can be found in [9].

Collecting of mobility information based on spatial analysis with support of GIS is characterized by [10]. Possibility of real-time collecting of data about actual numbers of passengers in public transport system is discussed by [11]. Microscopic simulation of demand after transport of seniors and transport of people with reduced mobility in relation to plan of rolling stock circulations is characterized by [12]. The article [13] is focused on interface between a prior transport demand and posterior transport demand in the point of view of reachability of destination and frequency. Method for network evaluation of timetable is introduced.

Some Internet websites for transport time schedules can be applied for surveying of a priori transport demand as well. Information system of IDOS can be mentioned as an example. This system is applied in the Czech Republic. Time schedules of trains transporting passengers, long-distance as well as regional bus services and of urban public transport in individual cities are collected in this system. It is possible to use combination of transport modes for one searched journey (trip). So, it is possible to search the whole connection e.g. from selected stop of urban public transport in city of origin to the selected stop in city of destination, including transfer between cities by train or bus. Requests after
connections can be possibly surveyed, because they can be related to a priori transport demand [14]. Issues of information content and of quality aspects of websites of transport operators are discussed by [15].

Other software tools can be applied for assessment of posterior transport demand as well. The Automatic passenger counting (APC) tool provided by the company BUSE s.r.o. is one of them. The BS 300 on-board computer or BS 308 recorder unit gets accurate data from APC sensors or the on-board computer calculate them from vehicle load data [16]. Devices for issuing and printing of tickets produced e.g. by Mikroelektronika company [17] can be applied for assessment of posterior demand including surveying for price of fare and used payment method (cash, card).

Analysis of data about surveying of passengers, tools for improvement of organization of public passenger transport and the methodology for selection of strategy for regional passenger transport in Kaunas in Lithuania is presented by [18].

3. Requirements of Individual Subjects in Public Passenger Transport

Fundamental requirements in mobility are time, cost and comfort. Fulfilling of requirements on required level is a basic presumption put on public transport to reach the target. These requirements are divided according to requiring subjects as requirements of:

- current passengers;
- potential passengers;
- transport authority (contractor for public transport);
- organization authority of integrated transport system;
- transport operators;
- public.

Requirements of individual subjects on public passenger transport are displayed in the Fig. 1.

![Fig. 1 Sources of requirements on public passenger transport](image-url)

Some of these requirements are the same or similar by all participating subjects (e.g. maximal level of transport safety, maximal accuracy of operation according to time schedule). The others can be specific and different, e.g. price (fare) is required to be minimal by passengers, but the same price can be maximized in the point of view of income of transport operator. For instance, the difference can be also in demanded and supplied time locations of individual transport services. It can be caused e.g. by effort about as most as effective circulation of vehicles.

4. Sustainable Mobility and Mobility Management

Sustainable mobility must be ensured. The field of public passenger transport is not an exception. It must be continuous and uninterrupted process. It is necessary to design and to operate public transport system according to current as well as according to anticipated future requirements for ensuring of sustainable development. Public passenger transport must be developed in the way that each passenger can have possibility to travel. It is not possible to presuppose in an automatic way that everybody can be holder of a driving license for passenger car. Driving is not allowed by children (young people), but also by some of other adult persons, e.g. due to health reasons. Issues of ability to drive a car by older drivers in regard to health conditions are also often discussed. The life expectancy increases.

Mobility management is focused on mobility of individuals. The scope of mobility management is consisted of all activities related to transport behavior according to sustainable development.

Characteristic features of these activities are:
- voluntariness – positive motivation is applied rather than restrictions to influence the behavior;
- application of marketing, providing information for target groups of inhabitants, application of improved controlling methods together with investments of smaller extent especially on the local level;
- incorporation of companies and institutions into the process of change; motivation of employees, customers and visitors of institutions;
partner cooperation with all the subjects from public as well as private sectors interested in transport issues. The new set of techniques of transport planning has been introduced by the system of mobility management. These techniques are based on providing of information, coordination and organizing. The aim is to decrease number of trips and to limit the need to use individual cars. People may be motivated to using of sustainable transport modes.

Mobility and sustainable development are closely related to the issues of living, employment policy, structure of school system, ensuring of basic medical care, location of authorities and development of trade and services. Solution of these basic transport needs is influencing organization and the way of ensuring their accessibility in transport point of view. There is an effort to search for answers on following basic questions within marketing-oriented approach.

- Who is travelling, for who is or will be transport provided?
- When is needed to travel (time position of transport demand)?
- Why is needed to travel (purpose of trip)?
- From where to where is needed to travel (origin and destination of trip)?
- How many passengers are or will be using transport?

Mobility management is related to assessment of passengers’ requirements. It is focused on a prior transport demand. These requirements are considered as inputs into the system of public transport. Data related to posterior demand are suitable especially for calibration of models.

5. Possibilities of Transport Demand Modelling

Modelling of demand after public passenger transport takes a complex part of transport modelling. Data for this modelling can be based on:

- transport surveys of some kinds (focused on passengers living in modelled area, on passengers incoming to modelled area and on passengers transiting in this area or staying here for a limited time only);
- available statistical databases (like statistics of sold tickets or data surveyed by public census);
- application of technical devices installed in vehicles;
- general data can be specified by application of empirically defined procedures (methods for trip generation, trip distribution or modal split).

6. Transport Survey

Accurate data about transport flows can be collected in the way of a complex transport survey. The survey is valid to a given time horizon only and transport irregularities (daily, monthly, seasonally) must be reflected by the organization of the transport survey. Transport surveys focused on a priori transport demand can be made in households, on Internet, at schools, in firms or in individual municipalities. Data about posterior transport demand can be collected on board of vehicles or at public transport stops.

Stratified selection sometimes called as two-layer selection can be applied by transport survey in municipalities. Surveyed area (basic set) is divided into different parts according to categories of municipalities (e.g. by population). Finally surveyed units (municipalities) are selected from these subsets to represent each part (e.g. municipality with defined number of inhabitants). Determination of survey extent marked as $n$ is next important step. The aim is to reach results on defined quality level able to be generalized with the confidence interval like 90%, 95% or 99%. It is suitable if the ratios of passengers (e.g. ratio of passengers from countryside, ratios according to age and ratios of everyday and irregular passengers) surveyed within the transport survey will be in proportions to the structure of the basic set (consisted of all passengers). Extend of selection of $n$ is depended also on the way of surveying. The survey can be realized in the way:

- with return of all questionnaires – asking person gives and takes the questionnaire to/from a respondent in personal way. He can help to understand the surveyed questions as well. Survey extent of $n$ is set by the formula (1) in this case:

$$n = \frac{t^2 \cdot \sigma}{d^2};$$  

(1)

- without return of all questionnaires – number of returned and filled questionnaires can be between 15% and 30% of distributed questionnaires. Extent of survey of $n$ is set by the formula (2) in this case:

$$n = \frac{t^2 \cdot \sigma^2 \cdot N}{t^2 \cdot \sigma^2 + (N-1) \cdot d^2},$$  

(2)

where $n$ – extent of survey (number of elements in selected subset); $t$ – reliability coefficient based on the level of confidence; $\sigma$ – standard deviation; $d$ – acceptable error of subset (expressed by %); $N$ – extent of basic set.

The results of a complex transport survey focused on transport behaviour made in the city of Pardubice (Czech Republic) from 1 September 2017 to 1 September 2018 are: 33% of inhabitants are using individual car; 31% are walking;
22% are using urban passenger public transport and 14% is going by bike within the city of Pardubice [19]. Transport routes of passengers were determined by transport survey as well.

7. Utilizing of Accessible Statistic Data

Posterior transport demand can be modelled for example by using of data from cashiers for issuing and printing of tickets. There are examples of posteriory demand data in the Tables 1 and 2. EM-Test cashier (placed in bus) and evaluation by the software DHV BUS 5 were applied by collecting of data. Posterior demand is referred (expost analysis).

<table>
<thead>
<tr>
<th>Day</th>
<th>Stop number</th>
<th>Municipality</th>
<th>Location in municipality</th>
<th>Number of services</th>
<th>Number of boarding passengers</th>
<th>Income (CZK)</th>
<th>Number of alighting passengers</th>
<th>Output – income (CZK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6.2018</td>
<td>37852</td>
<td>Ústí n. Orl.</td>
<td>aut. nádr.</td>
<td>240</td>
<td>678</td>
<td>9818</td>
<td>541</td>
<td>7791</td>
</tr>
<tr>
<td>1.6.2018</td>
<td>34431</td>
<td>Svojanov</td>
<td>u mostu</td>
<td>10</td>
<td>15</td>
<td>180</td>
<td>5</td>
<td>55</td>
</tr>
</tbody>
</table>

Number of passengers and incomes expressed for individual transport relations between 2 stops per day

<table>
<thead>
<tr>
<th>Day</th>
<th>Line</th>
<th>Service</th>
<th>Stop</th>
<th>Municipality 1</th>
<th>Locality 1</th>
<th>Municipality 2</th>
<th>Locality 2</th>
<th>Number of passengers</th>
<th>Income (CZK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6.2018</td>
<td>700993</td>
<td>22</td>
<td>37852</td>
<td>Ústí nad Orl.</td>
<td>aut. nádr.</td>
<td>Lanškroun</td>
<td>aut. nádr.</td>
<td>34</td>
<td>777</td>
</tr>
<tr>
<td>1.6.2018</td>
<td>700906</td>
<td>12</td>
<td>31770</td>
<td>Skuteč</td>
<td>Botana</td>
<td>Lužé</td>
<td>aut. st.</td>
<td>116</td>
<td>1177</td>
</tr>
</tbody>
</table>

Next possible way how to asses transport demand is analysis of (demanded) connections searched by using of electronic timetables (e.g. Internet timetable information systems). Disadvantage is that it is usually not possible to identify if the trip was made or not. Passengers search sometimes for connections which they will not use, e.g. for connections substituting possibly lost connection (originally searched). They can search for the same connection more times as well. The exception will be the case if this searching will be directly connected to ticket purchasing. This must be considered by this typical example of assessment of a priori transport demand.

8. Utilization of Technical Devices Installed in Vehicle

Technical devices installed in vehicles allow to register technical features (oil pressure, temperature of cooling liquid, level of diesel) as well as features interesting in the point of view of transport services (actual velocity, vehicle load, number of stamped tickets, deviations from timetable). The programme named as BUSE can be an example. It can be applied in buses [16]. Result of measurement is in Fig. 2.

Fig. 2 Output of service evaluation provided by on-board computer BUSE

Modelled region is divided into zones (areas) by modelling of transport demand. Each zone is represented by one point named as centroid. Following process can be divided into these phases: trip generation, trip distribution, modal split, traffic assignment.

**Trip generation** – the aim of this phase is assessment of the numbers of trips with origin and destination in each individual zone and in given time frame. The results are based on factors determining transport demand. It is realized in the way of transport survey or in the way of multiple regression analysis by using of existing data or surveys finished in the past. The aim is to define a set of equations representing production and attraction of zone. Production and attraction are depended variables expressing how many trips have origin and destination in given zone. Trips can be divided according to purpose with relation to place of living (trips to work, school etc.) and without this relation (trips for leisure activities etc.). Demographic variables like number of inhabitants, students, retail shops or workplaces (in zone) are applied as independent variables in these equations. These equations can be often determined by using of linear regression analysis, see formula (3). The regression constant of $k$ can be discussed, because it can provide some value of production or attraction also for specific zones with the values of independent variables equal to 0. On the other hand, possible positive impact on accuracy of results can be seen in the chapter 10 as well. Specific cases (zones) with the value of 0 by independent variables can be excluded in advance.

$$y = b_1 \cdot x_1 + b_2 \cdot x_2 + \ldots + b_n \cdot x_n + k,$$

where $y$ – depended variable (number of trips in assessed time period); $b_1, b_2, \ldots, b_n$ – regression coefficients; $x_1, x_2, \ldots, x_n$ – independent variables; $k$ – regression constant.

The value of forecasted traffic volume in individual zones $D_i^f$ can be determined e.g. by application of regression coefficients. Forecasted values of number of inhabitants and number of workplaces can be applied, see formula (4). It is presupposed that the relation between depended and independent variables will not be changes in the future.

$$D_i^f = a + b \cdot Q_i^f + c \cdot P_i^f,$$

where $D_i^f$ – forecasted traffic volume in the zone of $i$; $Q_i^f$ – forecasted number of inhabitants in the zone of $i$; $P_i^f$ – forecasted number of workplaces in the zone of $i$; $a, b, c$ – regression constant.

**Trip distribution** – this phase is related to analysis of routing and to determination of traffic relations between zones. Origin-destination matrix (OD matrix) is the result. Intensities of traffic flows between all pairs of zones are expressed. Analogic and synthetic methods are applied. Analogic methods are based on trend analysis and on the presumption that future traffic situation will be analogic to the current one, see formula (5).

$$d_{i,j} = d_{i,j} \cdot f(k),$$

where $d_{i,j}$ – forecasted volume (intensity) of traffic flow from the zone of $i$ to the zone of $j$; $d_{ij}$ – current intensity of traffic flow from $i$ to $j$; $f(k)$ – function of coefficients of growth.

Synthetic methods are applied within trip distribution phase in the case that current OD matrix is not at disposal. Transport gravity model can be applied for larger areas like regions, states etc.; see formula (6).

$$d_{ij} = k \cdot \frac{P_i A_j}{f(c_{0})},$$

where $d_{ij}$ – current intensity of traffic flow from the zone of $i$ to the zone of $j$; $k$ – constant (parameter of transport gravity model); $P_i$ – production of origin zone of $i$; $A_j$ – attraction of destination zone of $j$; $f(c_{0})$ – function of traffic resistance based on $c_0$ – costs for transport between zones of $i$ and $j$ (usually expressed by money).

**Modal split** – the volume of traffic flow between each pair of transport zones is divided between individual transport modes as ratio (percentage). The LOGIT model is typical tool applied for modal split. It is a model based on willingness to pay for more expensive alternatives. Distribution of passengers between more alternatives of routes is provided in macroscopic point of view, see formula (7).

$$P_r = \frac{e^{-\varphi c_i}}{\sum_{i=1}^{n} e^{-\varphi c_i}},$$

where $p_r$ – probability of selection of an alternative of $r$; $\varphi$ – parameter expressing willingness to select more expensive alternatives; $c_i$ – costs for an alternative of $i$; $n$ – number of considered alternatives.
Traffic assignment – specific routes for transport are determined within this model phase. Transport flows of passengers are distributed between individual lines in the case of public transport. Occupation of lines, time loss of passengers, number of interchanges etc. are evaluated. The LOGIT model is important for traffic assignment in public transport as well (distribution of passengers between individual alternatives of route – e.g. lines).

10. Transport Demand in City Agglomeration of Hradec Králové and Pardubice and Surrounding Areas

City agglomeration of Hradec Králové and Pardubice is located in the Czech Republic. It is about 100 km to the East from Prague. The agglomeration is consisted of 146 municipalities. Border of this agglomeration is created by municipalities of Týniště nad Orlicí, Jaroměř, Chlumec nad Cidlinou and Chrudim. It is well interconnected area located in flat terrain with minimum barriers for transport.

The major cities of Hradec Králové and Pardubice are centres (capitals) of two neighbouring regions although that distance between these cities is 25 km only. Both cities have ca. 90,000 inhabitants. The regions of Hradec Králové and Pardubice are consisted of 448 and 451 municipalities respectively. These regions cover larger area than mentioned city agglomeration including more distant and mountainous areas (Krkonoše and Orlické hory). Features of these two regions are quite similar. This is advantageous in the point of view of transport demand analysis. Both regions and the central city agglomeration on the border of them can be compared. This comparison is based on 2 presumptions. The first is that number of inhabitants is an important feature for modelling of transport demand. This feature will be analysed as isolated (only one). The second presumption is that linear functions are suitable [20]. The example is the formula (3) for the case of more independent variables. In general, the article is focused on the trip generation phase and on the importance of numbers of inhabitants for this phase of modelling.

Relation between number of inhabitants (as independent variable of \(y\)) and number of people commuting out of home municipality to work or to school (as depended variable of \(x\)) is assessed. The values of depended variable come from public census 2011 organized by the Czech Statistical Office [21]. There are incorporated all the people they mentioned the municipality as the place of stay in the census (official registration to stay is not crucial). Other purposes of travelling are not involved. Next public census will be in the year 2021.

Applied numbers of inhabitants registered in each individual municipality were also published by the Czech Statistical Office for the year 2011 [21]. Relative incompatibility of these data (number of registered inhabitants and trips made by everybody who expressed it in the census) is not a problem. It is not easy to reflect this difference in practice as well. Passengers not living in surveyed areas can take a part of traffic flow as well. On the other hand, assessed variables are creating a base for assessment of transport demand.

Linear regression analysis (in specific expression the least squares method) is applied for this assessment by the software support of Microsoft Excel application.

Resulting regression functions for prognosis of number of commuting people out of municipality based on number of inhabitants [21]

<table>
<thead>
<tr>
<th>Municipality (number of inhabitants)</th>
<th>Region of Hradec Králové</th>
<th>Region of Pardubice</th>
<th>City agglomeration of Hradec Králové and Pardubice (central part crossing border of both regions)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression function</td>
<td>Average relative error</td>
<td>Maximal relative error</td>
</tr>
<tr>
<td>All (y = 0.071x + 96.045) (n = 448)</td>
<td>107% 1335% (y = 0.087x + 92.370) (n = 113)</td>
<td>3083% 451</td>
<td></td>
</tr>
<tr>
<td>(0 - 500) (y = 0.232x + 2.029)</td>
<td>23% 161% (y = 0.260x - 1.783) (n = 276)</td>
<td>401% 282</td>
<td></td>
</tr>
<tr>
<td>(500 - 1k) (y = 0.224x - 3.339) 19% 84% (y = 0.249x + 0.525) (n = 93)</td>
<td>17% 62% (y = 0.194x + 101.897) (n = 16)</td>
<td>45% 45</td>
<td></td>
</tr>
<tr>
<td>(1k - 2k) (y = 0.085x + 255.730) 19% 66% (y = 0.141x + 139.371) (n = 21)</td>
<td>25% 48% (y = 0.141x + 101.897) (n = 16)</td>
<td>45% 45</td>
<td></td>
</tr>
</tbody>
</table>

\(y\) – number of people commuting out of municipality per day [persons], \(x\) – number of inhabitants [persons], \(n\) – number of municipalities in set [municipalities]
The assessment is presented in practical point of view, what is difference between forecasted numbers of people commuting out municipalities (forecasted by regression functions, Tab. 3) and the numbers expressed in the public census [21]. Common statistic indices are replaced by the values of average and maximal relative errors (deviations expressed in percentage). All the errors are considered as absolute values so that the positive and negative values of deviation are not compensated.

The quality of results can be improved by calibration in a lot of cases. For example, one of the maximal values of relative error of 140% (Region of Hradec Králové; municipalities from 1,000 to 2,000 inhabitants) is occurred for the case of Špindlerův Mlýn. Transport demand can be assessed individually in this case because the municipality is a famous ski resort. Transport needs are different also by inhabitants living (registered) here. Other serious values of error (401% and 390%) are occurred in the case of Selmice. There are only 5% of inhabitants commuting out of this municipality. This is a minimum value in the assessed area (average ratio of commuting inhabitants is 23%). It can be potentially considered as statistically outlying value.

Following conclusions can be made on the base of the Tab. 3. Number of inhabitants is key factor influencing number of commuting people, but it is not the only one factor influencing this. Representativeness of this factor can be evaluated as 75% based on average relative error. Trip generation as the part of modelling process can be based on more factors. It is not possible to be presupposed that the same and only one regression function will be suitable for all municipalities (including the major cities of Hradec Králové and Pardubice). The most serious values of average as well as maximal values of errors between forecasted and actual number of commuting people were reached in the case of this approach. If the municipalities are stratified (like in the Tab. 3 according to population) and if compound function is applied, the quality of results may be improved. It is possible to be seen that some features able to be generalized are occurred as well. It can be declared by comparison of results for both neighbouring regions. Generalisation of modelling procedures is possible within individual categories of municipalities.

11. Conclusions

Assessment of a priori as well as posterior transport demand is crucial for public passenger bus transport system. Transport demand of passengers is based on requirements on transport of students to and from school and on requirements on transport of employees to/from work. Other requirements are related to transport to doctors, offices, shopping, culture and sport. Transport authority is also important customer next to passengers. The transport authority signs a contract for the provision of passenger transport services with individual transport operators and provides loss compensation for a service. The system of public bus transport must ensure sustainable mobility for all the categories of passengers. It is necessary to answer on the questions: “Who? When? Why? From where? To where? How many persons?” in the field of mobility management. Transport survey, accessible statistic data and outputs of technical devices (if they are installed in vehicles) can be applied for modelling of transport demand by using of empirical models.

The article is focused on prognosis of numbers of people commuting out of (home) municipality in relation to numbers of inhabitants registered in municipality. Creation of a theoretical model for this relation is the target of this article. The model is based on regression functions expressing the relation between these variables. Data from the last public census made in 2011 [21] are applied for this purpose. Number of inhabitants is examined as a feature influencing transport demand individually. It is the key feature for the step of Trip generation applied within so called four step transport model. The main result is that this feature plays crucial role, but there are also other features influencing transport demand. Representativeness of this factor as individually applied feature can be evaluated as 75%.

It can be presupposed that this assessment can belong to one of the first steps by modelling of transport in the city agglomeration of Hradec Králové and Pardubice or in whole area of both regions of Hradec Králové and Pardubice.

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Container Transportation by Rail Transport Within the Context of Ukraine’s European Integration

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Abstract

The Agreement on Association between Ukraine and the European Union signing requires of the former an in-depth development and compliance with European standards. One of the important grows trends is the development of Ukraine’s transport system both generally and of different transport modes. Advantageous geographical situation of Ukraine, its position as a transit east-west country and a tremendous growth of container transportation requires corresponding measures for retaining the positions achieved on the container transportation market and for further increasing of freight flows. The paper attempts to analyse the volume of container transportation by Ukraine’s rail transport within the current decade and to trace the container transportation promises correspondingly to the European integration commitments made by our state. During the recent decades the volume of container transportation all over the world shows a stable trend to increasing, the world financial crisis of 2008 having slightly influenced it. Owing to this trend, many countries pay greater attention to establishing reliable transport “bridges” between east and west, as well as to developing container transport system. Ukraine is to pay more attention to developing container transportation by rail as the best European experience proves they have many advantages over road transportation and are capable of increasing considerably Ukraine’s competitiveness on the container transportation market.

KEY WORDS: commodities, container, freight flow, multimodal transportations, transport system

1. Introduction

“The Association Agreement between Ukraine, on one part, and the European Union, the European Atomic Energy Community and their Member States, on the other part” [1] (signed and ratified by Ukraine in 2014 and which took complete effect in September, 2017) provides for implementation of Ukrainian Transport Legislation and subordinate legislation regulations into the field of rail transport. Advantageous geographical situation of Ukraine on the Euro-Asian continent determines its paramount potential as a transit country, a country bridging west and east, north and south. Fast world growth of multimodal and intermodal transportation calls for relevant national solutions aimed at achieving economical advances in transport freight flows increasing.

2. Analysis on Previous Researches and Publications

Foreign practices show that in the transport field one of the main factors to increase efficiency is the multimodal transportation development and its sufficient stability providing. In this respect, the scientific works of Brands & Berkum [2], Wismans et al. [3], Hammad & Ksouri [4] and others are worth of distinguishing.

Some national researchers (Okorokov [5], Kurhan [6], Myronenko & Aleksiichuk [7] and others) study in their papers the improvements of their results on the national transport market after introducing up-to-date instruments of logistics and multimodal deliveries under favourable economic environment creation. However, the given results of researches reflect mainly technical and technological aspects of multimodal transportations, the problems of economic security remaining not highlighted. Some issues stay out of researchers’ sight including those of determining the combination of principles to arrange and carry the international freight service, the latter being the grounds ensuring economic security for supplying chains in multimodal freight transportations both on operative, tactical and strategic levels.

Darabann [8] stresses that European Commission while developing the transport policy attaches particular significance to intermodal transportations providing reliability, environmental friendliness and cost-effective use of resources on transport. Thus, scientists and experts consider the growth of container transportation to be one of the main factors of solving the problem of Europe transport sector security. This results from the fact that intermodal transport
allows to combine the advantages of each transport mode, for instance, the mobility of road transport, the high carrying capacity of rail transport, the operational efficiency of water transport and high speed of air transport.

In economically developed countries, logistics and intermodal transportation have become the main factors for economic growth and market integration. International transport flows practically are not analysed beyond the intermodal technologies, the researchers emphasized this in the papers [9-12]. However, to expand this system, the container terminals’ technical provision and simplified proceeding of shipping documents are to be worked out carefully. Marinov et al. [13] point out the promises of rail/road combined freight transportations as an integral logistic transport chain. The technical possibilities for container transportations have been analysed and some ways to improve the shippers’ servicing have been suggested in the paper.

Lavruckin et al. [14], Kolar [15] outline the dynamics in re-distribution of freight flows after European Union extending, explaining it with its actual geographical situation between stable markets of sales, distribution and consumption of such countries as Germany, Austria on the one hand and developing markets such as Ukraine, Romania, Bulgaria on the other hand. The cited papers analyse freight flows distribution, particularly focusing on intermodal infrastructure. In these papers, the authors consider intermodal terminals and their interrelationship as well, the latter stressed as one of paramount significance.

Some countries experience proves economic efficiency of intermodal transportations [16], door-to-door transportations appear to be particularly advantageous, main drawbacks are described as time-consuming operations on containers transshipping and non-availability of mathematical reasoning for transport technologies.

Marinov et al. [17] suggest some ways to improve the infrastructure of terminals intended for freight transshipping from rail to road or water transport in order to increase the competitiveness on the freight transportations market.

Kotenko et al. [18] study the rail transport technology within bimodal transport system, but the researchers do not take into account transport vehicles’ inactivity time in terminals, although it influences substantially the efficiency results.

Thereby, the analysis of the researches on multimodal and intermodal transportations proves the problems of their efficient implementation in Ukraine and other East European countries as well as the complicated implementation procedures have not been researched sufficiently yet.

In our paper, we apply analysis, system approach, technological and economical evaluation grounded on the relevant mathematical models, and other methods necessary for research purpose achieving.

3. Analysis on the Volume of Container Transportation by Rail Transport of Ukraine

The Transport Strategy of Ukraine until 2020 [19] approved by the Cabinet of Ministers in 2010 states the provision of accessibility and high quality of transport services by means of sustained growth of intermodal transportations as one of the priority challenges. Sustaining the combined freight transportations is one of the main trends in actual European transport policy. International practice proves that recently combined transport modes run two thirds of international freight services according to “door-to-door” transportation principle.

Thus, to begin with we are to consider the grounding transport provisions in The Agreement on Association between Ukraine and the European Union, namely the Article 367 and the Article 369 [1]. The former is stating: “The Parties shall: (a) expand and strengthen their transport cooperation in order to contribute to the development of sustainable transport systems; (b) promote efficient, safe and secure transport operations as well as intermodality and interoperability of transport systems; (c) endeavour to enhance the main transport links between their territories”. The latter one gives more details: “This cooperation shall cover, among others, the following areas: (a) development of a sustainable national transport policy covering all modes of transport, particularly with a view to ensuring efficient, safe and secure transport systems and promoting the integration of considerations in the sphere of transport into other policy areas; (b) development of sector strategies in light of the national transport policy (including legal requirements for the upgrading of technical equipment and transport fleets to meet highest international standards) for road, rail, inland waterway, aviation, maritime transport and intermodality, including timetables and milestones for implementation, administrative responsibilities as well as financing plans; (c) development of the multimodal transport network connected to the Trans European Transport Network (TEN-T) and improvement of the infrastructure policy in order to better identify and evaluate infrastructure projects in the various modes of transport … ” [1].

Another integral part of The Agreement are the ANNEXES. ANNEX XXXI in the chapter “Railway transport” provides for implementation of a number of Directives and EU Regulations into national Legislation. Our special attention is focused on the Council Directive 92/106/EEC of 7 December 1992 establishing common rules for certain types of combined transport of goods between Member States. This document’s provisions are basic for ensuring container transportations within the European Union. Thus, Article 1 of the Directive gives some definitions we base on in our research: “For the purposes of this Directive, ‘combined transport’ means the transport of goods between Member States where the lorry, trailer, semi-trailer, with or without tractor unit, swap body or container of 20 feet or more uses the road on the initial or final leg of the journey and, on the other leg, rail or inland waterway or maritime services where this section exceeds 100 km as the crow flies and make the initial or final road transport leg of the journey; - between the point where the goods are loaded and the nearest suitable rail loading station for the initial leg, and between the nearest suitable rail unloading station and the point where the goods are unloaded for the final leg, or, - within a radius not exceeding 150 km as the crow flies from the inland waterway port or seaport of loading or unloading”.

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From the above-cited documents, it becomes clear that container transportations by rail transport are only a part of common combined traffic, a considerable one. According to definitions, the transportations may be internal and international. Internal transportation means freight transportation between the points of departure and destination within Ukraine. International transportations are usually divided into import, export and transit. Due to the research problem, we are focused on the international transportations, that is why we are to analyse the dynamics of international container transportations grounding on the data of State Statistics Service of Ukraine [20-22] and railway sectoral statistics (Figs. 1 and 2).

Analysing data of the above-given diagrams it is necessary to take into account that the currency exchange rate of Hryvnia to Dollar US has risen more than 3 times from 2013 to 2016. Therefore, we can see that the most transportations both in export and in import falls to maritime transport. Nevertheless, commonly the deliveries to/from maritime ports are provided by road and rail transport regarded as internal transportations. Nowadays in the total volume of internal intermodal transportations in Ukraine, the share of rail transport is 29%. European Union pursues an active policy aimed at re-orienting freight flows from road transport to rail and water (maritime, inland) transport. Transport experts estimated such negative impact of road transport as increased environmental pollution, roads destruction because of heavy trucking, delays because of traffic congestion, and then suggested economically justified subsidies to rail and water carriers.

Ukrainian railways have a great experience of operating container freight flows, both as single wagon deliveries and container trains as well. Nowadays within Ukraine nine container trains and one combined train run regularly [23], carrying local and international traffic. Container transportations in container trains count 40 % in total volume of container transportations by rail transport within Ukraine [24].

Strategy on Development of PJSC “Ukrzaliznytsya” provides for increasing the intermodality share up to 45% until 2021 [25], i.e. on one third to previous. Here rises a question whether it is possible. Let us analyse the dynamics of rail container transportations during recent years [26] (Fig. 3).

As everybody can see in terms of weight indices (in tons) the situation with export/import container transportations quite differs from the same analysed points in terms of currency indices as well as they are different if analysed in terms of payments for container transportations by rail transport (Hryvnia) [27] (Fig. 4).
In spite of positive railways experience to operate international container trains the total volumes of container transportations performed in two past years are steadily dropping. A number of factors influence the situation, such as economical downturn, general decrease of volume of container traffic to Black Sea region, negative sequences of reforming management system on rail transport. Transferring the rolling stock from inventory fleet to private involves extra “mediators” in receiving empty wagons to use, which results in the prices increase for using rolling stock.

Therefore, if Ukraine wants to keep existing positions on the market of container transportations and to attract additional freight flows, it is to take certain measures to improve work on a number of directions. In particular, it is necessary to create more favourable social climate, clients-oriented policy of openness and flexibility should be implemented as well. All these refer both tariff policy and all the aspects of transport management, introduction of up-to-date logistics methods and comprehensive informational support of a shipper in real-time regime. Otherwise, favourable conditions for increasing the volume of container transportation by rail transport available now may be lost, and shippers will return to road carriers.

It also is very interesting to analyse how changes the range of commodities carried in containers during two past years [28]. To illustrate these changes we give several diagrams (Figs. 5-8).

Tailing transportation tariffs we believe can help Ukraine to use the above-mentioned opportunity. Now road transport carries more valuable freight (as a rule, they can be transported by rail too). Road transportation tariff is 0, 1 dollar US for 1 t/km (1 dollar US is an average cost of transportation of 10 tons (freight weight) to distance of 1 km).

Rail transportation average tariff is 0.0375 dollar US for 1 t/km (30 dollars US is an average cost of transportation of 1 tons (freight weight) to average distance of 800 km). If railways offer a tariff twice lower than that of road carriers (we mean 0.05 dollars US for 1 t/km), transit container transportation of 15 tons to distance of 800 km will cost 600 dollars US by rail compared to 800 dollars US by road. Thus, savings in transport expenses of a shipper will be 25 %, which is very attractive. As for railways, under these tariffs container transportation of 1 ton earlier carried by road transport will give an income 33% more than the transportation of 1 t of cheap “mass” commodities.

Having in mind European choice of Ukraine, its desire to integrate into the European transport and trading space, container railway transportations become an essential element of the transport system and an important indicator of its development. European practice shows that encouraging rail freight transportation, including container, gives the opportunity to achieve greater energy efficiency, environmental friendliness and safety of transport compared with road transport.

As we note above, The Agreement on Association between Ukraine and the European Union, signed by Ukraine in 2014, includes a separate provision on the development of combined and multimodal transportation, harmonization...
of the regulatory and legislative framework with European requirements. The Plan for Implementation of Council Directive 92/106/EEC, approved by the Cabinet of Ministers of Ukraine on 02/25/2015 No 142-r, has a direct commitment undertaken by our government to develop a separate Law of Ukraine “On Multimodal Transport”. The working team of the Ministry of Infrastructure, which includes representatives of rail, road and water transport, with the participation of EU experts, carried out corresponding work. On December 11, 2017, a draft law was published [28] on the website of the Ministry of Infrastructure in order to submit it to public discussion. In our opinion, approving by the Verkhovna Rada of Ukraine of this grounding document is of vital significance in the context of achieving the strategic goals of the national transport sector. The growth of the container transportations system is unthinkable without harmonious development of all modes of transport, organization of coordinated interaction between them, establishment of an acceptable and economically justified level of tariffs and legal protection for shippers.

Unfortunately, at present, despite the disposal of modern, powerful container terminals in seaports, Ukraine does not have sufficient transport facilities to move them effectively farther into the country and into the European Union. Rail transport in Ukraine currently is carrying a significant share of container transportations and possesses a considerable potential to increase its share in this direction. However, a number of unresolved issues, both of technical and technological, and legislative character, as well as inflexible tariff policies, are still deterring from rail transport a significant amount of clients. Crisis phenomena in the Ukrainian and world economy, on the one hand, have an additional negative impact on the transport industry, but at the same time allow them to increase their market share by offering more advanced and cheap services. However, it should be noted that to take up these opportunities, sufficient investments and their rational use in the most problematic areas are needed – technical modernization of the rail transport, improvement of information security systems, increase of the level of transport service, etc.

Transportations by means of container trains is the future of the railway industry, especially in Ukraine, which seeks to enter the European market. Containers have advantages over a range of parameters: they can be downloaded 30% more than a road truck; in a number of areas the transportation in a container is 15-40% cheaper than by road transport, and with properly designed scheme, transit time during transportation by rail is equal to the period of delivery by car.

In addition, we are to mention such type of transportation, as piggyback transportation, which also falls under the concept of “multimodal”. For almost 15 years, the combined train “Viking” carries out regular transportations of heavyweight highway trucks along the route Chornomorsk (Illichivsk, Ukraine)–Klaipeda (Lithuania), from time to time this type of route is complemented with the train “Yaroslav”, its route is Kyiv–Slavkov (Poland). A very promising type of transportation, popular in Western Europe, whose further development still requires additional scientific substantiation and regulatory support [6], will undoubtedly give an additional impetus to the European integration prospects of Ukraine.

4. Conclusion

To sum up, we can affirm that the main directions to ensure the complete integration of Ukraine into the international transport system and the maximum utilization of its transport potential are the following:

- adoption and implementation of the concept of the creation and functioning in Ukraine of a national network of international transport corridors, the development of transport infrastructure at places of checkpoint and along all routes;
- the introduction of the newest transport technologies and transportation schemes, the development of mechanisms to increase the quality of transport services, the use of combined transportations, that will create real prerequisites for improving the socio-economic development of regions and the economy of Ukraine as a whole;
- technical re-equipment of all modes of transport, growth of the transport sector informatization, increase of investment attractiveness of the transport industry and the sphere of transit transportations, working out of forms and methods of state financial support for the development of public transport network of Ukraine.

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Experimental and Model Study of High Frequency Oscillations in Suspension Components

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Abstract

During the vehicle movement, the road surface disturbs the pneumatic tyre in the contact patch with forced oscillations. These vibrations have different frequencies, which depend on the speed of the vehicle and the wavelengths of road irregularities. In this work it’s examined the interaction between the tyre and the road unevenness, which creates forced oscillations in the tyre's natural frequency range. The first resonance of the tyre belt occurs when driving on pavement at speeds typical of urban conditions. It is in the frequency range between 90 and 110 Hz. This resonance increases the levels of high frequency oscillations of the wheel axle and of the suspension components. These vibrations are transmitted to the chassis of the vehicle through the mounts of the suspension components.

In this work, road experiments are conducted on a front suspension, coupled with a radial type pneumatic tyre. A pavement surface, which creates distinctive road noise in the passenger cabin, is selected. The characteristics of the pavement road are represented by its random functions. Experiments are conducted in urban conditions with different tyre pressures and driving speeds. During the experiments, the acceleration signals of the wheel axle and different mounting points of the suspension components are measured. On the grounds of the conducted experiments, a finite element model is being constructed. A comparison between the experimental results and those from the model study is made. The natural modes of the suspension components are obtained and compared with those of the tyre.

The purpose of this work is to investigate the effect of structure-borne road noise on the high-frequency oscillations formed by the pneumatic tyre and their propagation in the suspension and chassis components of the vehicle.

KEY WORDS: high frequency oscillations, suspension, tyre, vibrations

1. Introduction

When the pneumatic tyre interacts with the road, the excited vibrations are transmitted to the body of the vehicle through its suspension. For disturbances with low frequencies up to 30 Hz, the pneumatic tyre acts like spring element of the vehicle's suspension. The inflation pressure influences the stiffness of the tyre in similar way like the stiffness of the air-spring [1]. The inflation pressure has an impact also on performance parameters such as the braking deceleration [2] and the coefficient of rolling resistance [3]. For high-frequency oscillations with a frequency of 50 - 250 Hz, the tyre must be considered as a system with distributed parameters [4]. The vibrational behaviour of the pneumatic tyre at these frequencies is characterized by the first radial mode of the belt, which has a large amplitude and several subsequent modes, which have smaller amplitudes [5]. These vibrations reach the elements of the vehicle's body with membrane effect such as doors, windows, ceiling, etcetera [6]. The vibrations of these elements cause the structural noise in the passenger compartment.

In [7], it is determined that the first radial mode depends mainly on the stiffness of the sidewall, which is confirmed by the experimental studies [8]. Tyre pressure also affect the first radial mode. There is a relatively small increase in the frequency of the radial mode with increasing the pressure [9]. The theoretical studies present the pneumatic tyre in different mathematical models. In some, it is considered to be a rigid ring with a flexible base, taking into account the internal pressure and damping [10, 11]. Experimental studies are conducted both with a pneumatic tyre rolling on a drum [12] and with a fixed pneumatic tyre using vibration stands [13].

In order to assess the tyre vibration behaviour, it is sufficient to determine its output characteristics such as the frequency response of the car axle. The output characteristics of the pneumatic tyre can be used for input characteristics of the suspension - body system.

2. Experimental Study

Selection of a road surface

Two types of road surface were selected to conduct the experimental study. The first is stone pavement in urban conditions. The second is rumble strips on the national (Bulgarian) road network designed to alert drivers to slow down. Both types of road surfaces cause structure-borne noise in the passenger compartment. Structural noise levels are greater at a resonance of the tyre, which is achieved at a certain speed. The road surfaces are presented in figure 1. Their correlation functions are determined to show that the chosen surfaces cause harmonic disturbances in the tyre contact patch.
Measurement of the profile of the road surface

The measurement of the profile of the road surface is carried out with the device shown in Fig. 2. It consists of two displacement transducers - one in the longitudinal direction (pos. 3) and one in the vertical direction (pos. 1). The vertical displacement transducer is mounted on a stand (pos. 6) that moves along the guide rails (pos. 4) of the device. The end of the transducer for vertical displacement is provided with a sliding tip (pos. 5), which allows the transducer's end to roll over obstacles. The end of the transducer for longitudinal displacement is fixed to the stand of the other transducer. The longitudinal displacement is controlled by sliding device (pos. 2). To level the whole device, there are screws (pos. 7) located at its ends.

Selection of the locations for the measuring points

A total of four points are selected from the car's suspension and body (Fig. 3). The first measuring point is on the axle of the front right MacPherson strut suspension. The second point is on the lower control arm, located next to the rear rubber mount to the subframe. The third point is located on the body of the vehicle, just after the upper mount of the front shock absorber. The fourth is located on the roof of the vehicle. These measuring points provide enough information for the propagation of structure-borne vibrations and noise from the road to the vehicle's passenger compartment.

Measuring scheme

An accelerometer is attached to each measuring point. A total of four uniaxial accelerometers are used – one capacitive PJM LN and three piezoelectric accelerometers Brüel & Kjaer. They measure the accelerations in the vertical direction. The piezoelectric accelerometers are equipped with the appropriate charge amplifiers. The accelerometers are connected to the HBM DQ401 (DAQ DC module) and via it the oscillograms are recorded in the computer (Fig. 4).
Plan of the experiment

The experiments on the pavement are conducted at different speeds and air pressure in the tyres. Running speeds of 40, 50, 60 and 70 km/h (step of 10 km/h) are selected. These are typical speeds of the traffic participants without exceeding the speed limit. The experiments are made for three different tyre pressures: 1.8, 2.1 and 2.4 bar. The experiments are conducted over a wide range of velocities and pressures to determine at which values of these parameters is going to be observed a resonance of the pneumatic tyre.

The experiments on the rumble strips are conducted at speeds of 40, 50, 60 and 70 km/h. These speeds are determined by the speed limitation on the road marking. The air pressure in the tyre is 2.1 bar. The results for this pressure are compared with those obtained from the experiments on pavement.

All experiments are carried out on dry road surfaces at ambient temperature of 25°C.

The frequency of excitation $f$ can be calculated from the equation [14]:

$$ f = \frac{n \cdot V_a}{3.6}, $$

where $n$ - the number of the stones blocks (rumble strips) in one meter; $V_a$ – speed of motion, km/h.

When driving on the stone pavement surface ($n \approx 7$) at 40 to 70 km/h, the excitation frequency is in the range 75 – 135 Hz. In the case of the rumble strips ($n \approx 3$), speed of 40 to 70 km/h corresponds to excitation frequency of 35 – 60 Hz. At the selected speeds, a frequency range of 35 to 135 Hz can be provided for the disturbing excitation. Within this frequency range are the resonances of the tyre, due to its construction.

Processing the results of the experiments

For comparing the results, the standard deviation of the measured accelerations is used:

$$ \sigma_a = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (a_i - M)^2}, $$

where $n$ is the number of elements in the sample; $a_i$ – measured accelerations; $M = \frac{1}{n} \sum_{i=1}^{n} a_i$ – mean value of accelerations.

The standard deviation of the measured accelerations is calculated for each speed of motion and for each air pressure in the tyres.

3. Model Study

A structural model with finite elements of the studied suspension is built. SolidWorks Simulation software is used. The coil spring is made of spring steel C60E with elastic modulus $E = 2.1 \times 10^{11}$ N/m², Poisson’s ratio $\mu = 0.28$ and mass density $\rho = 7800$ kg/m³. The hub carrier (axle) is made of cast iron with an elastic modulus $E = 6.6 \times 10^{10}$ N/m², Poisson’s ratio $\mu = 0.27$ and mass density $\rho = 7200$ kg/m³. All other metal elements are made of plain carbon steel with an elastic modulus $E = 2.1 \times 10^{11}$ N/m², Poisson’s ratio $\mu = 0.28$ and mass density $\rho = 7800$ kg/m³. The rubber mounts of the suspension are presented as distributed springs without their own mass (spring connections). The locations of the rubber mounts are shown in Fig. 5. The rubber mounts between the control arm and the subframe have radial stiffness of $8 \times 10^5$ N/m (pos. 1 on Fig. 5). The ball joint between the control arm and hub carrier has normal (axial) stiffness of $1.4 \times 10^6$ N/m (pos. 2 on Fig. 5). The upper mount of the shock absorber has normal stiffness of $1.2 \times 10^6$ N/m (pos. 3 on Fig. 5).

The shock absorber is modeled as a rod system made up of two elements: a rigidly coupled piston and a piston rod, and an external cylinder (tube). Distributed springs with total stiffness of $1 \times 10^7$ N/m connect the two elements of the shock absorber. This stiffness describes the compressibility of the fluid that affects high frequency oscillations. The bearing in the hub is presented in the model as bearing connection.
The input parameter for the model study is a harmonic vertical acceleration, the values of which are taken from the experiment. The excitation is applied to the wheel hub (Fig. 6). The frequency responses of different points of the suspension are used for the assessment of their vibrational behaviour. The studied points are shown in Fig. 6. The suspension model is tested in the 35 to 150 Hz frequency range, which overlaps with that of the experimental study. The purpose of the model study is to determine whether in this frequency domain the suspension elements have their resonances and whether they overlap with the modes of the tyre.

4. Results

In Fig. 7 is shown the measured profile of the stone pavement surface. The respective correlation function in Fig. 8 is limited to a wavelength of 0.13 m, which is the distance between the centers of two adjacent stone blocks.

In Fig. 9 is shown the measured profile of the rumble strips surface. The respective correlation function in Fig. 10 is limited to a wavelength of 0.3 m, which is the distance between the centers of two adjacent rumble strips.

The two correlation functions indicate for harmonic excitation by the road surfaces. The harmonic excitations have wavelengths corresponding to the distance between the centers of two adjacent stone blocks or rumble strips. Longer wavelengths do not create structure-borne vibrations and noise.

In Figs. 11-13 are shown the standard deviations of the measured accelerations for driving on stone pavement...
surface. The values of the standard deviations are determined for different speed and air pressure in the tyres. In Fig. 14
is shown the standard deviation of the measured accelerations for driving on rumble strips surface. The values of the
standard deviation are determined for different speed and air pressure of 2.1 bar in the tyres.

![Fig. 11 Standard deviation of the measured accelerations as a function of speed for 1.8 bar tyre pressure when driving on stone pavement surface](image1)

![Fig. 12 Standard deviation of the measured accelerations as a function of speed for 2.4 bar tyre pressure when driving on stone pavement surface](image2)

![Fig. 13 Standard deviation of the measured accelerations as a function of speed for 2.1 bar tyre pressure when driving on stone pavement surface](image3)

![Fig. 14 Standard deviation of the measured accelerations as a function of speed for 2.1 bar tyre pressure when driving on rumble strips surface](image4)

![Fig. 15 Frequency responses of acceleration of the defined in the model measuring points](image5)

In the figures from 11 to 13, a maximum value of the accelerations in the suspension elements and the body is
observed at a speed of 60 km/h on stone pavement surface. This speed corresponds to an excitation frequency of 115 Hz.
The maximum standard deviation of accelerations value is due to a resonance of the tyre. This is established by the
response (accelerations) measured on the hub carrier. This resonance propagate to the control arm and the roof of the
vehicle, creating structure-borne noise in the passenger compartment.

The input parameter for the model study is a harmonic vertical acceleration applied to the wheel hub. The values
for the excitation are taken from the experiment. In Fig. 15 are shown the frequency responses of the defined measuring
points (Fig. 6). The results of the model study confirm the results of the experiment. There is clear propagation of the tyre
resonance vibrations through the suspension elements.
5. Conclusions

The study shows that the maximum axle (hub carrier) accelerations for both stone pavement and rumble strips are close, creating vibration phenomena above 50 Hz. These vibrations create the structure-borne noise inside the passenger compartment. The smaller number of rumble strips per linear meter results in a resonance of the tyre at higher than 80 km/h speeds. The studies of the rumble strips are conducted at the exit of a highway, where cars developed such speeds.

The study can be used to select the rumble strips' dimensions. A well-sized rumble strips causes disturbance at a frequency close to the resonant frequency of the tyre when traveling at a certain speed range. In this case, the height of the rumble strips cross section can be reduced in order to avoid powerful impacts on the suspension elements.

The measured accelerations in the axle indicate that a resonance of the pneumatic tyre occurs at a speed of 60 km/h on a stone pavement with a wavelength of 0.13 m. This disturbance corresponds to a frequency of about 115 Hz.

For this speed range on stone pavement are expected lower grip, increased rolling resistance, increased fuel consumption and consequently worse emissions. This is a subject of research in subsequent studies.

The vibrations of the tyre's resonance reaches body elements with a membrane effect. In the specific study, the roof of the vehicle has the maximum vertical accelerations at the 115 Hz resonant frequency of the pneumatic tyre. The roof is one of the sources of structure-borne noise in passenger compartment of the vehicle. To avoid the membrane effect (reduction of structure-borne noise) in the roof, it is necessary to stiffen its construction.

The vibrations of the tyre's resonance are propagated by the suspension elements. The maximum value of vertical acceleration for the control arm corresponds to the tyre mode frequency. The damping of the structure-borne vibrations in the suspension elements is accomplished by the rubber insulators located at the suspension mounting points.

The results of the model study of the suspension components confirm the expectation of propagation the resonance of the pneumatic tyre. Although the control arm has its natural mode frequency above 300 Hz as calculated by the model, it transmits the oscillations through the connections to the chassis and further these oscillations are transmitted in the structure of the large shells (door panels, roof, windows, etcetera).

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Risk Monitoring in Rail Transport Performed at the Operational Level

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Abstract

Safety management in rail transport lacks procedures at the operational level. Widely developed regulations require the implementation of safety management systems, but they do not indicate detailed guidelines/procedures as to how such an implementation should look like. The problem concerns almost all processes in risk management. We decided to show how to solve this problem for risk monitoring processes. Usually, such processes are carried out retrospectively (based on existing events). We think that this is not enough. Therefore, we have presented three approaches to risk monitoring - retrospective, proactive, and predictive.

KEY WORDS: safety, risk monitoring, rail transport

1. Introduction

In rail transport, safety problems have always been treated with due attention. Railway undertakings were required to implement safety management systems and conduct risk assessments, the main point of which is the characterisation of safety systems [6]. The European Commission has developed a set of legal regulations, but it did not indicate what appropriate documentation should look like, especially how to prepare it in the scope of safety systems. This situation makes it possible to act at the strategic level, on the other hand, it makes it difficult to manage safety at the operational level. Not without significance is the observation that legal regulations do not always reflect the original concepts of scientific solutions [2].

The importance of safety management problems in transport has also resulted in undertaking project activities. In Poland, an example is the ZEUS (Zintegrowany system bezpieczeństwa transportu [Integrated Transport Safety System]) project that was implemented in 2007-2010. Works in the project were carried out in four research teams representing individual transport modes. Their goal was i.a. the analysis of possibilities of unification of concepts and intermodal knowledge transfer in the field of risk management in transport, of which safety systems are components. It should be pointed out that one of the final postulates of this working group was to express the need to develop detailed processes, procedures and models in safety management, separately for each mode of transport (including rail transport).

Summing up the activities undertaken in the field of risk management in rail transport, it can be concluded that at present they are in the phase where there are enough solutions in the strategic dimension. However, the deficiency of such solutions is visible at the level of operational risk (the level concerning the development of detailed processes, procedures and models). There are no tools to respond to risk using safety systems. This is particularly true for tools that:
- take into account the specificity of functioning of safety system domains in the areas of their application;
- guarantee the integrity of risk response processes with the processes of risk evaluation;
- are effective and understandable enough for people who are not specialists in safety;
- take into account new research trends regarding correct implementation of the tasks of the systems (e.g. the idea of Safety-II, Hollnagel [10]).

The purpose of this article is to provide the concepts and indicate the methods of risk monitoring in rail transport being realized at the operational level.

2. Materials and Methods

The presented cycle of works concerns the implementation of risk management within one of its phases – responding to risk. Within this phase, the following processes are usually distinguished (Fig. 1): risk treatment, risk monitoring and risk communication [14]. Each of the mentioned processes is important in achieving the risk management goal, i.e. reducing risk to a rational level [16]. Risk monitoring is a main process of risk management methods. The realization of this process consist of regular action provided the control of analysis area, covered by the risk management. The scope of those actions is show on Fig. 1. Risk monitoring may also include some means or resources like safety measures, control measures, risk reduction measures, etc. Errors of these measures should be
treated as sources of hazards.

According to Zou and Sunindijo [21], risk monitoring is particularly required in cases where:
- when the control measure is deemed ineffective;
- before a change at the work place that is likely to introduce a new or different risk for which the control measure may not be effective;
- if a new hazard or risk is identified;
- if the results of consultation or communication with other stakeholders indicate that a review is necessary;
- if a health and safety representative requests a review.

According to the Hollnagel [11]:
- the monitoring must cover an organisation’s own performance as well as what happens in the operating environment;
- effective monitoring must be proactive; it must be able to recognise upcoming situations and make use of leading indicators;
- monitoring, regardless of whether it is of the exterior or the interior can be based on either indicators or trends;
- the purpose of monitoring is clearly either to trigger a response or to cause an organisation to change from one state to another, from ‘hot standby’ to ‘operation’;
- monitoring must take place all the time – although possibly with varying frequency;
- monitoring may often require specific sensors, equipment or technology, particularly when physical or physiological processes are involved;
- monitoring may be done locally or remotely; in the latter case the access to communication technology and transmission channels is essential;
- monitoring in many cases relies on people as sensors or interpreters, not least if the focus is on social or organisational processes;
- monitoring must be focused. It must be known what the object or target of monitoring is and especially why;
- the result or outcome of monitoring is not just the specific value (of the indicator) or the specific trend, but the interpretation of that.

The positive effect of monitoring is improving an organisation’s potential to cope with possible near term events – threats and opportunities alike (Fig. 1) [11].

![Fig. 1 Risk monitoring in the structure of processes responding to risk in transport. Own study based on [16]](image_url)

The priority role is played by risk treatment, which is implemented by undertaking various forms of actions tactics aimed at [12]: avoiding hazard sources (risk factors), risk transfer, risk retention and risk reduction.

Risk communication is the interactive process of exchange of information and opinions among individuals, groups, and institutions concerning a risk or potential risk to human health or the environment. Any risk communication effort must have an interactive component, if only in soliciting information about the audience in the beginning or evaluating success in the end [18].

3. Results

We propose three variants of monitoring analysis area, based on safety management strategies postulated i.a. in
air transport [13]:
  1. Retrospective risk monitoring.
  2. Proactive risk monitoring.

First variant is based on statistical data concerning the time of use of non-regenerated elements of technical objects (which are parts of the mechanical type). The reason for the analysis domain adopted in this way is that damage to the elements of these objects is identified as the main hazard source in technical systems. Related risk reduction measures are organized in the form of maintenance systems – which can be treated as specific safety systems.

In all periods of the life cycle of technical objects, there is a need to predict the number of failures to components. This is required by the processes of estimating the demand for exchangeable elements, the need to configure maintenance systems taking into account the number of exchanges of elements, as well as implementing risk response procedures that anticipate damages to those elements that generate hazards with unacceptable risk.

During the observation/testing of elements of objects, the number of their failures in time intervals is usually recorded and on this basis the characteristics in the form of empirical reliability functions are determined. In work [8] a method of monitoring the empirical failure intensity function (also called risk function) has been presented. The universality of the applied solution lies in the possibility of using empirical failure intensity function instead of the theoretical one, as well as of using the method of fuzzy logic as input information about observed objects.

In work [3] a method is proposed of detecting the onset of the object wear-out period and determining the maintenance efficiency based on, as the authors of [3] would call it, a step model of aging and the Bayes techniques. In [4] a new reliability model is presented of complex repaired technical objects/systems based on the bathtub curve.

Due to the random nature of vehicle breakdowns, knowledge about stochastic processes is necessary to maintain their efficient and safe operation. The replacements of failed parts are unexpectedly created at random moments of operating means of transport, usually between scheduled maintenance. Due to the variety of failure processes of individual parts of the vehicle, the methods and applications of stochastic modelling for simple failures modelled by the Poisson process are presented in work [1]. A similar approach to retrospective risk monitoring has been presented e.g. in papers [15, 19].

In the second variant of risk monitoring (proactive), it is assumed that the area of analysis are subject to continuous observation testing with the use of measuring devices and recorders or using indirect observation methods (for example video recording). The aim of this monitoring way is to registering changes in states and or attributes of factors (hazard sources) occurring in the analysed area using video-monitoring.

The results of risk monitoring are particularly interesting from the point of view of the tasks of achieving an appropriate level of safety of means of transport. This is particularly true for public transport, but it is also characteristic for transport infrastructure in various modes of transport [2, 17]. For example, in the process of designing light rail vehicles (trams), the tasks in the scope of safety include: striving to equalise the loads of individual wheels on rails, reducing forces in inter-articulated joints, ensuring proper running properties of the vehicle, designing the interior of the vehicle taking into account the actual passenger preferences. Because these activities translate directly into the achievement and maintenance of passenger safety while operating a tram, they are also safety functions that should be implemented by the safety systems of light rail vehicles. The hazard sources for which these functions are implemented include variable vehicle mass and mass moments of inertia of the entire vehicle structure, caused by the distribution of individual masses of passengers in the vehicle.

As an example of implementing a proactive approach to risk monitoring, the interior of the tram was selected [7]. It presents the monitoring methodology and the results of the distribution of passengers standing inside the tram and the results of the impact of passenger load on the vehicle’s driving characteristics. In addition, numerical and functional characteristics of the distribution of passengers inside the tram were developed. Due to the fact that in the current domain observation, the parameters describing the process of filling the tram zones change in a random manner, a correspondingly large number of implementations of a random variable (around 950 realizations in each of the 21 highlighted tram zones) were prepared, and the designated numerical and functional characteristics were based on statistical and probabilistic models.

In a modern approach to safety management, it is postulated to make decisions based on the risk value of formulated hazards (including identified sources of these hazards), and not on the past events – accidents [5]. For this reason, a third (predictive) variant of risk monitoring was established. The aim of this variant is to develop and present tools to identify existing hazard sources and to predict the possibility of new hazard sources in the analysed area.

Work [6, 9] presents methods that are proposed to be used in the processes of identifying hazard sources as elements of the domains of these systems. To facilitate the review of the described methods, their classification was made and the specificity of each of the proposed identification processes was discussed. The discussed processes are certain mappings of human reasoning, used by a risk analyst or an expert who is modelling the safety system. In the works [6] and [9] the twofold form of these processes has been distinguished and discussed.

4. Discussion

The results of risk monitoring should have a significant impact on other risk response processes, in particular on risk treatment carried out using safety systems. The identification of hazard sources is a factor facilitating the identification of risk reduction measures. For a risk analyst or modelling a safety system, a relatively easy task should
be to adjust existing and known risk reduction measures to recognized sources of hazards. In addition, the hazard sources include failures in the operation of safety systems, which makes it possible to indirectly indicate the elements of these systems.

Risk monitoring is most often implemented in a retrospective manner. However, these results limit the range of areas in which risk monitoring can be carried out. In order to obtain the results of the retrospective monitoring, a sufficiently large number of data (usually statistical) should be collected, showing the functioning of the analyzed area in the past. Not in all analyzed areas such bases are available. On the other hand, an advantage of the retrospective approach is the ease of formulating hazards based on past events, especially when the reasons and effects of these events are known.

According ICAO [13] – the fact nevertheless remains that safety data from reporting programmes becomes available only after safety deficiencies trigger a low-consequence event. Is this not too late? Adverse events may quickly develop into dangerous events, without the reactions from safety systems. Perhaps such a state should be immediately reversed by the reaction of those systems or even more – safety systems should not to admit to low-consequence events base on the results of proactive risk monitoring.

Most of methods proposed in predictive variants of risk monitoring are commonly used in risk assessments. They are particularly suitable for hazard identification processes, although their applications are also seen at the risk estimation stage. In addition to the known and widely used methods, it was proposed to use a self-designed method, which is based on a specific model of hazard identification and so-called HIM worksheets (work [9]). The method is a relatively new, original study by the author of this scientific achievement, but has already found practical applications, among others, in the production processes of railway infrastructure elements. Its attractiveness results from the combination of concepts used in known methods with a relatively new approach to the process of hazard identification based on the idea of coincidence of hazard sources.

Interesting approach to risk monitoring should be the use of hybrid methods, which aggregate three variants of monitoring proposed in this paper. Although this approach is often realized intuitively, it lacks formalized procedures for its implementation.

An important aspect of applying risk monitoring is the organization's ability to learn and therefore improve / develop monitoring procedures. As Hollnagel points out [11] – without the potential to learn, monitoring will always look for the same signs and signals, and the responses will always be the same.

5. Final Remarks

Risk monitoring is a key risk management process. The legislative activities of government organizations as well as the safety policy of transport entities which deliberately use risk management in their business activities have shown that risk monitoring will be even more important. Unfortunately the risk monitoring is very rarely described in detail, with adequate examples of its application. In this article, we showed that it is possible to realize this task in three ways (three approaches). For each of those ways we have indicated possible solutions provided in the operational level. It can be added that along with a modern approach to safety management, particularly important task and challenge for entities in rail transport will be the predictive risk monitoring.

References

Factors Influencing Season Ticket Ownership: An Example from the Czech Republic

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Abstract

Mode choice models are very important tool in transport planning and modelling. Mobility tools such as car or public transport season ticket ownership influence further mode choice decisions of individuals. These tools enter the mode choice models mostly as attributes of individuals and are not predicted in the mode choice models. The paper presents an approach to model the public transport season ticket ownership based on the binary logit model. In the model there are used sociodemographic variables and accessibility measures of the home and work location of the individuals. The case study uses data from the travel behaviour surveys of the City of Prague and of the Central Bohemian Region.

KEY WORDS: mobility tool, public transport season ticket ownership, car ownership, Prague

1. Introduction

By mode choice modelling the sociodemographic attributes of individuals play important role. In the set of these attributes there are also included variables describing car ownership or public transport season ticket ownership of the individuals. These factors can also be called mobility tools. The mobility tool can be defined as “…an item, which after a substantial down-payment provides permanent access to a certain mode of mobility at low or zero marginal cost for a time-span of at least one year” [1].

In the City of Prague public transport plays very important role. Currently 42% of all trips on city territory are made by public transport over the typical (average) working day [2]. We asked ourselves at the beginning, what factors influence the decision about public transport season ticket ownership among the inhabitants of the Prague Metropolitan Area. For the experiment we used the data from travel behaviour surveys purchased by the Technical Administration of Roads of the City of Prague and we limited the experiment for the commuters to work.

The paper is structured as follows: Section 2 provides description of the data, preparation of the accessibility measures and hypotheses of the results. Section 3 presents the results of the experiment and Section 4 provides a discussion of the results. For accessibility and statistical calculations we used the language R [3] and the environment RStudio [4].

2. Materials and Methods

For our experiment we used data from the Travel behaviour survey of inhabitants of the City of Prague and The Central Bohemian Region and for calculation of the potential accessibility we used the model of the Prague Metropolitan Area. This administrative unit covers the City of Prague and a significant part of the Central Bohemian Region around Prague.

The model is operated in the software PTV VISUM. The model covers area of approximately 2 million inhabitants. The complete four-stage model is used for passenger transport. In mode choice there are used only two modes, namely public transport and private motor vehicle transport (for simplicity “car”).

The model uses travel behaviour surveys as the main source of data. The surveys are conducted regularly at intervals 5 or 10 years. The last on residents of Prague was carried out in 2015 and the last for the Central Bohemia in 2016. The forms of both surveys were CAWI (preferred) and CATI and the sample was approximately 5,000 respondents in both cases. The population was always people aged 6 and over. The data was collected for a so called typical (average) working day. More information about the model and the surveys can be found in [5].

For the binary logit experiment we had to calculate accessibility indicators at first. We can define accessibility as a “…measure of the capacity of a location to be reached by, or to reach different locations. Therefore, the capacity and the arrangement of transport infrastructure are key elements in the determination of accessibility” [6]. There are two core concepts used in accessibility – location and distance. Each location has a set of certain attributes, such as its population or number of employment positions. The distance represents separation between locations. The separation can be measured in different ways, such as travel time, travel distance or generalized cost.

As we can read in the definition of the accessibility, we can formulate it for two situations – to reach other locations and to be reached from other locations. For our experiment we prepared two accessibility measures based on the model
of the Prague Metropolitan Area. The first describes, how many employment positions are potentially accessible by public
transport from each zone of the model. The second describes, how many inhabitants can reach each zone of the model.
The formulations are as follows:

\[ A_{empl}^i = \sum_{j=1}^{N} Employment_j \cdot f\left(GC_{ij}\right); \]  
\[ A_{pop}^j = \sum_{i=1}^{N} Population_i \cdot f\left(GC_{ij}\right). \]  

\[ A_{empl}^i \] is the potential accessibility to employment positions from the zone \( i \) and \( A_{pop}^j \) is the potential accessibility
describing, how many inhabitants can reach the zone \( j \). The factor of distance is presented by a distance decay function
which describes the at which the spatial interaction diminishes.

For formulation of the distance decay function we used the principles of survival analyses, as they were used in [7].
Survival analyses works generally with random variable \( T \) with probability distribution \( f(t) \) and cumulative distribution
function \( T(t) = Pr\{T < t\} \), giving the probability that the event has occurred by duration \( t \). Usually the complement of the
cumulative distribution function is used, the so called survival function \( S(t) = Pr\{T \geq t\} \), which gives the probability of
being alive just before duration \( t \) [8].

The duration can be replaced by another quantity. We used the travel times of the trips from the travel behaviour
surveys. We joined the databases from the travel behaviour surveys of Prague and of the Central Bohemia. From the
database we filtered all trips from home to work made by employed people and by public transport, which were realized
between two different zones of the model of the Prague Metropolitan Area. Then the travel times by public transport
(from door to door) were imputed from the model for each trip.

For all filtered trips we made the empirical cumulative distribution function of the travel times and then we fitted
parametrical function to the observed values. We used the negative exponential function which was presented in [9],
where the parameters \( a_1 \) and \( a_2 \) need to be calibrated.

\[ f\left(GC_{ij}\right) = \exp\left(-a_1 GC_{ij}^{a_2}\right). \]  

The method of nonlinear least-squares was used for fitting the function. The estimated parameters are
\( a_1 = 0.000107 \) and \( a_2 = 2.391 \). The observed values and the fitted function are presented in Fig. 1.

\[ Fig. 1 \text{ Fitted (blue) and empirical (black) distance decay function} \]

After the distance decay function fitting we calculated the potential accessibilities according to both formulations.
The results of employment accessibility \( (Z\text{803}_\text{_A}_\text{empl}_\text{PT}) \) for each zone are plotted spatially in the maps that follow
(Figs. 2 and 3). We can see, that the values are dependent on the public transport lines in the region. Zones with the largest
value are situated along the main bus and railway lines.

We can see the same patterns also for the central area of the model. The most accessible zones are situated along
the main public transport lines. The system of the Prague Metro has the largest impact. Some tram lines are also
recognizable.
We used again the joined databases from the travel behaviour surveys of Prague and of the Central Bohemia for the binary logistic regression. All sociodemographic data of persons was connected with the trip data. The data about accessibility was imputed to the database, too.

We filtered all trips from home to work made by employed people and which were realized between two different zones of the model of the Prague Metropolitan Area. When some person made more than one trip from home to work at the same day, we chose only the first such trip in a day. At last we discarded all persons, who can use public transport for free, because such people do not make decisions about the public transport season ticket ownership. The resulting dataset consisted of 2418 observations. The summary statistics of variables are presented in Table 1.
For the experiment we used the variable public transport season ticket ownership as a dependent variable and other variables as independent variables. For better understandability of the model we used in the model the accessibilities divided by 10^6 and age was divided by 10. We used also the square of age (divided by 100) as an independent variable and natural logarithm of the household size.

According to [10] we expected that people who have car available as a main user tend to own public transport season ticket less than who do not. According to [1] we anticipated that better accessibility by public transport (both employment and population) have positive impact on decision about the public transport season ticket ownership. We expected that males tend not to use public transport season ticket in comparison with women.

### 3. Results and Discussion

Following the methodology outlined above the binary logit model was estimated. The results of the model are in Table 2. The variables of accessibility (both) and college or university degree have positive impact on decision about the public transport season ticket ownership. The variables age (considering both variables together), male, natural logarithm of household size and car availability as a main user have negative impact.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>Sign.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.290</td>
<td>0.705</td>
<td>**</td>
</tr>
<tr>
<td>Employment accessibility by public transport</td>
<td>1.717</td>
<td>0.259</td>
<td>***</td>
</tr>
<tr>
<td>Population accessibility by public transport</td>
<td>3.086</td>
<td>0.207</td>
<td>***</td>
</tr>
<tr>
<td>Age [y/10]</td>
<td>-1.254</td>
<td>0.335</td>
<td>***</td>
</tr>
<tr>
<td>Agesq [y^2/100]</td>
<td>0.136</td>
<td>0.038</td>
<td>***</td>
</tr>
<tr>
<td>Male</td>
<td>-0.292</td>
<td>0.112</td>
<td>**</td>
</tr>
<tr>
<td>log (household size)</td>
<td>-0.169</td>
<td>0.111</td>
<td></td>
</tr>
<tr>
<td>College or university degree</td>
<td>0.498</td>
<td>0.108</td>
<td>***</td>
</tr>
<tr>
<td>Car availability (as a main user)</td>
<td>-1.473</td>
<td>0.127</td>
<td>***</td>
</tr>
<tr>
<td>Pseudo R^2 (McFadden)</td>
<td>0.269</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of observations</td>
<td>2418</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant at: 0.1% ***; 1% **; 5% *; 10% .

Considering both of age variables together we can see, that age has negative impact in the whole range from 19 to 79 years, but the largest impact is in the range from 35 to 55 years. One explanation can be, that people usually are in households with children in this range. This explanation can be supported by the impact of the household size, but this coefficient is not significant (but has the same sign). The problem is, that number of household members itself is relatively course, because there can be many forms of households (living with friend, living with grandparents etc.).

Dummy variable male has negative impact. Braun-Kohlová [11, p. 98] suggested to explain this tendency to car...
use by men with psychological aspects (men seek after autonomy, like driving pleasure etc.). The impact of car availability as a main user is also negative. The natural explanation can be from the microeconomic theory, because car and public transport season ticket can be considered as partial substitutes.

Both accessibilities have positive impact, but the impact of population accessibility is almost twice as large as the impact of employment accessibility. It should be mentioned, that the population accessibility is larger than the employment one on average, so the impact of population accessibility is even greater. The positive impact of the college or university degree may be related with the fact, that people with higher education work mostly in administrative or similar buildings, which are good served by public transport.

4. Conclusions

In the binary logit model, we proved that there are significant factors influencing public transport season ticket ownership. The positive impacts of public transport accessibilities are very important. Many cities in Europe want to support usage of the public transport. They can do it not only through improvement of public transport supply, but they can support residential development in appropriate parts of the city with similar effects. In figure 3 we can see that the most of well accessible zones are relatively dense populated or have high density of workplaces. Lower costs of public infrastructure are also related with higher population and employment density [12], so the cities can optimize their structure in two directions at once.

The impact of age is also significant. We can see, that younger and older people use more public transport. It is important to know, when facilities for older or younger people are planning (e.g. dormitories). In these parts of the city there will be probably higher demand for public transport. The impact of household size is not significant. Its significance could become larger, if we change the structure of the variable. We could e.g. use dummy variable for households with children or single-person households.

The last question is in what direction to build on our existing results. The next step should be model of car ownership with similar attributes and then joint model of car ownership and public transport season ticket ownership. With this model we can identify interdependencies between these two mobility tools.

Acknowledgement

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Development of an Energy Generating Platform for Converting Kinetic Energy into Electrical Energy Using the Kinematic Synthesis of a Three-Stage Multiplier

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Abstract

This work relates to the field of renewable energy sources, namely the design, creation and development of various kinds of devices that are able to convert kinetic energy into electrical energy. The use of this kind of device in the field of transport will not only improve the energy efficiency of a particular object, but also to balance it on energy consumption. In the article, a kinematic synthesis of a compact drive (multiplier) of an electro-generating platform was carried out to find ways to minimize the cost of its production. A multiplier based on a pair of helical gears with a module of 1.5 and a total gear ratio \( i = 9.8 \) was proposed and designed. Force conditions are formulated to ensure the operation of the device’s electro-generating mechanism. A layout scheme for an electro-generating platform with a multiplier is proposed. Based on the research conducted, an experimental model of the power generating platform has been made. The layout of the main elements of the device allows it to be easily mounted in almost any place where there is a high density of human flow. In the field of transport and its infrastructure, the proposed device should be used as a platform or as steps for various pedestrian crossings. This device will also be in demand as an additional source of energy both in the vehicles themselves, for example, in electric buses, and at public transport stops.

KEY WORDS: green energy, energy conversion, energy saving technologies, energy efficiency, electricity generating platform, alternative energy sources, multiplier, power generation.

1. Introduction

Issues of energy efficiency and energy saving at the moment have acquired perhaps the greatest relevance. One of the ways to solve them is the introduction of various kinds of technical systems and devices that not only perform the function of energy saving, but are also able to generate electricity themselves for further use. [1-3].

This paper presents research on the issues of creation and design of energy-efficient and electro-generating devices, which are installed in places with a large cross of people. The use of such devices and systems will allow economizing the required amount of electricity, which will provide the power supply system with additional low-power energy sources. This will allow more efficient balancing of the power supply system in terms of power indicators of electricity consumption, as well as the introduction of modern energy efficient measures to save electricity [4, 5]. The proposed development is based on the methods and approaches for converting kinetic energy from pressing - into electric energy [6, 7]. It is proposed to carry out the kinematic synthesis of a three-stage multiplier of the electro-generating platform (step). The use of multipliers will significantly increase the generation of electricity by this device.

The aim of the work is to carry out the kinematic synthesis of a compact drive (multiplier) of the power generating platform to find ways to minimize the cost of its production. To achieve this goal it is necessary to solve the following tasks:

- to analyze the research and publications on this topic;
- to select the type and circuit design of the multiplier, taking into account the cost of its constituent elements;
- to determine the gear ratio of the multiplier and the moment of resistance on its shaft;
- to determine the conditions that ensure the operation of the electro-generating mechanism;
- to propose the layout of the power generation platform with a multiplier.

2. State of the Art

One of the analogues of the research development is Pavegen tile, developed by the Englishman Lawrence
Campbell-Cook, which converts the kinetic energy from the steps into electrical one [8].

A similar development is also described in the patent [9]. The invention relates to devices for collecting energy on roads and highways using piezoelectric generators. The disadvantage of this development is that it is stationary and requires the installation of special equipment.

In [10], it was proposed to combine the process of converting mechanical energy into electrical energy and the process of accumulating electrical energy in the form of chemical energy. The authors did not indicate the performance characteristics of this development.

In the article [11], scientists justify the use of piezoelectric transducers on an asphalt-covered road in terms of energy production efficiency. The work presents the conversion of kinetic energy from pressing into electric energy, but specific technical solutions for practical use of this process are not given.

In [12], a direct drive generator based on the principle of nonlinear switching was investigated and an analysis of the effectiveness of the control system for generating electricity was presented, but quantitative indicators of the generated power were not given.

The authors of article [13] investigate a device for converting kinetic energy from vibrations into electrical energy. In this paper, the prototype Vibration Energy Harvester was investigated, where the piezoelectric material is the main element of energy conversion. The common drawbacks of devices and systems based on piezo-elements are: a small resource of their work, low reliability and insignificant energy indicators in terms of generated power.

Very promising is the use of stepper motors (SM) in low-power generation systems, analogs of which are tiles or pavement that generate electricity [8, 14, 15].

In the works [16, 17], the results of numerical simulation for the SM are presented, but the energy characteristics are not given.

The article [18] proposed an interesting solution for portable equipment - a handheld LED flashlight, which includes a gear stepper motor and an integrated electronic circuit. However, no specific numerical values of the generated energy are presented. Also for this design is not given the construction of the reduction gear and its parameters.

At the moment there are a number of questions, the answers to which will allow you to create an effective, cheap, universal device that generates alternative electrical energy. Namely:

- how effective is the SD in the low-power electric-machine energy converter;
- how much electric power can be generated by an SM using multipliers in these converters.

Answers to the questions posed will be partially disclosed in the current article.

A review of publications shows that this topic is relevant to the general public.

3. Multiplier

The first problem faced by the authors of the article when creating a prototype of the power generating platform was the minimization of displacement (lowering) of the platform at the moment when a person steps on it. If the movement is large, then the approaching person, on the one hand, may seem to be falling, and on the other hand, he may lose his balance, from unexpected lowering of the platform.

Thus, to ensure an acceptable voltage level at the output of the generators, it is necessary to convert a small movement of the input link (stage) into a relatively large angle of rotation of the electric machine generator shaft.

For this purpose, it was decided to use a multiplier and a crank-crank mechanism. This article is devoted, first of all, to the peculiarities of the kinematic synthesis of the multiplier.

For the kinematic synthesis of the multiplier we choose the expanded scheme. It should be noted that at the moment, the state of the production sites in Kharkov greatly limits the range of parts that can be applied to the prototype. Therefore, it was decided to use standard parts for home appliance transmissions that abound in the spare parts market. This approach, in particular, due to the fact that the cost of manufacturing a gear wheel can reach up to 1500 UAH, while a pair of spare wheels (gear - gear) costs about 120 UAH.

Thus, a pair of helical gears, with a module of 1.5 and a gear teeth number of 14, as well as a gear wheel of 30 was selected as the main drive element. Such a pair can increase the angle of rotation of the generator shaft 2.14 times (Fig. 1).

![Fig. 1 A pair of gears used in the multiplier](image)

To ensure the angle of rotation of the generator shaft in one cycle of the order of 4000 ... 5000 it is necessary to use a three-stage multiplier. A general view of the multiplier layout scheme is presented in Fig. 2.
Let us dwell in more detail on the device of the generator block, Fig. 2. To generate voltage, two SDs of the DSHI200 1 type are used, installed coaxially on the output shaft of the multiplier 3. To prevent rotation of the SD cabinets, they are fixed against rotation by two jet rods 2. SD drivers are driven by a three-stage multiplier 5, the input movement of which is set by crank 4. Thus, the total drive ratio is:

\[ i_2 = i_1 \cdot i_2 \cdot i_3 = 9.8 \] (1)

For the generator block SD was chosen based on the results of experimental studies, which are described in detail in [7]. Studies have shown that in these working conditions and in the presented design (intermittent mode) Step Drive DSHI200 has the best energy performance. This is clearly seen from the graphs of generated energy obtained by various types of electric motors [7].

4. Working Conditions of the Electro-Generating Mechanism

An important step for the further design of the electric drive is the study of the real moment of resistance on the input shaft of the multiplier. Another difficulty faced by the authors is that the helical gears cause the appearance of axial force, which in turn, in view of the use of shaft bearings, leads to a decrease in overall efficiency.

Measurement of the moment of resistance was made by measuring the maximum force applied to the crank and setting the mechanism in motion. The overall layout of the bench for measuring the force is shown in Fig. 3.

With experimental measurements, the force was 98 N. To analyze the force scheme of the impact on the platform step, we shall depict all the forces acting on it. At the corners, springs will be installed on the platform, which will be deformed by the weight of the person and will ensure that the platform returns to its original position. The elastic force of the spring is shown in Fig. 4 \((F_{pr})\). At the center of the platform, the \((F_{ps})\) reaction is applied (this force was measured experimentally and is 98 N) from the side of the connecting rod mounted on the input crank of the
multiplier. On top of the platform affects the weight of the person. Take the average value of this force is equal to 700 N.

![Fig. 4 Scheme of force applied to the platform](image)

Thus, analyzing the given power scheme, we can single out several conditions ensuring the operation of the mechanism:

- the weight of a person \((G_p)\) must be greater than the sum of the force of the useful resistance \((F_{ps})\) and the maximum total force of the resistance of the springs \((4F_{pr})\) to ensure that the platform moves downwards;
- the total force of resistance of the springs \((4F_{pr})\) must be greater than the force of the useful resistance \((F_{ps})\) to ensure the platform returns to its original position.

Analytically, these conditions can be written as follows:

\[
\begin{align*}
G_p &> F_{ps} + 4F_{pr} \\
4F_{pr} &> F_{ps}
\end{align*}
\]

Thus, when a person weighs about 70 kg, the platform should provide the specified force on the crank of the order of 100 N, which will lead to the deformation of the springs. Based on the above conditions, it is possible to choose springs with an appropriate stiffness coefficient. The general layout of the platform is shown in Fig. 5.

![Fig. 5 The overall layout of the power generating platform](image)

The translational movement of the platform \(2\) provides four cylindrical guides \(3\). This translational movement is converted into rotational movement of the crank \(7\) of the three-stage multiplier \(6\) by means of a connecting rod \(4\). At the same time, the platform is transferred to the beginning of the working stroke using four return springs \(5\). The working elements are covered on both sides by two ramps \(1\).

According to the results of the research, an experimental sample of the power generating platform was manufactured. The appearance of this device is shown in Fig. 6. The power generating platform is designed so that all the main work items are located in the center, under platform \(2\).

![Fig. 6 Appearance of the power generating platform](image)

Under slopes \(1\) - there are empty cavities on the left and right of the platform. They are designed to install in them various electronic control boards, as well as rechargeable batteries, which will ensure the accumulation of electrical energy during operation of the device.

Fig. 7 shows an experimental sample of a multiplier with two Step Drive DSHI200 connected to it. This equipment is located under the central platform \(2\). This version of the multiplier was developed with the condition of its subsequent production in mass production. That is, its components and parts are widely represented on the modern
market, and its design is universal. This makes it easy to install the multiplier without using additional (auxiliary) equipment.

Fig. 7 The appearance of the multiplier for the power generating platform

In our opinion, this device can find quite wide application in the field of transport and its infrastructure. For example, the power generating platform can be equipped with various types of pedestrian crossings (both directly on the carriageway and outside it). Particularly beneficial is the use of this device in the form of steps in underground road crossings and transitions in the form of bridges. Also, the power generating platform can be equipped with public transport stops, where pedestrians, passing on these devices, will generate energy. This energy can be used, for example, for external lighting, for heating stops in the cold time of day, for charging mobile phones at stops, etc. It is important to note that the power platform is a “green”, additional renewable source of energy.

Not less interesting, in our opinion, is the use of the power generating platform directly on the public transport, where constantly observed a large number of people. It can be, for example, steps (platforms) at entrance doors of buses. This device is especially relevant for electric buses [19], as passengers, passing on such platforms can generate additional amount of electricity, which can be sent to provide their own needs of the electric bus (Lighting, ventilation, information boards, etc.). Such devices will contribute to a more efficient use of electricity and ensure its economy. That is, the complex applications of the proposed devices in the field of public transport allow covering part of the cost of electricity. On the other hand, it will allow unloading the main power grids and performing energetic balancing of the system.

Current solution needs also an adequate energy flow measurements. The system and method for monitoring real power consumption has been given in [20]. But installing devices for measuring/monitoring electricity near each consumer or generator is very expensive [21]. The authors of [22, 23] proposed several methods to reduce these costs. As well as measuring the energy consumption of a fuzzy sample has been proposed in [24].

5. Conclusions

The article presents a review of the overall layout of the power generating platform. When designing it, it is advisable to use ready-made parts of existing serial electrical appliances. This will ensure the economic feasibility of manufacturing such devices at the stage of launching them into mass production. The design kinematic calculation of the three-stage multiplier of the generator electric drive is presented. The generator uses two stepper motors type DSHI200. A multiplier based on a pair of helical gears with a module of 1.5 and a total gear ratio \( i = 9.8 \) was proposed and designed. Force conditions are formulated to ensure the operation of the device’s electro-generating mechanism. A layout scheme for an electro-generating platform with a multiplier is proposed.

On the basis of the conducted researches the experimental sample the power generating platform has been made. The layout of the main elements of the device allows it to be easily mounted in almost any place where there is a high density of human flow. For the transport sector the most promising is its use as a platform or as steps for various kinds of pedestrian crossings (underground crossings, bridges, tunnels, etc.).

This device will also be in demand as an additional renewable source of energy both in the vehicles themselves (e.g. in electric buses) and at public transport stops. Pedestrians and passengers stepping on the power generating platform will generate electricity that can be used, for example, for external LED lighting.

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Acoustic Comfort Tests in the Tractor Cabin

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Abstract

A correctly designed operator's cabin should meet a number of criteria in the field of ergonomics and work safety. The comfort of the cabin is influenced by the following factors: thermal comfort, vibroacoustic comfort, atmospheric comfort, good visibility and lighting, and ergonomic arrangement of control and steering elements.

Work safety in the agricultural sector largely depends on the expertise within the context of their operations agronomic, operation of machinery and equipment used in agricultural sector. The article presents the problem of noise comfort in the new design cabin of agricultural tractor in testing conditions. We present the main sources of noise in the cabin of tractor and solutions aimed at reducing the noise level in it.

KEY WORDS: noise pollution, work safety, reliability, design

1. Introduction

Currently in agricultural tractors the internal combustion engine remains the main source of propulsion. Development of internal combustion engines in recent years has been directed at improving the environmental and economic operating parameters [1]. Environmental parameters of the engine are related to the emission of toxic substances into the atmosphere in the exhaust gases, whereas economic ones are connected with fuel consumption [1]. In addition, noise emission is a very important problem during the operation of internal combustion engines. The noise is defined as an unwanted sound which has an unpleasant and annoying effect [2]. In [3, 4], noise is defined as a type of environmental pollution, which disturbs normal living functions by influencing conversations and sleep quality, or by causing changes in human health. It is classified by the World Health Organization as the second most serious environmental cause that threatens the health of the population [2]. Noise can increase the overall workload of operators during a specific task and can affect the performance [5]. A correctly designed tractor's cabin should meet a number of criteria in the field of ergonomics and work safety, as well as ensuring adequate acoustic comfort (noise suppression).

The topic of noise and its effects in agriculture has received much attention since 1960s [6] and the research is ongoing in various dimensions today [5]. Nowadays, widespread use of agricultural tractors and machines for field operations, in spite of their valuable advantages, have caused some occupational health and safety problems for operators of these machines, the excessive noise is an example [7-11]. Certainly people who are working in various agricultural affairs exposed to a lot of noise sources and it has not fully specified all the risks for people who have long been exposed to the noise, yet [11]. Among the main sources of noise in an agricultural tractor, the following can be mentioned:

- an internal combustion engine with accessories;
- transmission;
- axle bridges;
- hydraulic devices;
- operation of additional devices.

These sources can cause acoustic energy to penetrate by air (so-called primary noise) and material (secondary noise). The sources of primary noise are not directly related to the cabin, but are located in its direct surroundings / immediate vicinity. The secondary noise depends on the cabin structure and is generated by the vibrations of the cabin sheathing elements (the place where the cabin contacts the frame).

Recently, continuous development of diagnostic inference algorithms and signal processing methods have been observed [12-14], which have been successfully used in scientific research in the field of combustion engine diagnostics [15-17]. As an inference algorithms, artificial intelligence methods are used, mainly neural networks [18-23] and methods using wavelet transform [24-27] or less known methods, e.g. recurrence plots [28, 29].

The common denominator of the results of research in the field of diagnostics of internal combustion engines presented in the scientific literature is their purely empirical nature. To a large extent, this is due to the insufficient development of physical theories that would afford a quantitative description of the phenomena studied [22].

This article presents the problem of noise comfort in the new design cabin of agricultural tractor in testing conditions.

2. Main Goal of the Research

The aim of this research was to determine the noise propagation in the UK-5 type URSUS farm tractor with a
rated power of 110 hp, after verifying the effectiveness of noise suppression using new soundproofing materials in previously insulated areas of the tractor cabin. The schematic diagram of the tested tractor cabin is shown in Fig. 1.

Fig. 1 The schematic diagram of tested farm tractor cabin UK-5 type URSUS

3. Materials and Methods

The object of the study were two cabins type UK5 of farm tractor URSUS (Fig. 1), in two versions of acoustic finish:

1. UK5 with a standard sound-absorbing finish.
2. UK5 with a standard sound absorbing finish, plus modifications of soundproofing of the steering column, floor inside the cabin (different type of mat and foam) and cabin floor from the outside (from the chassis and hydraulic system of the tractor).

The measurements of cabin noise levels were carried out based on PN-90/S-04052 (ISO-5128:1980) and ISO 7216:1992 standards [30, 31]. All measurements were made in the so-called the "near zone" of the source performing frequency analysis. Spectral analysis concerned levels in individual octave bands. Frequency analysis of sound pressure waveforms are performed using an apparatus set: sound-level meter 955 Svan (class 1) SVANTEK - Data processing was performed using the computer program SvanPC ++.

The device contains octave filters with center frequencies up to 16 kHz, enabling real-time signal analysis. The measuring points have been selected based on the specific conditions and dimensions of the cabin interior, including the arrangement of the control equipment elements with the functions of the tractor units. Measurements of each test cabins were made with the same test procedure. The sound level measurements in the cabin were proceeded by an examination of the acoustic background and at appropriate atmospheric conditions (ambient temperature, air humidity and wind force). Atmospheric conditions on the day of the measurements: temperature 27.5 ÷ 26.9°C, relative humidity 30 ÷ 35.5%, light wind from the direction of N-S.

The measurement tests were carried out for two fixed engine speeds with the driver's cabin closed - a first attempt at 1,500 rpm, a second attempt at 2,000 rpm, in fixed diesel engine operation conditions. Measurements of sound intensity were made in three horizontal planes denoting them as: the zone near the floor – FZ, the central zone – CZ and the upper zone – UZ (at the height of the tractor's operator head). The place of research was a square with paved surface in the form of paving stones, in the free surroundings of the facility, allowing for eliminating external disturbances.

4. Results and Discussion

The measurements were obtained in octave bands for designated measurement points. The article presents average results.

In the following diagrams (Fig. 2), the sound level values in three cabin measurement areas for engine speed of 1,500 rpm for a cab with a standard finish – SF and with additional cab insulation materials – AF are shown.

The next graph (Fig. 3) shows the sound level values at individual cab measuring points for the engine speed of 2,000 rpm for a cab with a standard finish – SF, and with additional cab insulation materials – AF.

Analyzing the graphs in Figs. 2 and 3, it can be stated that at the engine crankshaft speed of 1,500 rpm, a very large drop in noise level (7dB diff) was achieved in the cabin with additional insulating materials in relation to the standard cabin. The value of the sound level difference is visible in all three measuring zones. For the engine crankshaft rotational speed of 2,000 rpm, the noise level difference was much lower (up to 2 dB) in the compared cabins, particularly pronounced in the floor zone and the driver's head zone.

Analyzing the data in the graphs, you can see the difference between the obtained minimum and maximum values at different speeds (higher at 1,500 rpm) in the test cabins. The standard cabin suppressing reported significantly greater volume at 1,500 rpm, for all tested zones.
Fig. 2 General noise level (correction curve A) of the cabin, with additional – AF, and standard finish – SF, for engine speed 1,500 rpm

However, for the rotational speed of 2,000 rpm, there are smaller differences. The lowering of the noise value is most visible in the zone near the head of the driver and near the cab floor (in 7 out of 10 points less noise values were obtained). And in the central zone (the top of the chart) at certain measurement points (4 measurement points of 10), reflected values are comparable or even higher in the cabin with additional material sound dampers. These results may indicate that for certain measuring points due to the frequency characteristics, the material used has a lower noise attenuation properties.

For the positive effect of soundproofing, it should be recognized that in the zone near the floor, i.e. where the additional material was applied directly, the obtained results confirm better insulation from the source of noise particularly visible at the speed of 1,500 rpm. In addition, there is a reduction in the noise level in the driver's head zone, which directly affects the operator's working comfort, both at lower and higher speeds of the engine's combustion engine.
5. Conclusions

On the basis of preliminary tests of sound pressure in the UK5 cab of the Ursus farm tractor, it has been demonstrated that there is a possibility to improve the acoustic climate in the examined cabin.

Based on results of the evaluation of noise level in the cabin with the modifications carried out, it appears that the applied modifications have resulted in a decrease in the noise emission level.

A significant drop in the sound intensity level at 1,500 rpm engine crankshaft speed was demonstrated. At engine crankshaft speed of 2,000 rpm, it was noted that there are measuring points in which the sound intensity level is similar in both cabs, and not at all measuring points there was a decrease in the sound intensity level.

Variances which were revealed during the tests at higher rotational speed of the crankshaft of the tractor's combustion engine may result from other noise suppression properties of the materials used at other frequencies of sound propagation in the cabin. The frequency of sound propagation may be different at these rotational speeds and may affect the attenuation of noise by insulating materials.
References

Design of the Stock Replenishment System Regarding Distribution to Minimize the Risk of Stock Shortages with Cost-Effective Spending and Respect to Stochastic Demand

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Abstract

The aim of the paper is to design the complex stock replenishment system to ensure production and distribution process continuity with efficient cost-spending. In order to achieve the predetermined objective, the stock replenishment concept was designed for individual stock groups created according to the stochasticity of their consumption. To compare the existing inventory management models, the added value of the proposed stock replenishment system consists in determining the appropriate order quantity, order cycle duration as well as ordering time. To specify the optimal order quantity, the proposed stock replenishment system regarding distribution uses the EOQ model as well as suggests a specific order quantity calculation for selected stock group. The comprehensive stock replenishment system applicable to a specific portfolio of industrial and distribution plant inventories is the most significant outcome of this research study.

KEY WORDS: stock replenishment system, Q-system, P-system, stochastic demand, production and distribution process

1. Introduction

P-system and Q-system are the basic approaches within the inventory management, which are used to absorb the probable fluctuation within consumption. These two systems are included in the group of dynamic models. It means that the individual decisions are time-dependent. The objective of these models is to find an appropriate ordering algorithm with a goal to take into account all kinds of costs regarding to stock. [1].

Dynamic models count on the unlimited long storage period. The stock overage, created in one period, may be consumed in the next period by decreasing the order quantity. An important part of inventory management is to specify the appropriate stock replenishment interval [2].

The objective of the paper is to create a specific stock replenishment system individually for different types of stock in terms of their consumption, which is a necessary prerequisite to ensure the production and distribution process continuity, and at the same time, avoid the stock overage in the store [3, 4].

2. Stochastic Inventory Management Models

As already mentioned, within dynamic stationary models, inventory management can be applied in two ways. The main distinction between the Q-system and the P-system consists in the way of how fluctuations during consumption are trapped. The first method is represented by the case that the order frequency is determined and order quantity is variable. Such a method is referred to as the Q-system. The second option is represented by the case that the order quantity is specified and order frequency is variable. Such a method is referred to as the P-system [5-7].

2.1. Q–System

The basic Q-system principle consists in the fixed order quantity and the variable order cycle. The Q-system is divided into two order policies which are vividly described in Table I [8].

<table>
<thead>
<tr>
<th>Policy</th>
<th>Stock level control</th>
<th>Order point</th>
<th>Order quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s, Q$</td>
<td>continuous</td>
<td>variable (when actual state falls below the signal stock level)</td>
<td>constant</td>
</tr>
<tr>
<td>$t, s, Q$</td>
<td>periodic</td>
<td>fixed (if the actual state is less than the stock level)</td>
<td>constant</td>
</tr>
</tbody>
</table>
Explanatory notes to the Table 1:
- $s$ – signal stock level [pcs];
- $Q$ – order quantity [pcs];
- $t$ – order point [day].

In practice, Q-system application means to determine a constant order quantity and a signal stock level. At the moment, when the stock quantity decreases to a predetermined signal stock level, the order is performed. The optimal signal stock level is set to a quantity covering needs in time between ordering and delivering. In case of consumption variability of the stock replenishment interval, it is also necessary to maintain a certain insurance stock level.

2.2. P–System

P-system is a system of periodic ordering and therefore, regular orders of material items are its basis. As in the previous system, the actual stock level is monitored constantly. Unlike the Q system, P-system does not compare the actual stock level with the signal stock level; however it compares the actual stock level with a predetermined maximum stock level [10].

The order quantity is specified as the difference between the actual and maximum stock level. Maximum order quantities are calculated so that it covers the stock consumption to the next periodic control and during the delivery time duration. P-system is divided into three ordering policies which are characterized in Table 2. [8].

<table>
<thead>
<tr>
<th>Policy</th>
<th>Stock level control</th>
<th>Order point</th>
<th>Order quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t, S$</td>
<td>periodic</td>
<td>regular</td>
<td>variable (the difference between the maximum and the actual stock)</td>
</tr>
<tr>
<td>$t, s, S$</td>
<td>periodic</td>
<td>regular</td>
<td>variable (the difference between the maximum and the actual stock)</td>
</tr>
<tr>
<td>$s, S$</td>
<td>periodic</td>
<td>variable (if the actual state is less than the signal stock level)</td>
<td>variable (the difference between the maximum and the actual stock)</td>
</tr>
</tbody>
</table>

Explanatory notes to the Table 2: $P = t$; $t$ – order point [day]; $S$ – maximal stock level [pcs]; $s$ – signal stock level [pcs]

In order to apply the P-system in practice, it is necessary to determine fixed order point. The order quantity is set so that the sum of the actual stock level in the store at the time when an order is performed is equal to a predetermined quantity, while quantity takes into consideration the fluctuations in consumption [11, 12].

Applying the P-model, it is possible to find the optimal order cycle duration and the optimal order quantity, to which the actual stock status is replenished by order in the ordering times. The order quantity is calculated as the difference between the order quantity and the actual stock level at the time of the performed order.

3. Stock Replenishment System

Fundamental aspect of the designed stock replenishment system is to determine character of consumption. In regard to the designed stock replenishment system requirements, stock group is divided into three subgroups [13]:
1. stock that are consumed continuously throughout the whole year;
2. stock characterized by fluctuations in consumption within year;
3. stock abruptly consumed several times within year.

3.1. Continuously Consumed Stock

Determining the appropriate order cycle for stock that is consumed continuously throughout the whole year is relatively reliable. The basis is to take into account the stock consumption intensity. Subsequently, the order cycle duration is calculated, as follows Eq. (1):

$$ t = \frac{Q_{\text{opt}}}{I} \{ \text{days} \}, $$

where $t$ – order cycle duration [days]; $Q_{\text{opt}}$ – optimal order quantity [pcs]; $I$ – stock consumption intensity [pcs/day].

Order point is calculated so that the order is available in a store, when the stock level decreases to the quantity corresponding to the calculated optimal stock level in store, by the Eq. (2):

$$ T = t - d \{ \text{days} \}, $$

where $T$ – order point [day]; $d$ – delivery time duration [days].
Graphic representation of the designed stock replenishment system in regard to distribution process is depicted in the Fig. 1. Since it contains continuously consumed stock, it is possible to determine the fixed order quantity and fixed order cycle as well.

![Fig. 1 Stock replenishment system for continuously consumed stock](image1)

Fig. 1 Stock replenishment system for continuously consumed stock: $Q_{opt}$ – optimal order quantity [pcs]; $T$ – order point [day]; $t$ – order cycle [days]; $I$ – stock consumption intensity [pcs/day]; $I^*d$ – consumption during the delivery time [pcs/day]; $P_{opt}$ – optimal insurance stock quantity [pcs]

### 3.2. Seasonal Consumed Stock

The second subgroup of stock is characterized by a certain fluctuations during their consumption. The second stock subgroup is consumed only throughout a certain season during a year. Throughout these seasons, the stock consumption is continuous. Following these statements, it is possible to determine fixed order quantity, similarly as it is in regard to the first stock subgroup [14].

The distinction occurs within the way to determine the appropriate order cycle and order point. Given the fact that the beginning of consumption season can be forecasted with a relatively low accuracy, the key question of designed system consists in the way of how to solve this fact. Primordial order point $T_0$ may be achieved when the stock level decreases to the determined optimal signal stock level quantity. Specifying the order cycle duration as well as order point during consumption season is identical to the previous group [14]. The Fig. 2. Shows the stock replenishment system for the second subgroup of stock.

![Fig. 2 Stock replenishment system for seasonal consumed stock](image2)

Fig. 2 Stock replenishment system for seasonal consumed stock: $Q_{opt}$ – optimal order quantity [pcs]; $T_0$ – primordial order point [day]; $T$ – order point [day]; $t$ – order cycle [day]; $I$ – stock consumption intensity [pcs/day]; $I^*d$ – consumption during the delivery time [pcs/day]; $S_{opt}$ – optimal signal stock level quantity [pcs]

### 3.3. Abruptly Consumed Stock

Consumption time forecasts probability of abruptly consumed stock reaches a zero value. On the contrary, risk of the stock shortages is high. The objective of managing the third stock subgroup is mainly to solve the matter: “to store or order after consumption occurrence” [15].

The distinction with other stock consists in the fact that the order cycle is not specified. Similarly to previous stock subgroup, there is a need to determine primordial order point $T_0$. In time when stock decreases below the
determined optimal signal stock level, the ordering is performed. Optimal order quantity is equal to consumption during the delivery time, as the Eq. (3) shows:

\[ Q_{\text{opt}} = I \cdot d \cdot [\text{pcs}] \]

(3)

where \( Q_{\text{opt}} \) – optimal order quantity [pcs]; \( I \) – stock consumption intensity [pcs/day]; \( d \) – delivery time duration [days].

Fig. 3 shows stock replenishment system for abruptly consumed stock.

Fig. 3 Stock replenishment system for seasonal consumed stock

4. Conclusion

The aim of the paper was to design stock replenishment system in order to minimize the risk of the stock shortages regarding distribution and production process continuity maintaining, and at the same time, to avoid the stock overage. Application of such a stock replenishment system allows for determining a signal stock level by individual way by the stock consumption character.

Individual approach to three subgroups of stock types, which were created with respect to their consumption character, and specific calculations of order quantity and order cycle duration are significant novelties of designed stock replenishment system compared to the existing inventory management models such as the Q-system and the P-system.

A comprehensive concept of stock replenishment, taking into account the fluctuations in consumption as well as abruptly consumed stock, was designed. Proposed stock replenishment system contributes to reduce an occurrence of risk of the stock shortages considerably, and at the same time, it avoids to create the stock overage in store, thereby making the supply process more reliable.

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Behaviour of BMW Drivers on Urban Roads: A Naturalistic Study

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Abstract

Previous studies classified BMW brand as status brand associated with more aggressive driving and higher risk of accident. There is still a great lack of knowledge about the behaviour of drivers of different car brands. This study aimed to compare driving behaviour of BMW, Volvo, and Volkswagen drivers on urban roads. A naturalistic observation was performed by one observer. Two urban road behaviours were observed during rush hours: signalling at the turn to the right where both turning and straight way is allowed and driving by public transportation lane which is forbidden if not turning right immediately. The total duration of observation was 11.5 hours. The behaviour of 1702 car drivers was recorded. The results revealed that BMW drivers did not differ from Volvo and Volkswagen drivers in signalling behaviour when intended to turn to the right. But BMW drivers used public transportation lane violating traffic rules significantly more often than drivers of other two car brands. Thus, BMW drivers demonstrated more aggressive intentional violations of traffic rules compared to drivers of Volvo and Volkswagen.

KEY WORDS: BMW drivers, Volvo drivers, Volkswagen drivers, behaviour, urban roads, naturalistic study

1. Introduction

It is estimated that up to 80 percent of all traffic accidents are caused by human factor [1, 9], nevertheless most of the investment in road safety is made for developing better road infrastructure and creating safer cars [7, 21]. Because of all these means the feeling “of being safe” in traffic has increased, especially during last decade. However, there are evidence that all these safety means increase risky driving behaviour as well. For example, Gintalas and colleagues reported that accident rates increased after the gravel road reconstruction [8]. Drivers of older cars and cars, equipped with airbag or anti-lock braking systems were found to be more prone to risky driving [18, 22]. Thus, the interaction between human psychology and external variables (such as road environment and vehicle itself) is under-investigated but very important aspect of traffic safety.

Several studies investigated the links between driving behaviour and vehicle characteristics. For instance, Arvidsson reported that owners of older vehicles had fewer speeding tickets, but more tickets for other traffic rules violations and more convictions [2]. Four-Wheel Drives (4WDs) vehicles were found to be associated with more frequent and more severe accidents [3, 4, 23], higher risk of traffic rules violations and convictions [3], and riskier driving style [3, 4, 14, 23]. Status cars (such like BMW, Porsche, or Lamborghini) were also associated with riskier driving and higher numbers of traffic rules violations in Sweden [2], but not in Israel [19]. Authors argue, that such choice of a high-powered car or status brand reflects the owner’s self-image, social status, and higher risk propensity [2, 13, 14]. That’s why people who take risks choose fast and powerful cars which allow them to drive “cool” and prove their image of power, skills or own importance. On the other hand, there is some evidence that vehicle characteristics (e.g. brand or power) might increase risky driving behaviour irrespective of personality or age [10, 14, 16, 20]. It is possible that powerful cars provide opportunity to drive faster or to manoeuvre easier and tempt to violate traffic rules. Besides, other traffic participants expect riskier and more aggressive driving from the drivers of high-powered cars and provoke them to behave as expected. Still, this data is not enough to state which of the two (car brand or driver personality) is the cause. However, car brand and human behaviour are related and worth to investigate further.

Scientific literature as well as media indicates BMW as the brand that most provokes risky driving behaviour [2, 6, 10, 16] while according to technical characteristics BMWs are considered as quite safe cars for passengers and other vehicles in the case of accident [11, 12]. BMW cars were found much more likely to be involved in accidents than other brands in Lithuania [6]. BMW drivers reported more aggressive driving behaviour in Latvia [16], had higher numbers of convictions due to traffic rules violations in Sweden [2], and drove faster compared to drivers of other cars in UK [10]. Even in hypothetical situations people indicate that they would drive BMW faster than any other car [10]. Media also reports every accident with loud headlines whenever BMW car was involved. Furthermore, this image is supported by the BMW manufacturer with advertising slogan “Sheer driving pleasure” where the power, status, and the pleasure of driving this car is emphasised. However, it is little known about the behaviour of drivers of different car brands and that’s why BMW drivers might be prejudiced and experience undeserved consequences (such like higher car incidence taxes or negative attitudes of other traffic participants). Thus, this study aimed to add some evidence to the
existing knowledge by comparing behaviour of BMW, Volvo, and Volkswagen drivers on urban roads. Based on previous literature we hypothesize that BMW drivers would commit more traffic rules violations while driving compared to Volvo and Volkswagen drivers.

Volvo brand was chosen for the comparison as Volvo cars were found to be very safe for passengers, the vehicle, and other traffic participants in the case of accident [2, 11, 12], still not very popular in Lithuania [5]. Volkswagen is the most popular brand among Lithuanian drivers [5], but not very safe for both passengers and other vehicles in the case of accident [11, 12]. Also, Arvidsson defined both Volvo and Volkswagen as family cars which did not provoke risky driving and was associated with lower rates of traffic rules violations, less traffic tickets and convictions [2]. The convenience, simplicity, and safety of the driving are highlighted in the advertising slogans too: Volvo declares that is “Designed around people” and Volkswagen was presented as “the car for an even simpler one” – “Das Auto”.

2. Method

A naturalistic observation was performed to evaluate the frequency of turn signalling and using public transportation lane. Researchers used the data of Kaunas city police department. Data was obtained by two cameras installed in public places for traffic and other safety reasons. Streets and intersections can be clearly visible from observing points.

Two urban road behaviours were observed: signalling at the turn to the right where both turning and straightway are allowed and driving by public transportation lane which is forbidden if not turning right immediately. These behaviours were chosen due to reason that they are easy to observe, can be described clearly, therefore less observer bias is possible. Additionally, both behaviours are quite often violations among Lithuanian drivers and might influence traffic safety and fluency.

For signalling at the turn behaviour three categories were derived: 1) signalling behaviour when driver succeed to signal about turning intentions before crossing Stop line at the intersection; 2) fail to signal at the turn when driver does not signal when turning in the intersection; 3) late signalling when driver starts to signal after crossing (current category was observed very rarely, thus was not included into data analysis). Observation of signalling at the turn was performed at intersection where Gimnazijos, Birštono, and Šv. Gertūdos streets cross (Fig. 1). Current intersection was chosen due to density of the traffic and presence of the lane where both turning right and proceeding straight is allowed legally.

Driving by public transportation lane (PTL) was described by three observed categories: 1) not driving by public transportation lane, driving next lane; 2) driving by public transportation lane due to necessity, in this case the need to turn right immediately which is allowed only from public transportation lane; 3) driving by public transportation lane with no intention to turn to the right – driver proceed straight by public transportation lane. Observation was completed at Vytautas avenue where public transportation lane might be seen clearly by police cameras; right turn from this lane is allowed legally (Fig. 2). Observation point was chosen due to convenience and quite big density of traffic where might be more tempting to break the rules.

The observation protocol was verified by initial one-hour session where two people completed their observations. Inter-rater reliability was measured by Pearson correlation coefficients. Coefficients ranged from .85 to 1.00. This meant that observers agreed on most instances, they identified drivers’ behaviour and brand of the car quite precisely. Therefore, it was concluded that protocol might be used for main research without changes.

Observation was performed by one observer during rush hours on workdays. Driving behaviour was observed in a cycle of 45 minutes: the certain behaviour (signalling at the turn to the right or driving by public transportation lane) of one car brand was observed for 10 minutes followed by the break of 5 minutes, then the behaviour of another car brand was observed with another 5 minutes break, and finally the behaviour of the last car brand was observed. 23 such cycles were implemented. The total duration of observation was 11.5 hours. The behaviour of 1702 car drivers (27.7 percent were BMW, 16.5 percent – Volvo, and 55.8 percent – Volkswagen) was observed and recorded.
3. Results and Discussion

Signalling behaviour at the intersection when turning right was compared separately for BMW and Volkswagen, as well as for BMW and Volvo drivers. Data is presented in Table 1. 17.6 percent of Volkswagen drivers, 11.8 percent of BMW drivers, and 9.1 percent of Volvo drivers failed to indicate turning signal before manoeuvring. Results showed that BMW drivers did not differ significantly in signalling behaviour when intended to turn. However, such result is not very surprising. Certainly, signalling is critical to avoiding an accident as it allows the driver to warn other traffic participants of a planned manoeuvre. But most traffic psychologists such failure to signal consider as a driving error related to lack of driving skills, poor information processing, or inattention [15, 17]. Drivers tend to rate not signalling at the turn to the right as insignificant and non-dangerous behaviour too. Besides, the failure to show turn signals is one of the most often violations, therefore, drivers might learn not to signal from each other. Thus, failure to signal when turning to the right reflects negligence and irresponsibility of a driver rather than deliberate violation of traffic rules or aggressive driving. Such driving error could not strengthen the image of skilful and important driver of BMW and that’s why BMW drivers didn’t differ in signalling behaviour in our study.

![Table 1](image)

We also found that significantly more Volkswagen drivers didn’t signal when turning right compared to Volvo drivers ($\chi^2 = 5.974$, $df = 1$, $p = .015$). However, such unexpected result might be related to the fact that Volkswagen is the most popular brand among Lithuanian drivers [5] and represent more than a half of all records in this study. Thus, Volkswagen brand in Lithuania represents the widest variety of drivers and different driving behaviours as well as the wide range of different technical characteristics of a vehicle (model, age, power, etc.). Meanwhile Volvo brand is more preferred of certain groups of drivers and is evaluated as surely safe family car [2, 12].

![Table 2](image)

The data about driving by public transportation lane (PTL) behaviour across BMW, Volkswagen, and Volvo cars is presented in Table 2. It was found that 15.1 percent of BMW drivers used PTL violating traffic rule while only 8.7 percent of Volkswagen drivers and 3.7 percent of Volvo drivers drove by public transportation lane illegally. Volkswagen drivers and Volvo drivers didn’t differ according illegal use of PTL ($\chi^2 = 4.268$, $df = 2$, $p = .118$). As expected, BMW drivers used public transportation lane violating traffic rules significantly more often than drivers of other two car brands. Driving by public transportation lane is forbidden if not turning right immediately and usually this lane is separated by a continuous road marking line. Thus, driving straight by public transportation lane is an intended and conscious violation of traffic rules related to risky and aggressive driving [15, 17]. Also, this violation might be related to higher insolence and wish to outperform other drives or be smarter, especially during rush hours. This result supports the idea that BMW drivers are riskier drivers [2, 10, 16].
4. Conclusions

Results of this research confirmed previous findings that BMW drivers demonstrate more aggressive intentional violations of traffic rules compared to drivers of safer car brands like Volvo and Volkswagen. However, this study was limited by observing only two driving behaviours which are very different in their psychological nature (even though both are considered as traffic rules violations). In future research it would be also valuable to gather more information about car model, age, size, power, and other technical characteristics that might influence the behaviour of a driver.

References

Optimization of Design Parameters of Bernoulli Gripper with an Annular Nozzle

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Abstract

Functional application advantages of the contactless Bernoulli grippers with an annular nozzle at robotization of handling operations are presented in the current paper. The method of calculation of power characteristics of Bernoulli grippers is presented as well. Computational modeling of dynamics of air flow in the camera, an annular nozzle of Bernoulli gripper and in a radial interval between its active surface and a surface of a flat object of transportation is for this purpose carried out. Modeling is carried out in the environment of computing hydraulic gas dynamics of Ansys-CFX with use of SST of γ-model of turbulence. For increase in power characteristics of Bernoulli grippers’ options of constructive improvement of a form of an annular nozzle and its active surface are offered. What is more, the results of computational modeling of Bernoulli grippers with different design data are presented, contrastive analysis of constructions is carried out.

KEY WORDS: object of manipulation, Bernoulli gripper, transonic flow, supersonic nozzle

1. Introduction

Creation of transport and loading mechanisms with the high operational reliability and productivity, with broad universality and accuracy of positioning is a current problem, which demands constant search for further improvement. There are some problems in finding the solutions for creating highly reliable and high-performance samples of industrial robots, when creating essentially new types of their gripping devices. The main advantage of grippers of the industrial robots, based on Bernoulli’s effect, is the lack of contact or limited contact with a surface of the taken object of manipulation. It allows to hold the fragile, thin-walled, heated to high temperatures and polluted objects of manipulation of any material.

For contactless gripping and deduction of objects weighing up to 1 kg Bernoulli grippers with one cylindrical nozzle are more often used [1-4]. Simplicity of a design of these grippers provides them high reliability, durability and low cost. Higher power characteristics and the best energy efficiency have Bernoulli grippers with a annular nozzle [5-8]. In this grippers an air flow from the annular nozzle at the expense of the ejection phenomenon forms a zone of steady depression on a surface of a flat object of manipulation, provides them high loading capacity. Important advantage of these devices is the ability to hold the porous and punched objects.

The purpose of the present paper [9, 10] is to provide a technical review of a new Bernoulli gripper development using computed fluid dynamics (CFD) modeling, as well as to outline an appropriate independent testing method for validating and evaluating process capability in terms of automated thin wafer handling. The investigation has been carried out by a collaborative way of Festo and Fraunhofer IPA as a connecting link between applied research and industrial needs.

In articles [11, 12] schemes of gripping devices with the use of combination of several Bernoulli grippers are offered. Such designs provide the minimum deformation at the expense of more equal distribution of pressure on surface of object of manipulation. Probe of power impact of ejections Bernoulli grippers on deformation of objects of manipulation are presented in papers [13, 14]. Bernoulli grippers are actively used for capture of fabrics and textile materials [10, 15]. In particular, with annular nozzle possibility of capture of skin authors of article [16] were engaged in influence of designs of grippers. Comparison of energy efficiency of Bernoulli grippers and vortex grippers is presented in [17]. This study systematically compares the two grippers and provides an objective reference to enable users to choose an appropriate gripper.

Bernoulli grippers have a number of advantages, but in this direction there are no sufficient theoretical and pilot studies which would allow to create the designs having the increased loading capacity and economical use of compressed air. In particular, it is expedient to carry out the analysis of influence of geometrical parameters of an annular nozzle and an active surface of Bernoulli grippers on its power characteristics and energy efficiency.
2. Methodology of Investigation

A typical constructive scheme of Bernoulli gripper with annular nozzle is shown in Fig. 1. The deflector 2, forming with the internal surface of the case camera 3 for supply of compressed air through bore 4, and with facet of the central bore of the case annular conical nozzle 5 is installed in the case of 1 gripper. Annular air flow, escaping through nozzle 5 and refracting to surface of object of manipulation (OM) 6, further, between butt of the case and object, forms flat radial stream. High speed of stream at the exit from annular nozzle promotes the ejection phenomenon, as a result, absolute pressure $p_1$ on surface of OM, in zone opposite to conical insert 2, decreases to size smaller atmospheric $p_a$. It leads to emergence of aerodynamic effect of attraction of OM to gripper butt. Side offset of OM in its own plane prevents special thrust blocks [18] or frictional elements [19-22].

Considering that distribution of absolute pressure of $p_1$ on surface of OM, it is almost symmetric concerning the BGD shaft and it is possible to find the size of power interaction.

$$F = 2\pi \int_0^\eta (p_a - p_1) rdr.$$  

The mathematical model of course of air in radial interval between the interacting surfaces of BGD and OM is based on Navier-Stokes's equations average according to Reynolds (RANS) [23, 24]. The SST model of turbulence [25] and γ-model of laminar and turbulent transition are used [26] for carrying out modeling. The γ-model of a laminar-turbulent transition is described by one differential equation for the coefficient of interference γ:

$$\frac{\partial (\rho \gamma)}{\partial t} + \frac{\partial (\rho V_j \gamma)}{\partial x_j} = P_k - E_k + \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\gamma} \right) \frac{\partial \gamma}{\partial x_j} \right],$$

where $\rho$ – air density; $t$ – time; $x$ – coordinate; $V$ – vector of air velocity; $P_k, E_k$ – respectively generative and dissipation members of managing directors of laminar and turbulent transition; $\mu$ – molecular dynamic viscosity of gas; $\mu_t$ – turbulent dynamic viscosity of gas; $\sigma_\gamma = 1.0$ – model constant.

In the γ-model of the transition, the modified SST model equations are used:

$$\frac{\partial}{\partial t} \left( \rho k \right) + \frac{\partial}{\partial x_j} \left( \rho V_j k \right) = P_k - R_k - D_k + \frac{\partial}{\partial x_j} \left( \mu + \sigma_k \mu_t \right) \frac{\partial k}{\partial x_j},$$

and

$$\frac{\partial}{\partial t} \left( \rho \omega \right) + \frac{\partial}{\partial x_j} \left( \rho V_j \omega \right) = \alpha \frac{P_k}{v_t} - D_\omega + C_d \omega + \frac{\partial}{\partial x_j} \left( \mu + \sigma_\omega \mu_t \right) \frac{\partial \omega}{\partial x_j},$$

where $k$ – kinetic turbulent energy; $\omega$ – the specific speed of dissipation of kinetic energy of turbulence; $P_k, D_k$ – original generation and dissipation of the SST model; $R_k$ – the additional part, which provides the correct gain of turbulent viscosity in transitional area at a very low level of turbulent viscosity of the running stream; $v_t$ – turbulent kinematic viscosity of gas; $\sigma_k, \alpha, \alpha_1$ – empirical constants of a model.

Numerical simulation of the air flow dynamics in the chamber, nozzle, and radial gap using the SST γ-turbulence model will be carried out in the ANSYS-CFX computing hydro-gas dynamics environment. For calculation purposes, the environments of this program in a settlement area have constructed unstructured final and differential grid. The total number of knots in a settlement area makes 3 million. Knots of a grid are united in volume elements (tetrahedrons and prisms). The total number of volume elements of a grid equals to 7 million. The total number of tetrahedrons makes 3 million. The air as ideal gas, is used as a material, from libraries of the program. Boundary conditions for a model of the air flow are presented in Fig. 2.
3. Results and Discussions

Characteristics of the BGD and their energy efficiency depend on the following basic parameters: air pressure in the working chamber \( p_3 \); geometric parameters of the annular nozzle \( 5 \), which affects the form and direction of air jet leakage; geometric parameters of the radial gap between the interacting surfaces of the BGD and the OM.

The air pressure in the gripper chamber determines, to a large extent, the velocity \( V_1 \) of the jet at the outlet of the annular nozzle \( 5 \) and the mass flow rate of air \( G \). Given that the cross-sectional area of the \( 3 \) BGD chamber is much larger than the annular nozzle, one can determine the velocity \( V_1 \) of the air jet at the outlet of the nozzle using the Saint-Venant-Wantsel formula [27].

\[
V_1 = \varphi \sqrt{\frac{2k}{k-1} \left( \frac{p_0 - p_1}{\rho_0 - \rho_1} \right)}, \tag{5}
\]

where \( k \) – adiabatic index (for air \( k = 1.4 \)); \( p_0, \rho_0 \) – respectively, the absolute pressure and air density in the gripper chamber \( 3 \); \( p_1, \rho_1 \) – respectively, the absolute pressure and air density in the outlet section of the annular nozzle; \( \varphi = \frac{1}{2} \left( 1 + \zeta_0 + \zeta_1 \right) \) – the coefficient of speed, which depends on the coefficients of flow energy loss at the inlet of the air into the nozzle \( \zeta_0 \) and the losses of air friction to the nozzle walls \( \zeta_1 \) [28].

At gauge air pressures in the chamber \( 3 \) of the gripper of the larger \( p_{bg} > 0.08 \text{ MPa} \) [29], at the point of greatest narrowing of the annular nozzle the radius \( r_0 \) reaches a critical velocity equal to the local velocity of sound [27].

\[
V^* = \sqrt{\frac{2k}{k+1} RT_0}, \tag{6}
\]

where \( R = 287.14 \text{ J} / (\text{kg} \cdot \text{K}) \) - gas became for air; \( T_0 \) - absolute temperature of air in the chamber \( 3 \) of the gripper.

Taking into account that in the factory pneumatic networks pressure is \( 0.5 - 0.7 \text{ MPa} \), for determining the mass flow of air we use the formula for supercritical regime (\( p_a / p_i > 0.53 \)).

\[
G = \mu S_0 p_0 \sqrt{\frac{2}{RT_0} \frac{k}{k+1} \left( \frac{2}{k+1} \right)^{\frac{3}{4}}}, \tag{7}
\]

where \( \mu = \varphi \varepsilon \) – air flow coefficient; \( \varepsilon \) - coefficient of compression of the flow in the nozzle (for \( l_b/h_0 > 4 \), \( \varepsilon = 1 \) [28]); \( S_0 = 2\pi r_0 h_0 \) - the area of the smallest (critical) section of the annular nozzle.

From formula (5) it is obvious that in order to achieve maximum vacuum (\( p_a - p_i \)) on the surface of the OM, it is necessary to ensure the maximum speed at the exit from the annular nozzle. Accordingly, an increase in the velocity of the air flow from the annular nozzle will increase the lifting capacity of the gripper, also increase the zone of aerodynamic effect and reduce the time of capture of objects.

Often, in the designs of the Bernoulli gripper, a circular taper (Fig. 1) or a radial nozzle having a constant thickness \( h_t \) is used. However, these nozzles will not achieve high supersonic velocities due to the lack of expansion of the flow and the loss of the air flow on the viscous friction. The speed of air at the outlet of these nozzles slightly exceeds the speed of a sound in the critical section (7). To achieve supersonic velocities at the outlet of an annular nozzle, it is necessary to provide a greater degree of expansion of the air flow (usually 2.5... 3 times). To determine the effect of the shape of the nozzle on the nature of the air flow and its velocity, numerical simulation was carried out in the Ansys-CFX medium for the boundary conditions given in Fig. 2 and the geometric parameters of the transonic and supersonic nozzles represented in Fig. 3 and Fig. 4. In this case, other design parameters are taken equal: \( r_3 = 30 \text{ mm}; h_1 = h_2 = 0.2 \text{ mm} \).

![Fig. 3 Geometrical parameters of an annular transonic nozzle](image3.png)

![Fig. 4 Geometric parameters of an annular supersonic nozzle](image4.png)
The results of modeling in the form of a line of the air flow in the chamber, in the BGD nozzle and in the radial interval with a graphical representation of the velocity distribution are shown in Fig. 5.

Fig. 5 The speed and lines of the air flow in the chamber, in the nozzle of the BGD and in the radial gap: a - is an annular transonic nozzle; b - is an annular supersonic nozzle

As it can be seen from the figures above, the flow enters the annular nozzles at a speed equal to 270...290 m/s, which corresponds approximately to the local sound speed of 312 m/s according to formula 7. At the exit of the transonic nozzle, the speed on the midline is 370 m/s, and at the output of the supersonic nozzle - 550 m/s. The nature of the flow of air at the exit from the annular nozzle and when entering the radial gap is sufficiently complex. For example, when the flow enters the radial gap, it gradually expands to magnitude, so for the transonic nozzle the air velocity reaches supersonic values $h_2$, and for the supersonic nozzle it continues to grow. Such conditions of the supersonic flow are unstable for further expansion, therefore, on a certain radius, the supersonic flow is jump-free in the subsonic stream. The subsequent expansion of the flow, as a rule, leads to the emergence of critical conditions and the subsequent occurrence of supersonic flow. Accordingly, in the future, the flow will again jump to subsonic. As a result of further expansion, the velocity of the subsonic flow decreases.

In addition, the shape of the surface of the capillary end has a significant influence on the air velocity in the radial gap and the nature of the pressure distribution on the OM surface. It should be smooth and ensure smooth flow expansion in order to ensure its intrusive mode of motion. The active surface of the gripper can be flat, conical, spherical, toroidal or consist of a combination of these elementary surfaces [29]. The greatest strengths of the BGD are achieved when the active surface is a combination of plane and toroidal surfaces (Fig. 1).

The results of numerical modeling of pressure distribution on the surface of the object of manipulation for various variants of the construction of the annular nozzle and the end surface of the Bernoulli gripper are presented in Fig. 6. Simulation was performed for the radial gap $h_2 = 0.2$ mm. For the gripper with a plane-toroidal active surface is taken $r_2 = 13$ mm, $\delta = 0.3$ mm. Other design parameters have not changed.

Fig. 6 Distribution of pressure on the surface of the manipulation object in various embodiments of the gripper design
Consequently, when using a supersonic nozzle in the design of the BGD, approximately 20 kPa increased the dilution in the zone in front of the conical insert. Compared to a typical planar active surface layer, the width of the supersonic dilution zone has increased with the use of a combination of a plane and a toroidal surface. In this case, in the subsonic zone, instead of excess pressure (in the case of a flat surface), the rarefaction will act on the surface of the OM (in the case of a combination of a plane and a toroidal surface).

As a result of the integration of the pressure distribution data on the surface of the object of manipulation, according to formula (1), graphs of the dependence of the attraction force of the object on the magnitude of the radial gap for different variants of the constructive execution of the annular nozzle and the end surface of the BGD (Fig. 7) were constructed.

![Fig. 7 Charts of the dependence of the lifting force of the object of manipulation on the magnitude of the radial gap](image)

As it can be seen from the graphs, the growth of lifting force with the use of a plane-toroidal active surface of the gripper is 60% compared to a typical gripper with a plane active surface. The use in the design of the gripper of the supersonic annular nozzle will further increase the lifting force by 15%, with the increase in compressed air consumption by only 5%. Also, when using a supersonic annular nozzle, the maximum attraction force will be reached at higher values of the radial gap \( h_2 \), which is a positive factor in manipulating objects with significant deviations from the plane or with a significant surface roughness.

The studies confirm the need to improve the design of the Bernoulli grippers, in particular the shape of the annular nozzle and its active surface. In the future, a study of the dynamic characteristics of the Bernoulli grippers should be conducted in order to find such structural parameters, which provide high speed, reliability and stability of contactless gripping of objects of manipulation.

4. Conclusions

Based on the results of numerical simulation of airflow dynamics in the annular nozzle of the Bernoulli gripper and in the radial gap between its active surface and the surface of the plane transport object, the need for improvement of these structural elements of the gripper has been proved.

It was established that the execution of the end of the Bernoulli gripper as a series of combinations of plane and toroidal surfaces increases the size of the supersonic dilution zone and the amount of rarefaction in the subsonic zone on the object of transport. Compared to a typical Bernoulli gripper with a flat end surface, it provides a lift of up to 60%.

It was found that an increase in the velocity of the air flow from the annular nozzle will increase the lifting capacity of Bernoulli grippers. It has been proved that when using the supersonic annular nozzle jet extractor, the amount of rarefaction on the surface of the object of manipulation in the area opposite the conic insertion increases, which allows an additional increase of lifting force by 15%, with the increase of compressed air consumption by only 5%.

References


Modeling the Demand for Transport Services with the Use of Joinpoint Regression

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Abstract

Currently, demand forecasting is an integral part of strategies of companies – including transport companies – allowing to adjust the potential and resources to the expectations of the market. Effective actions in this area guarantee achieving a competitive advantage and increasing sales of products and services. Such permanent data analysis is also a specific element of company diagnostics. It provides a chance to learn the relations taking place in the company, notice irregularities and correct them quickly. The key, however, is to apply the right mathematical methods and tools to describe economic phenomena in a reliable manner and to draw reliable conclusions. This article uses the example of a transport company to present the application of a joinpoint regression to mathematically describe the unexpected market situation in which the company finds itself and to formulate an appropriate forecast.

KEY WORDS: transport services, joinpoint regression, demand, forecasting

1. Introduction

The subject of the survey is a company providing national transport services. The company's offer is very flexible and includes transport of standard parcels and pallets, as well as oversized cargo. High quality of services provided, safety of transport, a large fleet of owned trucks and a team of experienced employees resulted in gradual building of the brand and strengthening of the position on the market, as evidenced by the constantly growing group of customers.

However, at some point in time this situation was threatened by the entry on the market of a large international company offering a wide range of transport services at lower prices. This had a negative impact on sales in the examined company and forced the company to rebuild its strategy. Analytical tools for forecasting future developments, based on time series analysis provide support for such decisions. This article presents an example of their application.

2. Analysis and Assessment of Collected Observations

2.1. Preparation of Data for Research

The analysis covered transport operations carried out since the beginning of 2016. These were monthly observations expressed in the number of kilometers driven. It is not without reason that such a measure was chosen. This translates into the assessment of the number of vehicles maintained. In the case of demand much smaller than the potential available, selling on of the trucks may be considered, whereas if an upward trend is noticed, it is necessary to increase the transport capacity by purchasing new ones. The analysis proposed in the article is also a tool conducive to making decisions in this respect.

An important step in the methodology using time series analysis is the visual assessment of the collected information. It makes it possible to assess the shaping of demand over the period in question. It becomes the first source of information on the dependencies taking place. The number of kilometers driven (when carrying cargo loads) in the analyzed period from January 2016 to April 2019 is presented in Fig. 1.

![Fig. 1 Diagram of the time series of transport tasks carried out [thousands of km]](image)

The presented graph clearly shows the monthly seasonality occurring in transport, quite characteristic of this industry. A collapse of the trend (in April 2018) is also noticeable, which results from the emergence of strong competition...
on the market. It is clearly visible on the graph of transport variability in individual years of the analyzed period (Fig. 2).

![Fig. 2 Diagram of transport variability in individual years](image)

Fig. 2 shows a characteristic increase in demand for transport in the period from March to September in 2016 and 2017, while in March 2018, this trend is clearly collapsing. However, the seasonality is still preserved, the occurrence of which is confirmed by the calculated measures of descriptive statistics (Table 1). A gradual rebuilding of the position after the emergence of competition is noticeable as well.

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<td>305.2</td>
<td>221.2</td>
<td>336.6</td>
<td>50.7</td>
<td>17.3</td>
</tr>
<tr>
<td>February</td>
<td>297.2</td>
<td>310.9</td>
<td>220.4</td>
<td>346.5</td>
<td>54.6</td>
<td>18.4</td>
</tr>
<tr>
<td>March</td>
<td>355.4</td>
<td>370.9</td>
<td>273.6</td>
<td>406.4</td>
<td>57.6</td>
<td>16.2</td>
</tr>
<tr>
<td>April</td>
<td>331.1</td>
<td>333.6</td>
<td>262.4</td>
<td>394.8</td>
<td>61.1</td>
<td>18.5</td>
</tr>
<tr>
<td>May</td>
<td>352.8</td>
<td>374.9</td>
<td>280.6</td>
<td>403.0</td>
<td>64.1</td>
<td>18.2</td>
</tr>
<tr>
<td>June</td>
<td>377.8</td>
<td>404.8</td>
<td>300.8</td>
<td>427.9</td>
<td>67.7</td>
<td>17.9</td>
</tr>
<tr>
<td>July</td>
<td>390.2</td>
<td>418.0</td>
<td>310.0</td>
<td>442.8</td>
<td>70.6</td>
<td>18.1</td>
</tr>
<tr>
<td>August</td>
<td>402.9</td>
<td>434.5</td>
<td>319.8</td>
<td>454.3</td>
<td>72.6</td>
<td>18.0</td>
</tr>
<tr>
<td>September</td>
<td>424.1</td>
<td>454.4</td>
<td>337.0</td>
<td>480.9</td>
<td>76.6</td>
<td>18.1</td>
</tr>
<tr>
<td>October</td>
<td>405.7</td>
<td>439.2</td>
<td>320.6</td>
<td>457.3</td>
<td>74.3</td>
<td>18.3</td>
</tr>
<tr>
<td>November</td>
<td>372.1</td>
<td>405.6</td>
<td>293.5</td>
<td>417.1</td>
<td>68.3</td>
<td>18.3</td>
</tr>
<tr>
<td>December</td>
<td>317.6</td>
<td>342.0</td>
<td>244.0</td>
<td>366.8</td>
<td>64.9</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Therefore, the main conclusion from the preliminary analysis is the observed monthly seasonality, the occurrence of a development trend and the collapse in demand resulting from the emergence of competition. All these elements must be included in the mathematical model [1].

### 2.2. Construction of Model 1

In the first stage of the study, the considered relationships were described by means of a function taking into account only the trend and the random fluctuations (1):

\[
y_i = f(t) + \xi_i,
\]

where \( f(t) \) – the analytical form of the trend function; \( \xi_i \) - random fluctuations

A linear function – Fig. 3 and a polynomial function – Fig. 4 were proposed.

The linear function decreases from the very beginning, while the values of the quadratic function, after reaching the maximum in the first quarter of 2017, also begin to decrease. This result is not consistent with intuition and indications found on the graph in Fig. 4, where the value of transport tasks is steadily increasing until competition emerges, as confirmed by the frame graph of transport tasks carried out in 2016 and 2017 (Fig. 5).
As the proposed functions of the trend did not reflect satisfactorily the realization of the phenomenon, a decision was made to use a segmented trend, estimated on the basis of the observed turning point [2, 4]. To this end, an additional variable $k$ corresponding to the emergence of competition had to be introduced into the model. It takes a value of zero for the observation before the shift in the trend and the value of one after the shift. This makes it possible to estimate the parameters of the model (2):

$$\hat{y}_t = a_0 + a_1 t + (b_0 + b_1) k.$$  

(2)

As a result, at the turning point the absolute term $a_0$ is modified by $a_1$ while the directional coefficient $b_0$ is modified by $b_1$. The parameters of such a model can be estimated in the way adopted for traditional joinpoint regression, using 2 exogenous variables [2, 5]. The results of this estimation are presented in Table 2.

<table>
<thead>
<tr>
<th>Absolute term</th>
<th>t</th>
<th>k</th>
<th>b</th>
<th>b SE</th>
<th>t(37)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>371</td>
<td>1.4</td>
<td>-135.64</td>
<td>17.9</td>
<td>1.1</td>
<td>20.71</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Table 2

Results of model 1 parameters estimation

In this way the following function was obtained (3):

$$y = 371 - 135k + 1.4t.$$  

(3)
The graph of which, together with the course of real observations, is presented in Fig. 6.

![Graph showing observed and forecasted transport tasks](image)

Fig. 6 Linear trend functions and empirical observations graph

Although Fig. 6 shows that the proposed function reflects the upward trend well, it does not take into account existing seasonal fluctuations. Moreover, the parameter for the variable \( t \) is statistically insignificant. All this causes the fit of the model to the empirical data to be unsatisfactory. This is also reflected in the adjusted determination factor, which is only 66%. Therefore, it is necessary to include seasonal variations in the model as well. For this purpose, model no. 2 was proposed, which takes into account not only the segmented trend, but also the monthly seasonality [2, 4].

### 2.3. Construction of Model 2

The fact that the monthly seasonality model does not include the classical exogenous variable (a quantitative one) in the regression model. The dependent variable corresponding to individual calendar months is a qualitative variable and therefore should be recoded into binary variables (with values of zeros and ones) corresponding to individual months. They were marked from \( M_1 \) (January) to \( M_{12} \) (December). Since the number of qualitative variables is limited, they cannot be treated in the regression model as continuous variables. Estimation of model parameters using the least squares method is only possible if one of these variables is omitted. The excluded variable is then the reference level for the others. In this case it was decided to remove the variable from the model \( M_{12} \), which corresponds to December, and carry out the estimation of model 2 parameter, the results of which are presented in the Table 3.

<table>
<thead>
<tr>
<th>Results of model 2 parameters estimation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N = 40 )</td>
</tr>
<tr>
<td>Absolute</td>
</tr>
<tr>
<td>( t )</td>
</tr>
<tr>
<td>( k )</td>
</tr>
<tr>
<td>January</td>
</tr>
<tr>
<td>February</td>
</tr>
<tr>
<td>March</td>
</tr>
<tr>
<td>April</td>
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<td>June</td>
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<td>July</td>
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<tr>
<td>August</td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>October</td>
</tr>
<tr>
<td>November</td>
</tr>
</tbody>
</table>

In this way the following function was obtained:

\[
y = 321 - 152.8k + 1.98t - 28.38M_1 - 25.25M_2 + 31.04M_3 + 42.9M_4 + 49.6M_5 + 72.08M_6 + 82.53M_7 + 93.17M_8 + 112.41M_9 + 92.05M_{10} + 56.45M_{11},
\]

(4)

the graph of which, together with the empirical observations, is presented in Fig. 7.
The fit of the forecast function is definitely better than in case of model 1, the deviations are not large which can be clearly seen in the approximate graph in Fig. 8. This is also confirmed by the calculated coefficient of determination, which in this case equals 99%.

The last element of the research is the diagnostics of the proposed model. It is based on the analysis of its residuals. If the model is properly constructed, the distribution of its residuals should be random and normal. In order to examine the above features, the autocorrelation function was determined first. As Fig. 9 shows, in most of its course there are no significant values of the function, which means that there are no dependencies in the residuals which were unexplained by the model.
The study on the normality of residuals distribution also provided satisfactory results indicating that it is consistent with the theoretical distribution. The result of the Kolmogorov–Smirnov test at the significance level \( \alpha = 0.05 \) did not allow to reject the \( H_0 \) hypothesis of normality of distribution (p-value = 0.75). The histogram of the distribution of residuals together with the fitting to the theoretical distribution is shown in Fig. 10.

Therefore, the conducted research allows to consider the model as correct.

3. Conclusions

Constructing mathematical models supporting the analysis of the company's functioning and enabling the forecasting of future events is one of the elements of gaining a competitive advantage. It allows to adjust the company's strategy to the needs and expectations of customers and, if necessary, to modify it in response to the changing market situation [3, 6]. Effective forecasting of demand is hampered by factors disrupting its stable course. These include – as presented in the article – e.g. seasonality of the process or occurrence of events that are difficult to predict. Often, a multitude of factors influencing the studied phenomenon can be a problem as well, especially when the capability of identifying and describing them is limited.

However, in many situations the use of appropriate econometric tools and methods enables the estimation of models taking such interference into account. The article presents the application of a jointpoint regression model with the use of a non-classical form of the trend. In a situation where traditional models of development trends did not produce the expected results, and even indicated a completely different interpretation of the phenomenon, the segmented trend proved to be a good solution. In addition, taking into account the monthly seasonality made it possible to obtain a reliable model allowing to describe the demand for transport services in the analyzed company. The study showed that the company is gradually rebuilding its lost position and that even in a difficult market situation of economic downturn, it is possible to restructure its strategy in a way enabling it to stay on the market. However, it requires rapid and effective intervention.

References

Use of Mobile Fans to Ensure the Safety of Road Tunnels During Fire

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Abstract

Tunnel structures are usually underground structures forming the infrastructure of a territory that has several specifics. Special requirements are also related to ensuring the safety of tunnels. One of the most important devices involved in ensuring safety is ventilation that is designed in many variants. Ventilation is a technical device where the possibility of defect or failure cannot be completely excluded. An alternative solution to ensure fire ventilation for tunnels can be the mobile fans of rescue units. The resulting effect achieved by mobile fans, especially the air flow velocity in the tunnel, is influenced by many aspects, including the length of the tunnel, the tunnel cross-section, the influence of external conditions, etc. The possibility of using mobile fans will be described in a case study based on a real experiment. Results of the case study show that in some cases mobile fans can be a suitable solution for directing the movement of smoke resulting from fires in a road tunnel. They can provide good conditions for firefighting. However, this is an extraordinary solution that can only complement the design solution for emergency incidents in a road tunnel. Standard tunnel safety systems, including ventilation, cannot be replaced by mobile fans.

KEY WORDS: tunnel, fire, ventilation, flow velocity, mobile fans

1. Introduction

The construction of a tunnel is a complicated building complex equipped with a number of elements, structures and devices that allow for the operation of the tunnel and participate, in many cases, in securing its safety. On the basis of the requirements of the Regulation of the European Parliament and Council (EU) no. 305/2011, which defines harmonised terms for the introduction of structural products to the market and cancels the Direction of the Council 89/106/EEC [1], the properties that the construction of road tunnels shall meet include requirements for fire safety. The mentioned requirements include the retention of the load capacity in the case of fire, the limitation of fire which defines harmonised terms for the introduction of structural products to the market and cancels the Direction of the Council 89/106/EEC [1], the properties that the construction of road tunnels shall meet include requirements for fire safety. The mentioned requirements include the retention of the load capacity in the case of fire, the limitation of fire spreading inside and outside of buildings, the provision of the evacuation and rescue of persons and the securing of the safety of fire and rescue units.

The requirements for the minimum level of the safety of tunnel structures within the European Union are defined by the Directive of the European Parliament and Council 2004/54/EC on minimum safety requirements for the tunnels of the Trans-European Transport Network. Technical and operating conditions are prescribed for tunnels with a length of more than 500 m. [2].

Inspiring ideas can also be taken from the recommendations of the World Road Association (PIARC) [3].

The most important national regulation in the Czech Republic from the viewpoint of fire safety is government regulation no. 264/2009 Coll., on safety requirements for tunnels on roads longer than 500 metres [4].

Other significant legal regulations that apply to the construction of road tunnels in the Czech Republic include especially Act no. 133/1985 Coll., on fire safety, as amended [5], Directive no. 246/2001 Coll., on the stipulation of the conditions of fire safety and the performance of the state fire safety supervision (the directive on fire prevention), as amended by Directive no. 221/2014 Coll. [6], and Directive no. 23/2008 Coll., on the technical conditions of fire safety in structures, as amended by Directive no. 268/2011 Coll [7].

An important technical standard is ČSN 737507 The Design of Road Tunnels [8], which defines detailed rules for the design of road tunnels. Another important supporting document for the design of road tunnels is composed of regulations issued by the Directorate of Roads and Highways of the Ministry of Interior of the Czech Republic within its quality policy [9]. The category of other regulations also includes the Fighting Rules of fire brigades and methodological sheets issued by the Ministry of Interior of the Czech Republic.

From the viewpoint of operating requirements the constructions of tunnels longer than 350 m are categorized as structures with increased or high fire danger [5, 6]. The mentioned classification means that as far as the operation of
tunnels is concerned, it is necessary to meet a number of requirements from the viewpoint of fire safety. In order to fight fires effectively it is obligatory to procure and install suitable types of fire fighting equipment, extinguishing substances, fire fighting technical devices, material means of fire prevention in working condition and to provide for their inspections and maintenance by qualified persons.

In order to be able to deal with extraordinary situations it is necessary to prepare the constructions of tunnels from the structural, technical and operational point of view. Meeting the stated requirements is based on the cooperation of the designer, the supplier of the construction, the tunnel operator and fire and rescue services.

One of the important requirements to secure safety is ventilation. The requirements for tunnel ventilation can be divided into operating requirements and safety (fire fighting) requirements. The operating requirements can be understood as securing a suitable environment for persons who might find themselves in tunnels. The safety requirements mean the creation of conditions to secure the safe evacuation of persons and to allow for the efficient intervention of rescue services [10].

The objective of this article is to assess the possible use of a mobile tunnel ventilator for the ventilation of the tunnel, the creation of the conditions for evacuation and the intervention of rescue services.

2. Extraordinary Events in Road Tunnels Abroad and in the Czech Republic

The operation of the structures of road tunnels has historically been accompanied by a number of extraordinary events. Fires are among the most dangerous of them. The most significant fires in road tunnels include the fire in the Salang Tunnel in Afghanistan in 1982, with 176 dead, the fire in the Mont Blanc Tunnel in France in 1999, with 39 dead, or the fire in the Gotthard Tunnel in Switzerland in 2001, with more than 100 dead. Other significant fires were the fire in the tunnel on the highway between Florence and Bologna in 1993, with 4 people killed, the fire in the Pfänder Tunnel near Bregenz in Austria in 1995, with 3 people killed, and the fire in the road tunnel near Palermo in 1996, with 5 people killed. The causes of these fires were traffic accidents or the ignitions of vehicles [3].

In the period between 2013 and 2018 there were annually 2 to 5 fires in road tunnels in the Czech Republic [11]. In relation to the mean total number of fires in the Czech Republic, which amounts to about 20,000, this number is negligible [12]. Although the mentioned fires in the Czech Republic did not bring about any significant loss in lives, material damage or damage to the environment, the historic events prove that the consequences of fires in tunnels may be catastrophic [13, 14].

3. The Characteristics of Tunnel Constructions

A tunnel is a linear underground structure with roads (highways, roads or local communications) passing through it that allows for the fluent and safe travel of vehicles by travelling under mountain ranges, water body obstacles, settled areas, culturally and historically or economically precious areas, etc. The tunnel shall meet the requirements of fire prevention, safety and health protection of persons (users and the operator’s employees), the fluent and safe travel of vehicles and also the terms of economic management and minimum demands for the working maintenance of tunnels under operation [8].

The tunnels may be categorized from many viewpoints. The most important categorizations of tunnels are based on their length, the type of operation and the combination of length and traffic intensity [8].

Based on length, tunnels may be divided into the following types:
- short (100 to 500 m);
- medium (500 to 1,000 m);
- long (over 1,000 m) [8].

From the viewpoint of operation, the tunnels are either for one-way traffic or for two-way traffic.

Based on length and traffic intensity tunnels are divided into the following categories:
- category TA;
- category TB;
- category TC-H;
- category TC;
- category TD-H;
- category TD [8].

The scope of requirements from the safety viewpoint significantly depends on the tunnel categorization based on the combination of length and traffic intensity. The requirements for the securing of the conditions of fire safety in tunnels increase with the increasing length and traffic intensity.

4. Influences Acting on the Flow of Smoke in a Tunnel

The movement of smoke occurring during fires in tunnels is, similar to other structures, influenced by a set of factors of lesser or greater importance. Basic factors acting on the movement of smoke for the aforementioned structures include especially the following [15]:
- the geometry of the tunnel;
- the chimney effect;
the influence of standing vehicles;
wind;
upward pressure effect created by fire;
increase in the volumes of gases;
air conditioning devices.

When designing fire ventilation in tunnels it is necessary to take the mentioned influences into consideration. The described influences also significantly influence the operation of mobile ventilators.

5. The description of the Object of the Case Study

This case study has been created for the existing road tunnels in Klimkovice in the Moravia-Silesian Region near the city of Ostrava in the Czech Republic (Fig. 1). The Klimkovice tunnel is a part of D47 highway in the section Bílovec – Ostrava, Rudná. The tunnel is constructed as a one-way tunnel with two tunnel pipes. The length of the tunnel amounts to about 1,000 m. The length of the roadway is 9.5 m, the width of two-sided pavements is 1 and 1.2 m, the height of the passage cross-section is 4.8 m. The tunnel pipes have a longitudinal incline of 0.6%. The tunnel pipes are interconnected with 5 shafts.

The tunnel is equipped with longitudinal ventilation composed of 8 pairs of ventilators. The ventilators comply with standard requirements in the Czech Republic, i.e. they shall retain their function in temperatures of 400°C for the period of 90 minutes. The ventilators are put into operation after every 5 seconds.

The operation of the tunnel started in 2008.

6. The Description of the Situation

When performing the tests of mobile ventilation the efforts were focused on the creation of conditions that would be close to the real conditions that may occur during the operation of the tunnel, especially in the case of an extraordinary event. In compliance with this philosophy, 14 trucks and 13 passenger cars were placed in the tunnel. The number of vehicles in the tunnel was determined on the basis of the data on the envisaged traffic intensity and the proportional representation of vehicles (cars, trucks and buses). The location of the vehicles is depicted in Fig. 2.

7. The Characteristics of the Mobile Tunnel Ventilator

The mobile tunnel ventilator MTV 2500 manufactured by Rosenbauer International Aktiengesellschaft, Austria, (Fig. 3) was used for the test. The ventilator with dimensions 5,200/2,180/2,800 mm and a weight of 2,800 kg is equipped
with a diesel operated motor with the output of 92.7 kW with a mechanical injection pump, a turbocharger of smoke gases, an intercooler and liquid-based cooling. The undercarriage is equipped with an axial ventilator with a diameter of 1,600 mm with the transported flow of air mass of 213,000 m³.h⁻¹ and, when used in the tunnel, of up to 1,000,000 m³.h⁻¹. The ventilator is equipped with a hoop with jets for the creation of water mist (the reach distance of mist is up to 70 m from the ventilator) [16].

The mobile ventilator was placed at the Ostrava portal and subsequently put into operation. The flow ventilators were in the static state (put out of operation).

8. The Measuring of Air Flow in the Tunnel

The efficiency of the ventilator was verified without the operation of the ventilation installed in the tunnel. The measuring was secured by fixed and mobile measuring points. These were:
- a meteorological station placed before the tunnel at the Brno portal (meteo);
- fixed measuring points embedded in the tunnel near the Ostrava portal (OV) and the Brno portal (BR) in the tunnel;
- mobile measuring points were secured by the Fire Rescue Brigade of the Moravian-Silesian region (HZS MSK), K.B.K. Fire company (K.B.K. Fire) and Technical University of Ostrava, Faculty of Safety Engineering (VŠB-TU).

The fixed measuring points were located approximately 300 m from each portal. Mobile measuring points were located approximately 100 m, 300 and 400 m behind the focal point of the fire (in the direction of the Brno portal).

All measuring points, with the exception of measuring provided by HZS MSK, measured continually. The measuring by HZS MSK took place intermittently with the interval of 1 minute.

9. The Results of the Study

Before the commencement of the measuring the longitudinal ventilation installed in the tunnel (flow ventilators) was put out of operation, subsequently the mobile tunnel ventilator was put into operation.

In the course of the test the following values were monitored:
- the speed of air flow in the tunnel;
- the time needed for the achievement of the highest air flow speed during the operation of the mobile ventilator.

The results of the test are depicted in Fig. 4.
The mobile ventilator achieved within 4 minutes the air flow speed of approximately 2 to 3 m.s\(^{-1}\) (mean measured value).

At the time of measuring, the speed of wind at the portal was approximately 5 m.s\(^{-1}\) in the opposite direction of the action of the mobile tunnel ventilator (data from Meteo). In the quiet state (without the action of headwind) the mobile ventilator can achieve an air flow speed in the tunnel pipe of 3 to 3.2 m.s\(^{-1}\).

### 10. Conclusions

In general terms it shall be stated that the results obtained from the study executed in the Klikovice tunnel can directly be related only to the constructions of tunnels of similar geometric dimensions and conditions corresponding to the terms of the tests. Under different conditions, especially if the geometric dimensions were different (especially the length), if a different number of vehicles was in the tunnel (the influence of traffic intensity) and if the ambient conditions changed, the results achieved may be different.

The use of the results is limited to a certain extent due to the missing real focal point of fire and heat output that would be generated in the case of fire. The system of fire ventilation in the tunnel is designed for the so-called design fire. The determination of the output of the design fire is significantly influenced by the intensity of the occurrence of trucks, related to a time unit (usually a day) and the length of the tunnel. In relation to this mentioned parameter the heat output of the design fire is 5, 30 and 50 MW. A different heat output can be determined as the basis of risk analysis. When designing the fire ventilation the output of 30 MW is usually taken as the envisaged heat output \[18, 19\].

Smoke shells placed in metal vessels were used to visualize the movement of air in the tunnel. Thus one of the factors that usually act on the movement of smoke in the tunnel, i.e. upward pressure effect created by fire, was missing.

In the course of the measurements the air flow speed achieved was 2 to 3 m.s\(^{-1}\), without the headwind at the portal it would be 3 to 3.2 m.s\(^{-1}\).

The Klikovice tunnel, where the case study was executed, is categorised as the tunnel of the T1 category from the viewpoint of the requirement for air flow speed to be achieved by longitudinal ventilation, i.e. the tunnel with one-way traffic and a small probability of congestion (typical for highway tunnels) \[10\]. For the stated tunnel category it is usually required that air flow speed at the level of so-called critical speed be achieved, however at most the speed of 10 m.s\(^{-1}\). The critical speed of air flow can be determined by the Kennedy model \[20\] and is usually within the range of 3 to 3.5 m.s\(^{-1}\).

The air flow speed achieved in the tunnel by the mobile tunnel ventilator was approaching the value of critical speed.

The results of the study can be interpreted as proving that in the case of the failure of the fire ventilation in the tunnel similar results could also be achieved with a mobile tunnel ventilator. A certain problem can be the time needed for the transportation of the ventilator to the tunnel and for its putting into operation. Such time includes the time for the detection of a fire with a system of electric fire signalization, the time for the dispatch of rescue units, the time of travel of rescue units to the tunnel, the time for the preparation of the ventilator for putting into operation. It is likely that this will be a time period during which the evacuation of persons will have already been completed \[21\]. Thus the mobile tunnel ventilator can be utilised rather only for securing the effective intervention of the rescue units.

The results of the study confirm that the mobile tunnel ventilator is a device that can effectively contribute to the solution of extraordinary events in the structures of road tunnels. The primary use lies in the creation of suitable conditions for the intervention of fire and rescue units.

The ventilation of road tunnels with mobile tunnel ventilators shall however be perceived as an extraordinary measure to deal with fires in tunnels, which is also related to the costs of their operation \[22\]. The standard design safety systems for tunnels, including ventilation, cannot be substituted with mobile ventilators.

### Acknowledgements

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Model for Investigating Characteristics of Tracked Vehicle Torsion Bar

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Abstract

Suspension system of tracked vehicles is often fitted with torsion bars. Torsion bar is a key element of the vehicle suspension system. A lifetime of suspension depends primarily on the fatigue life of the torsion bar. An experimental test rig was built to obtain characteristics of the torsion bar. This paper developed a virtual model of the experimental setup for the torsional test of the torsion bar. The torsion bar was modelled as an FE part and dynamic simulation was performed using MSC Adams. The comparison showed no significant difference between simulation results and physical test results on the test rig. The model can be used to investigate the characteristics of the torsion bar and produce load time histories for further fatigue analysis programs.

KEY WORDS: suspension, torsion bar, test rig, FE part.

1. Introduction

The combat vehicle is constructed for advance movement especially in a heavy terrain. The transmission mechanical system has to work under the heavily dynamically stress while the overcoming of heavy terrain (mud, snow, obstacles etc.). It is required that the combat vehicle has to work with the high performance and reliable transmission [1]. High speed tracked vehicles are usually fitted with a suspension system employing torsion bars and shock absorbers to mitigate the terrain-induced shocks and attenuate the vibrations of the vehicle body. The torsion bar substitutes the coil spring in earlier tracked vehicles as it performs spring actions with improved characteristics [2]. In order to evaluate the performance and ride comfort of the vehicle, it is necessary to investigate characteristics of the suspension spring element, whose parameter is the torsion bar stiffness.

Lifetime calculations for machine components represent an important foundation for quantitative reliability methods. For a prediction of a lifetime, all failure causes must be known. These can be divided into three categories [3]:

- Fatigue failures, aging failures, wearout failures and failures caused by environmental influences, for example corrosion, etc., caused by changes in the used materials, dependent upon time, e.g. highly loaded components in automotive technology.
- Tolerance failures lead to unreliable deviations, which forbid an efficient function, for example machine tools, which no longer achieve desired production precision, or seals, which show an unreliable high leakage.
- Failures caused by faults, which occur during production, assembly or during the operation of machines.

To obtain characteristics of the torsional bar, a test rig with a measuring system was designed and constructed at the Military Technical Institute of Ground Forces in Vyskov to measure the twisting moment acting on torsion bar and the corresponding twist angle. The test rig provides a sinusoidal excitation to the torsion bar with the same working conditions as the vehicle on road. The frequency and amplitude of terrain profile with constant vehicle speed were presented in the test rig by adapting the plane parallel motion of the hydraulic actuator. After that, the design and simulation of the test rig were carried out by the aid of MSC Adams software.

2. Characteristics of Torsion Bar

A torsion bar suspension, also known as a torsion spring suspension is a general term for any vehicle suspension that uses a torsion bar as its main weight bearing spring. One end of a long metal shaft is attached firmly to the vehicle body, the opposite end terminates in a road wheel arm, mounted perpendicular to the torsion bar. Vertical motion of the wheel causes the torsion bar to twist around its axis and is resisted by the bar's torsional resistance. The effective spring rate of the bar is determined by its length, diameter, and material.

The advantages of the torsion bar are the possibility to adjust the height of the vehicle, unobtrusiveness compared to coil springs and low cost in design and manufacture. Conversely, it also contains some disadvantages: it is heavy, it provides an inferior ride and handling characteristics and it is difficult to control non-linear spring rates.

While tracked vehicle is traveling on road, it is subject to excitation from the road. Vertical motion of the road wheel causes the torsion bar to twist around its axis and is resisted by the bar's torsional resistance. The resistance of the torsion bar to twisting has the same effect as the coil spring used in conventional suspension systems.

From the model of torsion bar suspension as shown in Fig. 1, the vertical force exerted on the road wheel and transmitted through the axle arm to the torsion bar is determined by the formula [4]:

\[ F = k \theta \]
\[ P_w = \frac{GJ}{L} \frac{\beta}{R \cos(\beta_0 - \beta)}, \]  

where \( P_w \) – vertical force transmitted from road wheel to the hull; \( G \) – shear modulus of torsion bar material; \( J \) – polar second moment of torsion bar cross-section, \( J = \frac{\pi d^4}{32} \); \( d \) – diameter of torsion bar; \( \beta \) – twist angle of torsion bar; \( \beta_0 \) – setting angle of torsion bar; \( L \) – active length of torsion bar.

\[ T = P_w R \cos(\beta_0 - \beta), \]  

where \( T \) – twisting moment on torsion bar; \( R \) – radius of road wheel arm.

Therefore:

\[ T = \frac{GJ}{L} \beta = C \beta, \]  

and

\[ C = \frac{T}{\beta}, \]  

where \( C \) - torsional stiffness of the torsion bar [4].

The torsional stiffness of a uniform rod is dependent on the cross-section diameter, the length, and the shear modulus of elasticity of the rod. Hence, the torsion bar spring rate can be varied by appropriately changing any of the previous parameters [6].

### 3. Design of Test Rig

An experimental test rig equipped with a measuring system has been designed and built to measure the moment acting on the torsion bar and the corresponding twist angle. The measured parameters were used to evaluate vehicle suspension characteristics.

There are several types of machines have been developed to apply this type of loading in laboratory tests. Zero and non-zero mean stress conditions can be reproduced. Torsional tests are performed on axial-type machine. A typical torsional testing machine is shown in Fig. 2. The test bench uses a highly reliable electro-hydraulic servo system, which enables static load and dynamic load to be configured independently.

The actual test rig consists of a hydraulic power unit, hydraulic cylinder - actuator, and a controller as shown in Fig. 3. The hydraulic cylinder with swing arm, substituting the rotary actuator in typical torsion test bench, provides the twist of the torsion bar. The MTS SilentFlo™ Hydraulic Power Unit 505.30 drives the road wheel arm into swing motion through the hydraulic cylinder. The MTS Model 493.02 FlexTest SE Controller made by MTS is a fully digital Proportional, Integral, Derivative, Feedforward (PIDF) servo controller. It provides complete control of one servomotor.
hydraulic channel in an MTS test system. The swing angle of the road arm is measured by the Gyro Enhanced Inclinometer FAS-G of the MicroStrain, Inc.

![Fig. 2 Typical hydraulic torsion test bench [7]](image)

The torsion bar mounted on the test rig, one end was fixed, the other end was connected with the swing arm, which rotated about the longitudinal axis of the torsion bar. Three torsion bars were tested at different twisting angles. The first torsion bar was twisted from 15° to 25° such as it operated in real tracked vehicle. The second torsion bar was twisted from 15° to 30°. The range of the third torsion bar was from 15° to 40°. The first and the second torsion bars were swung with a frequency of 1.5 Hz, it was 5400000 cycles. The third torsion bar operated with frequency 1 Hz, it was 360000 cycles.

Due to the limitation of the hydraulic power unit, the test rig was unable to work with the twisting angles of the torsion bar exceeding than 40°.

![Fig. 3 Experimental test rig](image)

The experimental results were obtained after measuring the applied torque on the torsion bar and the corresponding twist angle. The twisting angle was measured by means of the gyro inclinometer FAS-G while the applied torque was measured by a system of pressure gauges as shown in Fig. 4. The summary of the twist angle and the corresponding torque of the torsion bar measured was shown in the Table 1.

![Fig. 4 Experiment results](image)
Twist angle and torque of torsion bar

<table>
<thead>
<tr>
<th>Twist angle [°]</th>
<th>15</th>
<th>25</th>
<th>30</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisting moment [kNm]</td>
<td>7.7</td>
<td>13.0</td>
<td>15.5</td>
<td>20.6</td>
</tr>
</tbody>
</table>

4. Model of Experiment Setup

In this study, the model of the test rig was built and tested using MSC Adams software. Virtual model allows simulating the torsion bar at the large twist angles that test trig cannot. In this model, the torsion bar was represented by a 3D beam comprised of a single FE part of twelve nodes. One end is constrained with the ground and the other end is constrained with swing arm (Fig. 5).

The FE part is a wholly Adams-native modelling object with inertia properties and is accurate for very large deformation cases of beam-like structures. The FE part differs from the linear flexible body option within Adams Flex in two significant ways: Firstly, it has the ability to accurately represent large deformations which the linear modes approach cannot. Secondly, its modelling does not require an FEA-produced file like the modal neutral file. The FE Part also differs from the beam force element in that it possesses inertia properties [8].

5. Simulation Results

For the test rig model and through experiment, the following data were applied: torsion bar diameter – 52 mm, torsion bar active length – 1960 mm, shear modulus of torsion bar material – 80.23 kN/mm².

Running dynamic analysis, obtained the twist angle and the corresponding torque acting on the torsion bar, the simulation results were described in Fig. 6 and Table 2.

<table>
<thead>
<tr>
<th>Twist angle, °</th>
<th>15</th>
<th>25</th>
<th>30</th>
<th>40</th>
<th>53</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisting moment [kNm]</td>
<td>7.6</td>
<td>12.7</td>
<td>15.2</td>
<td>20.3</td>
<td>26.9</td>
</tr>
</tbody>
</table>
The comparison of experimental and simulation results was shown in the Table 3.

<table>
<thead>
<tr>
<th>Twist angle, °</th>
<th>15</th>
<th>25</th>
<th>30</th>
<th>40</th>
<th>53</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisting moment [kNm]</td>
<td>Experiment</td>
<td>7.7</td>
<td>13.0</td>
<td>15.5</td>
<td>20.6</td>
</tr>
<tr>
<td>Simulation</td>
<td>7.6</td>
<td>12.7</td>
<td>15.2</td>
<td>20.3</td>
<td>26.9</td>
</tr>
</tbody>
</table>

It is obvious from the Table 3 that the results of physical tests and simulation have an insignificant difference. The model can also provide the simulation results at the large twist angles which cannot be implemented on the test rig.

6. Conclusions

In this paper, an investigation of tracked vehicle torsion bar characteristics was carried out experimentally using a new designed and manufactured test rig.

The model of the test rig was built and dynamic simulation was performed. The simulation results were compared with experimental results, obtained on the experimental test rig. The comparison showed a good agreement between the results, which proved the accordance of the model.

For the model of the test rig, simulation conditions can be varied on demands and it saves time and experiment costs. The model can be modified and used to investigate the behaviour of a torsion bar and produce load time histories for fatigue analysis programs.

Acknowledgment

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References

Safety Analysis of Pedestrian as the users of Road Traffic in the Slovak Republic

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Abstract

The article deals with the current state of traffic accidents in Slovakia. The unfavorable trend is documented on the basis of statistical data for the last 7 years and on the assessment of the consequences of road accidents. Based on the assessment of the development of traffic accidents, the authors identify areas with the highest traffic accident, define risk groups of road users and determine possible causes of traffic accidents. Given that the current state of transport infrastructure in high-risk areas it does not allow sufficient throughput of traffic flows and additional infrastructure expansion is not possible in urban areas, it is important to look for new, progressive tools that will make the transport system more efficient and safer. The authors of the article propose appropriate precautions to reduce traffic accidents and reduce the negative consequences of road accidents. A separate chapter is a case study.

KEY WORDS: pedestrian, safety, accident, road transport

1. Introduction

The most vulnerable participants road traffic are pedestrians, and that notably children and the elderly. Pedestrian meetings and road vehicles may end up with with the consequences of minor or severe injuries in some cases and killing pedestrians. Pedestrian represents a person, that moves by walking on the roads thereby becomes a participant road traffic and team for him arising obligation to comply prescribed rules. Act of the National Council of the Slovak Republic no. 8/2009 Coll. on Road Traffic and about change and amendments to certain laws (hereinafter referred to as "Road Traffic Act") modifies basic concepts pertaining to road traffic rules of the road. Rights and obligations non-motorized road users as well as drivers of road vehicles and administrative offenses for violation this Act [1, 13].

Traffic accidents they have a stochastic character and therefore randomness is also present and the interplay usually hardly unforeseeable circumstances from the outside environment, as well as the inscrutability of behavior other participants road traffic. Large share on the creation accidents have chauffeurs of road vehicles with their ruthlessness, lack of foresight, aggressiveness and the driving hazard. From pedestrians drivers can expect that they suddenly enter the runway do not pay attention to road traffic and pedestrian crossings behave ill-considered. For children behavior is impulsive they are not able to estimate distance and time have a narrowed field of view and insufficiently developed motor coordination. Elderly among others have impaired visual ability and perception, less concentration and prolonged reaction time what leads to more difficult adaptation certain road traffic requirements [2, 6].

With traffic accidents with the participation of pedestrians You may be encountered almost daily, and therefore it's important to look for the causes of traffic accidents, the degree of fault on the part of road accidents, site with the highest number of road accidents, to analyze the seasonal development of traffic accidents, and also focus on traffic accidents among pedestrians as the most vulnerable a group of road users. The course of a traffic accident can be solved by mathematical-graphical analysis movement of vehicles processed by PC-Crash application program version 12.0. designed to simulate the interaction of vehicles and bodies. Accuracy of speed outputs is within ± 5% of the input variables. The course of the accident it is possible to comment based on facts that have been detected at the scene of the accident from the photo documentation technical description of the vehicle, inspecting the place of traffic accident and information obtained from the documents the accident in question. Based on the analysis of traffic accidents is possible then determine the appropriate preventive measures to reduce the accident rate. as well as reducing the negative consequences of road accidents [4, 5, 7-9].

2. Development of Traffic Accidents on Place of Slovak Republic

Statistical data on the development of traffic accidents criteria have a authorized importance, as these data are helpful in analyzing the causes and consequences of traffic accidents, in improving road safety, in identifying accident prevention measures, etc. Through traffic accident analysis is possible appropriate preventive measures to reduce traffic
accidents, as well as reducing the negative consequences of road accidents [3].

On the territory of the Slovak Republic (hereinafter referred to as SR) is dedicated attention trend in traffic accidents through traffic accident statistics because it is not essential to track only the number of traffic accidents but also the associated negative consequences. There is a substantial difference if in a traffic accident, the road user kills, if the participant gets hurt, or if the participant is not injured and only material damage occurred. Development of traffic accidents in the Slovak Republic during the period 2011 – 2017 is processed through statistical data (Fig. 1) which are targeted to the current status traffic accidents involving pedestrians as non-motorized road users.

By Fig. 1 shows that in the period 2011-2017 has the development accidents with minor injuries fluctuating tendency. During last three years the number of these road accidents increased by 16%. Is not successful well in the long run reduce the number of road accidents resulting in serious injuries. The development of these accidents was almost constant over the reporting period. Traffic accidents were reduced in the period 2011-2013 with the participation pedestrians of killed, whereas in 2013 this decline was almost 46%. The worst period was during 2014 and 2015, when he was in traffic accidents recorded the largest number of killed pedestrians. In the following years can be considered the development trend of traffic accidents with the participation of killed pedestrians.

Accident indicators are the most common criteria used for evaluating the safety of pedestrians in the Slovak Republic. They serve for a more detailed assessment of traffic accidents. Table 1 shows the severity of accidents moderate severity of accidents and the relative degree of safety.

<table>
<thead>
<tr>
<th>Year</th>
<th>Severity of accidents</th>
<th>Central seriousness of accidents</th>
<th>Relative degree of security</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>2,98E+04</td>
<td>2,55E+01</td>
<td>1,17E+03</td>
</tr>
<tr>
<td>2012</td>
<td>2,95E+04</td>
<td>2,39E+01</td>
<td>1,15E+03</td>
</tr>
<tr>
<td>2013</td>
<td>2,99E+04</td>
<td>2,68E+01</td>
<td>1,17E+03</td>
</tr>
<tr>
<td>2014</td>
<td>2,89E+04</td>
<td>2,42E+01</td>
<td>1,13E+03</td>
</tr>
<tr>
<td>2015</td>
<td>3,08E+04</td>
<td>2,50E+01</td>
<td>1,20E+03</td>
</tr>
<tr>
<td>2016</td>
<td>2,92E+04</td>
<td>2,33E+01</td>
<td>1,14E+03</td>
</tr>
<tr>
<td>2017</td>
<td>2,81E+04</td>
<td>2,25E+01</td>
<td>1,10E+03</td>
</tr>
</tbody>
</table>

More accurate view the situation can be obtained in differentiating regional differences, such as at the level of self-governing regions. More detailed development of traffic accidents involving pedestrians by region in the period 2010-2017 is shown in Fig. 2.

For negative perhaps evaluate the that, is not successful in the longer term, reduce the number of road accidents involving pedestrians and their development rather fluctuating in the period under review. Traffic accidents are most common involving pedestrians in the Bratislava and Košice regions, and vice versa the least in the Trenčín and Trnava regions. Between the counties with the largest representation killed pedestrians they mainly include the Žilina and Prešov regions. Region of Nitra and Trenčín have the lowest representation in these traffic accidents. In the Trnava Region as one it thrives longer reduce the number of traffic accidents resulting in death.

For more objective comparison number development accidents in individual regions is in the following Table 2 road accident calculation described the population and on the length of the road network individual regions. Most people live in Prešov and Košice regions, on the contrary, the least population has Trnava and Trenčín regions. Most kilometers of road network has Banská Bystrica and Prešov regions. The conversion is the order of the regions with the most traffic accidents the same as per 10 000 inhabitants, but dominates the Bratislava region, which exceeded other regions several times. Traffic Accident Results of the Bratislava Region they are markedly determined traffic situation in Bratislava, city with high intensity and concentrated traffic in a relatively small area. Relatively high accident rate compared to other regions also has the Žilina Region [12].
The most common traffic collisions occurs when a pedestrian suddenly enters the road from the sidewalk changes the walking path he doesn't look around or does not estimate the distance and vehicle speed. Most dead pedestrians usually resides in autumn and winter, which are characterized by bad weather, when drivers must drive in difficult conditions (rain, snow, fog, long nights and short days). These difficult conditions result reduced visibility which increases probability collisions. Pedestrians should be separately careful in winter and should be disciplined and considerate, do not overestimate your skills and skills and observe the principle of see and be seen. As for safe driving in the winter it requires experience from drivers and more demanding technology especially sense for gentle vehicle control in the case of shear. An important role he also has a good one technical condition of the vehicle [7, 8].

Vehicle drivers are in difficult conditions to drive at a reasonable speed under the NRSR Act no. 315/1996 Coll. on road traffic as amended in particular, given the fact that that while driving at night are often dazzled by headlights oncoming traffic. For that, to the driver of the person or objects noticed, not enough to be in the field of vision but they must also be aware of them. This term is called apperance - the conscious arrangement of perception. For safe driving is important, make the driver's optical look was fast enough and that drivers can do it quickly register items and the people around them [5, 6].

In the next part of the post is attention dedicated to accident analysis of a traffic accident pedestrian participation (specifically pedestrian and minor pedestrian) under reduced visibility (at night). In analyzing accident events will be based on the overall situation the occurrence and course of a traffic accident the place of collision between the vehicle and the pedestrian (road user) as well as vacation operating and impact speed at a traffic accident site. It also will determine the cause of a traffic accident from a technical point of view and will be considered the possibility of a traffic accident on the diversion.

3. Accident Analysis Selected Traffic Accident Pedestrian Participation

The accident in question between a ŠKODA passenger car and a pedestrian occurred during the night in a residential area and public lighting in the local communications sector where the maximum permitted speed is 50 km/h. At the time of the road accident reconnaissance, the road surface was dry unpolluted (coefficient of friction between vehicle tires and given road surface $\mu = \text{approx. } 0,8$) lit by lamps street lighting continuously located on the right side of the road. Based on groundwork from the file a plan was prepared from a traffic accident site real directional and width parameters on the basis of which she was then simulation of accident event performed by mathematical-simulation program for Traffic Accident Analysis PC-Crash 12.0 (Fig. 3) [10].
For accident analysis is necessary know mutual vehicle position and walker on the road at the time of impact. During crash the body with the vehicle occurred in the first phase to contact right and left foot, with the right front of the vehicle. Subsequently occurred, to positions when the hull of the pedestrian hit the front hood on the right with the emergence of all injuries in the pelvis and chest. In the next phase of the accident, the pedestrian's body rotated, where due to the rotation of the body come into contact head with windscreen (multiple skull fractures) and then the body hit the road, where the slip phase followed walkers to the final position biological (blood) footprint on the road [6]. See the following figure is the movement of the vehicle (2D and 3D) and pedestrians from the moment of collision, to stop them in their final positions (Fig. 4).

According to the analysis video recording that walker after entry on the road from the edge of the road made 8 steps in the first part motion 5 m for about 3.7 seconds to speed up from standing to reach maximum speed in a given section about 6 km/h taking after passing this track stopped. In the second part of the walker walk she took a step backwards with a distance of about 0.5 m for about 0.5 seconds. Walker Movement from entering the road until a moment collisions lasted approximately 4.2 seconds. Minor walker he began to walk about 0.8 seconds rather than a pedestrian. At the moment of collision the vehicle was moving from right to left lane and a walker she was approximately in the middle of the road mid-line left from the view of driving the vehicle. This pedestrian stood, respectively Just before the crash step backwards. In terms of pedestrian movement it is logical and corresponding to the standard and the expected movement of pedestrians in an effort to pass on the other side of the communication [10]. When analyzing a traffic accident in the dark or reduced visibility it is necessary to distinguish consistently when the driver can for the first time

Fig. 3 Road accident plan [10]

Fig. 4 The relative position of the ŠKODA and pedestrians at the time of collision [11]
an obstacle physiologically and technically observe and when it can recognize what an obstacle it is. The difference between sighting and recognition may be large and dependent on \( E \) (lx) lighting brightness \( L \) (cd.m) and contrast (%). The decisive quantity is the contrast margin at which the obstacle is still visible. Between the illuminated part of the road and a potential obstacle must the difference in brightness - contrast at such a value to be an obstacle perceptible to the human eye.

Driving a vehicle in the dark they provide the driver with a view of the headlights that direct light into a suitable light cone to illuminate the road effectively in front of the vehicle. The following picture the lighting analysis is displayed area in front of the vehicle on the road bounded by curves of approx. 1.5 lx (Fig. 5). This area is bounded by an inner green border [5, 6, 7].

Fig. 5 Analysis area lighting in front of the vehicle on the road bounded by curves of about 1.5 lx [11]

Inspection was found that pedestrian movement (left to right) is possible recognize the at a distance of about 40 m and in case the driver evaluates view the entire width of the road at the pedestrian crossing point across the road (Street lighting lamps improve street visibility). For minimum surveillance distance is possible 30 m. From accident analysis (including video analysis) revealed that the lotion started to react on pedestrians crossing across the road at the moment when from them located at a distance of about 29 m [10].

In contact body of a pedestrian with a vehicle, occurred to mutual force-to the action, pedestrian and vehicle. Mutual force action left on the vehicle deformation and damage which must correspond in kind, size and direction with the vehicle's relative position and the body of a pedestrian at the moment of collision and the walker movement immediately after collision. Damage to the vehicle (range and species) must correspond to the impact speed of the vehicle to the pedestrian, weight and height walker, walking away, which then have to correspond with injuries to the pedestrian. A walker's distance away about 10 meters corresponds to the impact speed between 34 and 43 km/h (minimum impact velocity value resulting from discarding). In this case speed appropriate to vision distance 40 to 50 meters moves between 66 and 77 km/h. Vehicle driver did not move at a higher speed what was the speed proportionate to the outlook. It should be noted speed of about 65 km/h she is considered based on video analysis at minimum speed movement of the vehicle at the time of the vodka reaction conflict situation road traffic. Lotion had no technical possibility to prevent a traffic accident earlier reaction when driving at 65 km/h. If the vehicle's driver was moving with the vehicle at the start of the reaction 50 km / h (maximum allowed speed for a given road segment) it would stop in front of the pedestrian movement corridor (accident prevention) at a distance of about 2 meters [10].

Before the clash, driver of the vehicle responded so, that vehicle was intense braked. In an effort avoid collision situation (avoiding the pedestrian on the left) she started to perform evasive maneuver where in the opposite lane your right front side she caught the pedestrian, taking a minor pedestrian went to the other side of the road. Under conditions which ones occurred during an accident (opposite vehicle movement) can be stated that it is technically acceptable and very likely that driver pedestrian movement responded in time. The evasive maneuver itself cannot be tagged for the wrong element of vehicle driving technique since the driver recognized the collision situation about 1.8 seconds before the crash and tried "in time" postpone deduction since stopping it was no longer possible. Impossibility of stopping to the point of collision she was in this case mainly due to the speed of the vehicle. At this point lotion she couldn't know that the pedestrian stops. Avoiding maneuver is common and subconscious reaction of drivers to a collision situation when is it obvious that it is not possible stop to the point of collision [10].

Technical cause the accident in question is necessary evaluate in relationship to the question legal and that or have pedestrians before entering the road expect, that on the road they can move and vehicles at speed over 65 km/h and therefore or with regard to this situation have evaluate movement of vehicles on the road. From a technical point of view it is acceptable that pedestrian not assessed real vehicle speed and, that lotion was moving at a higher speed like speed for that section maximum vacation [10].

The objective of traffic accident analysis is, to find such parameters in the technique of the drivings vehicles, and in how to use pedestrian communication, where a traffic accident would not occur. To stop the vehicle, in front of the before pedestrian crossing (accident prevention) would need to start at about 65 km/h react at a distance of about 40 m in front of the pedestrian movement corridor (approx. 3.4 seconds before collision). Pedestrians at unchanged speed movement would be safe have left the vehicle motion corridor. Based on results of the experiment can be stated that vehicle driver probably did not have a distance option (39 m) observe the pedestrian's movement on the road (also taking into account the unknown motor vehicle and the accident site communication profile). A pedestrian would be a traffic accident prevented in such a way if, before entering the carriageway, it assesses the actual vehicle speed and then transition through the road only after passing the vehicle. Probably due at your speed movement situation so that the incoming...
vehicle will pass (run across). Given to speed incoming vehicle your decision run over across the road and stopped roughly in the middle of the road near the center line what would be the case that would be a vehicle driver did not change the direction of travel in the opposite lane accident [10].

4. Precautions to Reduce Traffic Accidents Pedestrian

In road traffic is the safety of pedestrians determined by summary various sub-aspects but to meet challenging goals reduce the number of victims they have to be account is taken of all aspects. If it can't be avoid a clash between pedestrian and vehicle there is a possibility through various measures on the vehicle reduce the severity of the consequences traffic accident for pedestrians. Safeguard measures on the vehicle can be divided measures traffic accident or mitigating consequences of a traffic accident [2, 3].

Implementation of assistance systems for drivers (eg braking assistance) lead new approaches for pedestrian protection. Before the actual onset of a necessary pedestrian collision it is possible to reduce kinetic energy in the system and thus mitigate the consequences of a traffic accident. Attention and expands from the actual course of the accident also for a period of time before the first contact of the participants. In contrast, passive measures on the vehicle itself only then, when it happened to a clash between the pedestrian and the vehicle. Crucial is to reduce the speed difference between the pedestrian and the vehicle accelerating tolerable biomechanical human body. To alleviate the severity of the injury, he must be a contact area between the pedestrian and the vehicle. In traffic accidents the pedestrian is most often captured front of the vehicle therefore, these parts of the vehicle would should be secured mitigation measures accidents, especially bumper parts headlamp and radiator grille bonnet, but also the window area [4, 5, 8].

Fig. 6 shows categorization of measures on vehicles focused on to increase safety unprotected road users.

![Fig. 6 Categorization of measures on vehicles focused on to increase safety unprotected road users](image)

Fig. 6 Categorization of measures on vehicles focused on to increase safety unprotected road users [2]

Dangerous places for pedestrians they can for certain Circumstances all kinds of communications. Critical places are pedestrian crossings near large crossroads or in close proximity to directional arcs or multi-lane communications. Pedestrian crossings enable pedestrians to cross the road safely and they are equipped with horizontal traffic signs. Choosing the location of the passes it is determined on the basis of several aspects, for example, a safe place to allow pedestrians and drivers. Pedestrian crossings must be adapted to the type of communication as well as the intensity of transport of vehicles and pedestrians. Underpasses and entrances are often used, which serve as an alternative route in the area which is more difficult to pass through or completely impermeable. It is important that there are passages for drivers well visible to pedestrians and also, that pedestrians be able to see the vehicle at a sufficient distance when driving safely across the road. With reduced visibility and at night, the passage must be sufficiently illuminated [1-3, 7].

This issue has been solved for a long time from the perspective of pedestrians and their protection, and also in terms of security traffic flow. Many security measures have been introduced, such as the establishment of islets, that shorten the length of the pass on multi-lane roads or protective concrete blocks between driving directions or lanes. They are also important vertical and road signs or passages with increased crawl area that prevent drivers go disproportionately fast. Low budget measures include psychological and physical elements. Psychological elements can be used once or repeatedly. A disposable element is, for example, a device application to measure speed at the beginning of the village or when entering a residential area or a pedestrian crossing alert. Repeated element for example, it is forced to comply with the speed limit or repeating information with increasing force [2-4].

One of the main pillars of traffic accident prevention is a traffic education for children and youth. The main goal is to teach children and young people to be safe in the traffic environment could predict possible risks correctly assess the situation respond to these situations. Human education and education safety is a lifelong process which runs in several planes. Traffic education focused on adults and seniors should rest in maintaining previously acquired attitudes and
Pedestrian traffic accidents generally are events to which there road traffic when the vehicle moves with the pedestrian. These events, join with extensive material damage with light or severe consequences the health of road users or oftentimes even with irreplaceable losses on human lives. Accident indicators are the most common criterion for pedestrian safety assessment where the severity of traffic accidents is assessed and also the relative safety level. Traffic accident rate is stochastic which affects several factors, such as foreseeable circumstances from the outside unreasonable drivers unexpected or impulsive behavior of road users bad weather and other difficult conditions while driving.

In the contribution in question was made and the accident analysis of a selected pedestrian traffic accident Adult Walker and Minor Walker) under reduced visibility. Establishment was assessed and the accident, the place of collision of the vehicle and the pedestrian as well as operating and crash speed at a traffic accident site the cause of the traffic accident has been determined technically and options were also assessed accidents to avert it.

Traffic accident prevention is one of our company’s priorities. Number of traffic accidents pedestrian participation can be reduced for example with full speed reduction completing sidewalks with appropriate street lighting as well as deformation zones in front of vehicles to minimize pedestrian injuries. Attention should also be paid various preventive programs, activities and measures traffic education for children and youth, as well as lifelong learning road users which can be effective safety individual road users at the same time in reducing traffic accidents.

Acknowledgment

This article was supported by the scientific research project VEGA 1/0159/19 Evaluation of the level of resilience of key elements of land transport infrastructure.

References

10. Case study of an expert examination – Accident analysis selected traffic accident pedestrian participation
11. SW PC Crash, 10.9, SW XL Vision™

competences, or to obtain new information from this area. A large share of the population upbringing to safety they have driving schools in transport safe or defensive driving courses driver training, etc. [1-3].

For lifelong learning of man in the field of road safety perhaps media. Just daily press, Whether TV presents information to the public for example about planned changes in transport legislation on police traffic-safety actions or traffic accidents. Belongs here and a number of conferences and seminars organized for the general public which then content and knowledge of these shares in your problem-solving work in the field of road safety [2, 3].

5. Conclusion
Conditions of Loading of Live Animals in International Transport on the Example of Horses – EU Approach

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Abstract

The transport of live animals is determined by many factors. A particular determinant is the welfare of the animal, which is the basis of the ethical code of conduct with animals. Providing adequate physical and mental condition in international transport is a huge challenge for all participants in the transport process. As it results from the practice, the final quality of the transport process consists not only of the displacement itself and procedures related to it. An important determinant here is ensuring proper conditions for loading and unloading of animals. The quantity and quality of these procedures have a significant impact on the condition of the horses being transported. In the international system, horse loading procedures are subject to numerous regulations and procedures. The purpose of the article is to identify the conditions that must be met in order to safely and in compliance with the applicable regulations, load and transport horses as part of international movements. The article was based on the analysis of literature, legal acts and participant observations.

KEY WORDS: International transport, horses transport, loading horses, UE animal transport

1. Introduction

The globalization and internationalization processes have made transport one of the most dynamically developing economic areas in the modern world. It is determined by the numerous expectations of a diverse group of stakeholders. It must be implemented efficiently and effectively to bring appropriate benefits to its organizers and the network of entities participating in it. It should be implemented using appropriate technical means affecting its quality. It is important that it takes place in accordance with the legal and administrative conditions affecting its legality and suitability. The transport process must also take into account numerous standards specific to a given good, such as veterinary, sanitary or social norms. It must also create the right conditions for the benefit of owners of the transported goods and their subcontractors. And above all, it must ensure the proper condition of the object of transport. Modern technology makes it possible to transport almost everything. However, international transport of live animals such as horses is a special place in transport processes.

Horses and transport are interrelated elements. For hundreds of years horses were the essence of the terrestrial transport system - as a tractive force - they were transported themselves as sick animals themselves. In the given ages, a man who carried out his movements by water often took his companion - a horse- with him. What was the most difficult element in this whole process was the loading of horses - not used to traveling by means of transport. Over the years and technological development, especially changes in transport technology, the role and purpose of horses has also changed. Today, many of them are the subject of the transport process not only by water or land, but also by air. Regardless of changes in technology and development of means of transport, one of the most difficult elements of the horse transport process remains their loading.

Taking into consideration the specificity of the connection between man and horses and the special relationship of society to horses, it is extremely important to observe the General Welfare Conditions. Everyone, who meet and work with horses should accept that at all times the welfare of the Horse must be paramount. Welfare of the horse must never be subordinated to competitive or commercial influences. The most basic, generally respected by the environment, rules in this area include [1, 4, 10]:

- Good Horse management especially stabling and feeding must be compatible with the best Horse management practices. Clean and good quality forage, feed and water must always be available.
- Horses must only undergo training that matches their physical capabilities and level of maturity for their respective of type using. They must not be subjected to methods which are abusive or cause fear.
- During transportation, Horses must be fully protected against injuries and other health risks. Vehicles must be safe, well ventilated, maintained to a high standard, disinfected regularly and driven by competent personnel. Competent handlers must always be available to manage the Horses.
- All journeys must be planned carefully, and Horses allowed regular rest periods with access to food and water.
- Veterinary treatment and veterinary expertise must always be available at all horse procedure If injuries are sufficiently severe, a Horse may need to be euthanased on humane grounds by a veterinarian as soon as possible, with the sole aim of minimising suffering.
Observance of these rules affects the organization of all processes related to horses. This is a sine qua non condition. Considering the unpredictability of animal behavior and psychological and veterinary conditions to keep horses in proper condition during their movement - as an expression of concern for them - a number of regulations have been created to ensure the safety of animals and people. Their observance is one of the conditions for maintaining symbiosis in these relations.

The purpose of the article is to identify the conditions that must be met in order to safely and in compliance with the applicable regulations, load and transport horses as part of international movements. The article was based on the analysis of literature, legal acts and participant observations.

2. Loading and Unloading in the Animal Transport Process

The key determinant of animal welfare is the way in which transport is conducted. The stress response during loading and the initial stages of transport may be minimized by careful handling, good design of facilities, and appropriate stocking densities and driving techniques [18]. General rules for the transport of animals within the EU regulate Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations [14]. According to this Council Regulation, transport means the movement of animals effected by one or more means of transport and the related operations, including loading, unloading, transfer and rest, until the unloading of the animals at the place of destination is completed (Fig. 1). Apparently, this process is not a problem. In the place of departure, animals are loaded onto the means of transport, in order to move to their place of destination. There unloading takes place (Fig. 1). Whereby the place of departure should be understood the place at which the animal is first loaded on to a means of transport, provided that it had been accommodated there for at least 48 hours prior to the time of departure. And place of destination means the place at which an animal is unloaded from a means of transport and accommodated for at least 48 hours prior to the time of departure or slaughtered [2, 12].

![Fig. 1 Transport](image)

Council Regulation (EC) No 1/2005 defines the concept of journey and it means the entire transport operation from the place of departure to the place of destination, including any unloading, accommodation and loading occurring at intermediate points in the journey [14]. The intermediate points (Fig. 2) means place of rest or transfer means any stop during the journey which is not a place of destination, including a place where animals have changed the means of transport, with or without being unloaded. This is of particular importance when carrying out long-term transport, i.e. exceeding 8 hours, with the obligation to unload and load animals [3, 7].

![Fig. 2 Transport with intermediate point with loading and unloading](image)

A seemingly simple process involving the loading of animals at the place of shipment, moving them to the final destination and unloading, is in fact a sequence of complex operations with a set of their conditions, especially in relation to international transport (Fig. 3).
The international transport process means transport with crossing the country border at Border Inspection Point (Post) (Fig. 4). Customs, veterinary and safety inspections are carried out there. In these points, both persons, means of transport and goods transported are checked, both in terms of physical, documentation, technical and such that results from the specificity of the goods and the type of transport [6, 9].

General rules for the crossing of EU borders by live animals were developed in Council Directive 91/496 / EEC [11]. Procedures for the entering and disposal of live animals in relation to the EU territory are regulated in a number of specific provisions, including those relating to specific types of animals. The most important normative acts include [8, 14, 21]:


According to Community legislation each consignment of live animals and products of animal origin must be subject to official veterinary checks in the border inspection [9, 17]. The official controls include at least a systematic [10, 11]:

- documentary check shall mean verification of the veterinary certificates or documents accompanying an animal;
- identity check shall mean verification, by visual inspection only, for consistency between the documents or certificates and the animals and for the presence and conformity of the marks which must appear on the animals;
- physical check shall mean a check of the animal itself, possibly including sampling and laboratory testing and, where appropriate, additional checks during quarantine.

Live animals entering the European Union are inspected at a Border Inspection Post (BIP) - as listed in Commission Decision 2009/821/EC [4] and Council Directive 91/496/EEC [12] down the principles governing the organisation of veterinary checks on animals entering the European Union from non-EU countries [4]. Border Inspection Post (BIP) shall mean any inspection post located in the immediate vicinity of the external border of one of the territories referred to in Annex I to Council Directive 90/675/EEC of 10 December 1990 [11, 13] laying down the principles governing the organization of veterinary checks on products entering the Community from third countries and designated and approved in accordance with Article 6 CD 91/496/EEC [12]. The BIP must be located and constructed in such a way that animals can be inspected there and if necessary, to keep and store animals there. If any consignment of animals has to be detained during transport for more than two hours, the competent authority shall ensure that appropriate arrangements are made for the care of the animals and, where necessary, their feeding, watering, unloading and accommodation [5, 13, 14]. This means that in these points appropriate conditions must be created for unloading and loading of animals that will enable safe carrying out of this procedure. All animals are prioritized in border crossing procedures. The BIP must also include people with appropriate qualifications and skills to carry them out.
Movement of animals within the EU generally takes place without the need for controls at the internal borders of individual Member States. However, in the international trade involving road transport of goods, significant help is the use of the TIR Convention. The Customs Convention on the International Transport of Goods under Cover of TIR Carnets (TIR Convention) [15, 22] facilitates the international carriage of goods from one or more customs offices of departure to one or more customs offices of destination (up to a total of four customs offices departure and destination) and through as many countries as necessary (Fig. 5). As a rule, the vehicle remains sealed throughout the TIR transport and, thus, goods are generally not inspected at border crossings. The Convention applies to transports with road vehicles, combinations of vehicles as well as containers and allows for the use of the TIR Carnet for all modes of transport, provided that some portion of the journey is made by road [15, 22]. Such a solution significantly contributes to reducing the number of loading and unloading processes of animals - especially at intermediate border controls. However, it requires the implementation of border control at the place of loading and commencement of the journey and at the place of unloading and ending the journey.

The number of loading and unloading processes affects also of the number and type of transport modes used to carry the shipment from the place of departure to the place of destination, and the means of transport used to carry out the shipment [19, 25]. It is possible to distinguish the basic types of such transports and among them:

- transport by one mode and one means of transport along the entire route - from door to door - requires one loading procedure and one unloading procedure;
- transport by one mode and one means of transport on the main route of transport using the accompanying transport (transport arrangements) - it requires loading and unloading into the main means of transport as well as loading and unloading onto the transport arrangements (Fig. 6);
- transport by one mode of transport on the main transport route but using more than one means of transport - requires loading and unloading processes for means of transport arrangements; whereas, in relation to the change of the transport unit, it is possible to apply a direct trans-shipment from one means of transport to another;
- transport with various mode of transport on the main route of transport - requires loading and unloading from accompanying transport means, but also when changing the means and type of transport it requires unloading and loading along with adaptation to a new means of transport;
- transport by ferry or ro-ro ships - after loading, no animals are to be unloaded from the means of transport, appropriate technical furnishing must be made and the means of transport must be checked and other transport conditions checked, including temperature, air humidity, adequate ventilation of the air; unloading takes place at the destination or intermediate point.

Analyzing transport conditions resulting from the travel plan and their impact on the number of procedures for loading and unloading animals, it is also possible to indicate trips with stops in intermediate points, which are carried out with unloading and loading procedures in rest and transfer places, if the stoppage exceeds 2 hours or such procedures were planned in under the travel plan [21].
3. Transport of Horses

The basic rules for the movement of equidae between EU Member States are regulated in Chapter II, Council Directive 2009/156/EC on health conditions regulating the movement and import of equidae from third countries [10]. According to its provisions, Member States shall approve the movement of registered equidae on their territory or send equidae to another Member State only if they fulfill the relevant conditions. Among them is the requirement of origin from farms free from infectious diseases and bans identified in Article 4 paragraph 5, as well as the lack of contact with other equidae suffering from an infectious or contagious disease, 15 days before the examination confirming the proper health of the horse, confirmed by the appropriate document: a health certificate or a health certificate. This document shall be drawn up 48 days before loading, no later than on the last working day preceding loading. The period of validity of the health certificate or health certificate is 10 days. Registered equidae must be equipped with appropriate identification documents [24, 25]. The horse’s passport is such a document in the EU. The basic principle of the carried out movements is that the horses should be transported as soon as possible from the farm / place of origin to their destination, in vehicles or containers that have been regularly cleaned and disinfected. Transport must be organized in such a way as to effectively protect the health and welfare of equidae.

After reaching their destination, animals must be unloaded, fed, watered and rested for at least 24 hours [17]. If you do not reach your destination after 24 hours of travel, horses should rest (be unloaded, watered, fed) for the next 24 hours in an approved rest and transfer point. Therefore, it is recommended that the horses are fed several hours before the start of loading (3-4 hours before), and an hour before transport watered. Such prepared animals can be transported up to 24 hours without feeding. However, during movements above 24 hours, feed should be fed only when parking [24].

4. Load Space and Means of Transport Condition of Loading

An important technical element related to loading procedures is to ensure an appropriate size of the cargo space. The minimum parameters for individual modes of transport are set out in Annex I, Chapter VII, Council Regulation(EC) 1/2005 [14] (table 1). The processes of loading of animals should be supervised by persons authorized and carried out in such a way as to reduce the animal’s stress level as much as possible. Facilities for loading and unloading, including the flooring, shall be designed, constructed, maintained and operated so as to prevent injury and suffering and minimise excitement and distress during animal movements as well as to ensure the safety of the animals. In particular, surfaces shall not be slippery and lateral protections shall be provided so as to prevent animals from escaping and also be cleaned and disinfected. An element affecting the quality of loading processes is the appropriate construction of a loading ramp, the inclination of which cannot exceed 20 degrees. The ramp should also be equipped with hoof stops to ensure safe and easy entry and descent for horses. Where loading or unloading operations last for more than four hours, appropriate facilities shall be available in order to keep, feed and water the animals outside the means of transport without being tied. And of course operations shall be supervised by an authorised veterinarian and particular precautions shall be taken to ensure that the welfare of the animals is properly maintained during these operations.

<table>
<thead>
<tr>
<th>Transport</th>
<th>Space allowances for animals shall comply at least with the following figures:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Transport by rail</td>
<td>1,75 m² (0,7 × 2,5 m) The standard useable width of wagons is 2 - 2,5 m.</td>
</tr>
<tr>
<td>2 Transport by road</td>
<td>1,75 m² (0,7 × 2,5 m)</td>
</tr>
<tr>
<td>3 Transport by air</td>
<td>Loading density of horses in relation to surface area: 700 — 800 kg is 1,73 m²</td>
</tr>
<tr>
<td>4 Transport by sea</td>
<td>Live weight in kg: 600 — 700 is 2 - 2,25 m²/animal</td>
</tr>
</tbody>
</table>

Horses should be loaded and transported in individual boxes, and separation barriers must be constructed in such a way as to ensure safety and prevent physical interactions between loaded and transported individuals. They must be separated in such a way as to prevent them from digging, biting and tripping during loading and transport. An important element is the use of a suitable floor, ensuring stabilization during transport, and in the case of long-term transports equipped with mulch ensuring proper removal of manure. Means of transport should be constructed and equipped with devices ensuring adequate ventilation, temperature and humidity level, as well as devices to track these parameters and the behavior of horses during transport. All means of transport of animals should have certificates of approval issued by the appropriate authorities or bodies. Carriers should provide appropriate permits, licenses and knowledge and skills in the area of loading, unloading, transporting animals and caring for them. It should be noted that handling facilities can be either: simple economical and high skill depended or more expensive and less depended on the skill of the stock persons[20]. That is why to obtain the right permit, the carrier must also demonstrate the appropriate number of personnel and equipment as well as operational procedures and should have an emergency plan.

5. Veterinary and Psychological Conditions of Horse Loading and Transport

Horses should be loaded and transported under veterinary supervision [14, 17]. The unloading and subsequent
reloading of animals could also be a source of stress for them. Due to the psychophysical construction, frequent reactions to stress in the case of horses are health problems, especially in the area of the digestive system, eg manifested by the intestinal colic. Such situations are very dangerous because they can lead to the death of an animal.

Instinct is significant and must be taken into account. It is instinctive for the horse to get a predator off his back [1]. In a moment of crisis it may do the same to the handling staff. But also instinct tells them to respond to the threat of escape. The second problem is companions. Horses are the stood animal, so they react very badly for loneliness. That is why they travel with the familiar horse or anther animal. But at the same time, special care must be taken in the travel of stallions. The ones that are used for the reproduction are more aggressive and insistent. That is why they have to put up in isolation and under strict control.

Horses are animals of large, open spaces that are afraid of small, dark enclosed spaces. In order for the entrance to the transport unit (container, cargo area) to be safe, it is necessary for the horse to trust the person implementing the procedure [21, 23]. It would be best if the horse was properly prepared. Particularly sports, racing and used horses in demonstrations and security systems are suitable trained and accustomed to the implementation of loading and unloading procedures. The conditions under which these procedures are implemented are also important. Excessive noise, confusion, stormy surroundings - does not make it easier. Unfriendly surroundings may not only cause additional stress, but also cause that the loading will be dangerous (due to the animal's reaction) or make it impossible at all. And what is worth emphasizing premedication before the loading process is inadvisable and in some cases prohibited. The loading and transported horse is subjected to colic, diarrhea, pneumonia, laminitis, separation anxiety, confinement, ventilation and humidity fluctuations, exposure to fumes and particulates, loss of balance, rapid intensity or fluctuations in light levels, accelerations and decelerations, decreased function of the immune system and uncertain footing [16].

When carrying out loading and transporting horses, their limbs should also be secured. Special transport protectors are used for this purpose. Animals in the course of transport by means of transport should also have - in an appropriate way - limited movement to avoid injuries. The loading procedure must also include the time and opportunity to acclimate the animal to the means of transport. This is especially important when transporting wild animals and those that travel for the first time and have not been trained before or accustomed to loading and unloading.

6. Conclusions

The transport of live animals, regardless of their species and purpose, is a huge challenge. The procedures associated with it must take into account both animal welfare, species and individual conditions, veterinary regulations, legal regulations and industry standards. Properly planned, organized and transported is not only the displacement itself, but also the manipulation of the animal, associated, among others, with its loading and unloading. Taking into account the specificity of horses, both their physical and mental characteristics, proper loading is a significant challenge. Especially considering that manipulation procedures are an extremely stressful element for these large animals. Both the means of transport and the appropriate cargo space as well as the service of the processes carried out have a significant impact on the final result. Especially when it is necessary to re-load and unload horses on a single transport process. Improperly carried out loading may even exclude the possibility of carrying out the transport process. Therefore, people who carry out such processes must have not only great knowledge, but also experience in working with horses. This is important especially for animals that were not previously subject to procedures related to relocation. Animal transport is nowadays a widespread economic process resulting from the internationalization of economies and societies. Due to the position and role of horses in the system of relationships with humans, it is necessary to carry out transport and related procedures in such a way that they do not adversely affect the animals being moved.

In summary, there are many factors affecting the loading of horses in the international transport process. Among them, first and foremost, one should mention: the route of transport - its course and length; length and type of journey - planned being procedures its elements; type and amount of used mode and means of transport; formal and legal provisions; loading conditions - technical and surroundings, individual and psychological conditions resulting from the specificity of horses, veterinary conditions and human factor.

It is to be hoped that along with the development of transport technology, the movement of horses and other animals will become a common and harmless element for them and more and more effective for stakeholders.

References

4. Commission Decision 2009/821/EC of 28 September 2009 drawing up a list of approved border inspection posts,
laying down certain rules on the inspections carried out by Commission veterinary experts and laying down the veterinary units in Traces.


Estimation of Ecological Effectiveness of Rail Vehicle Operation in Eurasian Railway Corridors

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Abstract

The article considers the ecological effectiveness of operation of the Eurasian railway corridors. The land transport corridors of the renewable Silk Road are divided into North, Middle and South routes. Using the open access software package EKO TRANSIT WORLD (ETW), a comprehensive comparative analysis of the train pollution in the corridors under consideration was conducted. Ecological efficiency of using the corridor is estimated taking into account the type of energy used for traction on the railway full cycle of well extraction and energy use to the wheels (WTW), from the well to the tank (WTT) and the final phase of energy use from the tank to wheels (TTW). Finally, basic conclusions are provided.

KEY WORDS: railway transport, Eurasian transport land bridge, emissions, comparative analysis, Well-to-Wheels, Well-to-Tank, Tank-to-Wheel

1. Introduction

The main energy consumer and source of pollutants are transport, industry, energy companies, agriculture, households and service sector [1, 2]. In 2008, transport sector has generated one-third CO₂ emission of entire Europe [4]. In addition, emissions of NOₓ and particulate matter have decreased significantly in recent years due to emission control. Nevertheless, half of NOₓ emissions and 1/8 of particulate matters concentration in Germany occurs due to road freight transport.

As freight transport, railway cargo sector also relies mainly on traditional energy haulers like diesel, petrol and heavy fuel oil; it significantly contributes to major challenges of the 21st century pollution and climate change. Nowadays, the transport accounts for about a quarter of global energy-related carbon emissions. This contribution is rising faster than in any other energy end-use sector.

To protect the nature from the impact of economic activity, the following energy tasks are raised: to reduce the pollution of power plants and boiler houses, use renewable energy resources, save energy resources by increasing efficiency, and rationalize combustion processes [5]. It will be aimed in the nearest future to avoid CO₂ gas formation in human industrial activity, i.e., “total decarbonisation” of industrial and transport sectors. The mixed (intermodal) railway and road transport is the measure of ecologic (green) logistics ensuring the consistent implementation of “decarbonisation”. Recently, the land transport in Eurasian rail corridors via renewable “Silk Road” has increased [3]. So-called “Silk Road” is considered the main landbridge that once joined Europe and Asia. Usually, this name means three transportation systems: Land Silk Road, Maritime Silk Road and South Silk Road. The term Silk Road usually refers to land road.

The main energy sources used in rail freight transportation processes are liquid fossil fuel (diesel, kerosene, heavy fuel oil) and electricity. In order to compare an environmental impact of transport processes with different energy sources, it is necessary to consider the entire chain of energy production and use:

1) primary energy carrier (coal, oil, gas, nuclear, etc.);
2) research and extraction of primary energy sources (crude oil), as well as their transportation to oil refinery;
3) fuel production chain;
4) power extraction and transformation in power plant, including the construction and maintenance of power plants;
5) power distribution (electricity grids, transformation, contact losses, fuel transportation to petrol stations, etc.).

It must be noted that railway sector is the most ecologic land transport type; it uses the energy quite efficiently. The cargo transportation by international railways (long distances) can reduce the air pollution and its impact to climate change significantly, especially when electric power from renewable sources is used. Railway sector can provide qualitative and safe services, thus ensuring the sustainable development of Eurasia transport [6].

The sufficient interaction between different modes of transport is not ensured due to inefficient connections between separate modes of transport and lack of general transport network elements. The better interaction can reduce
passenger and cargo freight costs, increase flexibility of transport services and reduce the negative impact of transport system on ecology and social environment. Railway electrification is one of TEN-T development areas. The electrification of the main railway lines or Eurasia corridors would create preconditions for switching from the use of fossil fuels to renewable energy sources in the rail transport sector. Principles of EU transport policy continuity and cohesion retain the validity of previous projects and activities, as well as their development and adaptation potential due to further decision in TEN-T area. It is an important aspect of railway transport development in Europe and Asia, as well as large strategic challenge of European transport system that also requires avoiding any potential conflicts of interest between national sectors [3].

Emission estimation models are developed for the purposes of transport planning; it will be easy for transport managers to use them in assessing the efficiency of transportation processes [8, 9]. Regardless their compactness, the existing models can accurately describe the impact of various traffic conditions on transport emissions. In addition, they provide the transport models of both types using the common indicators (criteria), taking into account the load of roads or railways. The use of popular microscopic and macroscopic models, as well as their adaptation to artificial and real world transport scenarios enables to determine the circumstances under which kind of intermodal transport pollutes the environment less.

The present article analyses the applicability of one of the methodologies for assessing the environmental performance of rail freight. It solves the problems of efficient energy use and ambient pollution reduction of Eurasian railway corridors.

2. Methodology Estimation of Ecological Effectiveness

The EcoTransIT Initiative (thereafter – EWI) is an independent industry driven platform for carriers, logistics service providers and shippers [7]. This instrument is dedicated to maintain and develop a globally recognized tool and methodology for carbon footprints and environmental impact assessments of the freight transport sector. In line with its vision to increase transparency on the environmental impact of the freight transport and to demonstrate the continuous improvement of EcoTransIT methodology and EcoTransIT World (ETW) calculator, EWI members have commissioned their scientific and IT partners to provide an updated methodology report. The methodology was already embedded in the calculator; it follows the guidelines of the standard EN 16258 “Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services” and integrates latest research available for the air pollutants. EcoTransIT World is an Ecological Transport Information Tool – worldwide (ETW). It is free online application that shows the environmental impact of freight transport for any route in the world and any transport mode.

Considering the entire cycle of energy production, distribution and use WTW (Well-to-Wheel) and greenhouse gas emission in accordance with requirements of European standard EN 16258 [8], ETW methodology provides data about WTT (Well-to-Tank) and TTW (Tank-to-Wheel) cycles energy consumption, greenhouse gas emissions and total emissions to the atmosphere.

Eurasian railway transit has few significant advantages compared to air and sea freight services. The most important is the best balance between speed (freight duration) and freight price. Although air transport from China to Europe is the fastest (the journey lasts approx. two days), but the freight costs are few times greater than rail freight costs. The sea carriers offer the best prices, but they do not have the competitive ability to deliver on time; the freight duration may be up to 40 days. In addition, sea transport does not guarantee the safety of transported products (due to storms, pirates, etc.). After having considered these facts, the freight by Eurasian railway transport corridor routes is an attractive option. For instance, Suzhou-Warsaw train established by Russian Railways logistics in 2013 covers 11 000 km distance in 13-14 days. The average train distance per day is more than 1000 km using Russian Railway networks.

The present assessment divides Eurasian railway corridors to Northern, Middle and Southern routes. These corridors are presented in Fig. 1.
Considering the increasingly larger need to protect the environment against pollution, carriers seek to reduce the environmental impact of their shipments. Undertakings and logistics service providers face tougher legislation on the carbon footprint. The challenge is to improve the logistics chains from an environmental point of view continuously, including all modes of transport (trucks, railways, ships, planes and intermodal transport). The primary energy sources of railway transport means are usually electricity and diesel. Rail transport with diesel engine is a source of pollution with combustible toxic emissions through the exhaust system: carbon monoxide (CO), unburned hydrocarbons (CH), nitrogen oxides (NOx), particulate matters (PM) and final combustion product – carbon dioxide CO2.

Pulp and paper industry products, wood and chemical raw materials are mainly transported via Eurasian railway corridors. The quantity of cargo from EU to China has increased twice within the last decade (400 000 tons in 2016). The largest quantity of shipments are transported from EU to China in container trains delivering the metal and its products (15–20% in 2016), chemistry and wood products (5–8% in 2016) and other loads (72–80% in 2016). Platform cars with two 20 feet containers or one 40 feet container are used for Eurasian railway transportation.

The energy functions used in ETW Open Access methodology are confirmed average values of various European railways. In order to take into account the different topography (landscape) of European countries, three type features are used: plain (Denmark, Sweden, Finland and Baltic States), mountainous (Austria, Switzerland) and hilly (all other countries) topography. ETW feature was updated with new values and a special heavy train (> 2 000 tons) test.

3. Application of Methodology "Eko Transit World" for Estimation of Eurasian Railways Corridors

ETW methodology considers the emission of final energy (fuel, electricity) production and energy consumption. It also assigns infrastructure development impact on extraction and production, as well as emissions directly related to operation of transport means.

The main energy sources of freight transportation used in processes is liquid fossil fuel, for instance, diesel, kerosene, heavy fuel oil and electricity. In order to compare an impact of transport processes on environment with various energy sources, it is necessary to take into account the entire energy chain.

Electricity production chain:
1. Primary energy carrier (coal, oil, gas, nuclear, etc.). Research and extraction, transportation to power plant.
2. Reconstruction in power plant (including construction and removal of power plants).
3. Energy distribution (transformation and contact losses).

Fuel production chain:
1. Research and extraction of primary energy (crude oil), as well as transportation to oil refinery.
2. Processing at oil refinery.
3. Energy distribution (transportation to petrol station, filling losses).

Eurasian trainload factor $L_F$, \%:
$$ L_F = \frac{M}{PC} \cdot 100\% ,$$  \hspace{1cm} (1)

where $PC$ – container gross weight, t; $M$ – load (neto) weight, t.

Amount of train emissions $WTW$, t:
$$ EMT = D_t \cdot M \cdot (EMU_{tkm,i} + EMV_{tkm,i}) ,$$  \hspace{1cm} (2)

where $D_t$ – route distance, km; $EMU_{tkm,i}$ – amount of emission from tank to wheels $TTW$, t; $EMV_{tkm,i}$ – amount of emission from well to tank $WTT$, g/tkm.

Transport energy used quantity $WTW$, kWh:
$$ ECT = D_t \cdot M \cdot (ECF_{tkm,i} + ECU_{tkm,i}) ,$$  \hspace{1cm} (3)

where $ECF_{tkm,i}$ – final energy consumption amount $TTW$, kWh; $ECU_{tkm,i}$ – energy consumption $WTT$, kWh.

According to ETW methodology, these are the main parameters for energy efficiency and environmental friendliness:
1. Energy source = type of fuel.
2. Size of transport mean (train) and load weight.
3. Load factor of transport mean.
4. Idle factor (travel without load) of the journey.

Upon calculation of emission amount in open access ETW website, it is possible to see the amount of specific emission in detail. The comparative indicators of emission amounts are provided in Figs. 2 and 3.
After having compared the obtained data of emission amounts with EURO 3 Stage B standard, it has been established that the amount of particulate matters (PM) in Eurasian railway corridors is more than 35% greater than in provided standard. It shall be noted that the amount of emission CO$_2$ is significantly greater than the amount of NOx.

Based on distances of Eurasian railway corridor routes, the comparative amounts of emissions of nitrogen oxides NOx and particulate matters PM are calculated per 1 kilometer of run and provided in Fig. 4.

The generalized data of comparative analysis of Eurasian corridor use (1200 t weight container trains are considered) energy and ecology efficiency are provided in Table 1.
### Table 1
Comparative results of calculation (train – 1 200 t, 30 unites of containers with 6 TEU load, LF – 31.80%, ETF – 20%)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dimension</th>
<th>Northern corridor</th>
<th>Value</th>
<th>Medium corridor</th>
<th>Value</th>
<th>Southern corridor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Amsterdam</td>
<td>Nenst</td>
<td>Hamburg</td>
<td>Amsterdam</td>
<td>Nenst</td>
<td>Hamburg</td>
</tr>
<tr>
<td>Entire energy resources using from well-to-wheel (WTW)</td>
<td>kWh</td>
<td>353,315</td>
<td>351,799</td>
<td>344,747</td>
<td>399,000</td>
<td>418,699</td>
<td>383,136</td>
</tr>
<tr>
<td>Energy utilisation from tank to wheel (TTW)</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Energy resources share from well-to-tank (WTT)</td>
<td>t</td>
<td>64.00</td>
<td>94.00</td>
<td>64.00</td>
<td>93.00</td>
<td>62.00</td>
<td>92.00</td>
</tr>
<tr>
<td>Greenhouse gases (WTW)</td>
<td>-</td>
<td>5.22</td>
<td>1.70</td>
<td>5.22</td>
<td>1.70</td>
<td>5.22</td>
<td>1.70</td>
</tr>
<tr>
<td>Greenhouse gases (TTW)</td>
<td>-</td>
<td>58.80</td>
<td>92.30</td>
<td>58.80</td>
<td>91.30</td>
<td>56.78</td>
<td>90.30</td>
</tr>
</tbody>
</table>

*NOTE: The numbers mark some railway stations: 1 – Harbin (China), 2 – Beijing (China), 3 – Shanghai (China), 4 – Zhengzhou (China), 5 – Amsterdam (Netherlands), 6 – Neuss (Germany), 7 – Lodz (Poland)
4. Conclusions

Based on the main assessment results of Eurasian railway corridors and energy consumption efficiency, it was found out that railway electric traction is 1.4 times more energy efficient and 1.8 times less polluting than diesel traction. Therefore, electric powered railway traction units are the determinant factors of ensuring railways operating energy efficiency and environmental friendliness.

It was found that the biggest pollutant is the Southern corridor of Eurasian railways. In case of transit, the railways of many countries use diesel traction that increases the emission (especially Nitrogen oxides) up to 1.7 times.

If the goods are transported by rail in the Northern corridor, the comparative indicator of Particulate Matters is 2.04 g/km, in the Middle corridor – 2.62 g/km and Southern corridor – 2.25 g/km.

The assessment of Nitrogen oxide emissions showed the comparative indicator of Nitrogen oxide when transporting the goods in the Northern corridor is 19.62 g/km, in the Middle corridor – 20.55 g/km and Southern corridor – 33.82 g/km.

Acknowledgement

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References

Research into the Features of Service Damage in the Composite Material of Helicopter Rotor Blades

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Abstract

This article studies the features of service damage in the composite material (CM) of helicopter rotor blades. The strength of such a CM is characterized by the adhesion effect of connected surfaces with an adhesive layer, as well as by the cohesive strength of this layer and the connected material with the structure of the connecting joint. The authors of this article propose to evaluate the condition of rotor structure by an acoustic emission method. It is proposed to monitor the condition of CM in a full-scale model both at the post-production stage and at the stage of operation during the overhaul period.

KEY WORDS: helicopter, rotor blades, composite materials, condition monitoring, acoustic emission method

1. Introduction

At present, composite materials (CM), which possess a number of advantages over metals in terms of specific strength and rigidity, are widely used for producing elements of aviation structures. The efficiency of using composite materials (CM) in aircraft engineering lies in the reduction of structure weight without detriment to the required strength, condition-based operation, etc. However, CM have a multi-component structure, a spread in thermophysical, strength and physicochemical properties, which leads to various types of damage during the operation of aircraft structures. Damaged aircraft structural elements are often to blame for aviation accidents. For example, one of such accidents occurred due to the failure of helicopter tail rotor blade made of CM. The aircraft accident investigation committee arrived at a conclusion that the rotor failure occurred due to the delamination of composite material. The strength of such a CM is characterized by the adhesion effect of connected surfaces with an adhesive layer, as well as by the cohesive strength of this layer and the connected material with the structure of the connecting joint [1]. As a result of additional research, it was found that the separation of CM is caused by the low quality of adhesive joint between layers, which can be explained by the non-constant physicochemical properties of adhesive film. As a result, some "starved spots" are formed in the CM. Besides, in rotor blades made of the CM, there often occurs the separation of blade metal caps and separation of the filler from the spar and skin. During operation, these flaws can now be detected only by a free oscillation method and an impedance method.

Existing standard methods and means of control, diagnostics and testing are completely adapted to traditional structural materials (metals) [2-4]. Experimental methods used to study the mechanics of composites, such as the method of photo elasticity, strain method, moire and holography [5, 6], do not solve problems associated with destruction on the micro level. Therefore, it is clear that we need further experimental research giving the opportunity to reveal the actual mechanisms of deformation and destruction and take them into account in theoretical models aimed at determining the strength of composites. The authors of this article propose to evaluate the condition of rotor structure by an acoustic emission (AE) method.

2. Materials and Methods

As a result of analysing the nature of helicopter rotor blade operating failures, it was found that the structure of adhesive film changed in the bracket area, where the destruction began. Fig. 1 shows the appearance of the skin fragment of failed blade in the area of the adhesive failure of adhesive joint.

In Fig. 1, the arrows point to the areas of adhesion film that considerably differ by colour: 1 – the area of dark-brown adhesive, 2 – the area of light-brown adhesive. Such a clear difference in colour is an indicative of a change in the physicochemical properties of adhesive film.

Besides, during operation, the separation of blade metal caps and separation of the core from the spar or skin is observed on rotor blades made of CM (Fig. 2).

In order to evaluate the strength of CM and joints as well as to explore the possibility of monitoring during operation by using the AE method, some bench tests, which were as close as possible to the real operating conditions of rotor blade assembly, were carried out. The fragment of the bottom part of helicopter rotor blade was subject to testing (Fig. 3).
Fig. 1 Appearance of skin fragment at the bottom of failed blade in the area of the adhesive failure of adhesive joint (the failure zone is dotted)

Fig. 2 Diagram of rotor blade fault location: the failure of the adhesive joint of metal protective gasket A, separation of the core from the spar B and skin C, 1 – spar, 2 – skin, 3 – rubber gasket, 4 – metal caps, 5 – foam plastic

Fig. 3 Diagram of the fragment of helicopter rotor blade bottom part

The front part of the blade is a hollow spar 3 made of fibreglass-reinforced plastic with an aluminium alloy liner 1. The rear part is a structure made of honeycomb core 7 and fibreglass-reinforced plastic skin 6. A bottom anti-ice plate 2 and a top anti-ice plate 5 made of aluminium alloy are attached to the front part of the spar; the clearance between the plates is 0.2...0.3 (see Fig. 3).

In the hatched area around the leading edge contour (see Fig. 3, view I), at the joint of the bottom and top plate, there was installed a fluoroplastic strip 4 simulating a "starved spot" at this place.

The loading pattern (Fig. 4) allows to simulate the operating (during the flight of a helicopter) loads of this part of blade fragment 3. The test rig was equipped with three hydraulic power cylinders (items 5, 10 and 12 in Fig. 4). Hydraulic cylinder F1 simulates blade bending, and hydraulic cylinders F2 and F3 simulate the effect of centrifugal forces with torsion.

The fragment of helicopter blade is cantilever fitted with clamp 2 on the rig base 1; one end of hydraulic cylinder F1 is attached to the top part of helicopter blade fragment with joint 4, with the help of traverse 8, while its other end is attached to the fixed vertical rack of rig 7 with the help of joint 6. One end of hydraulic cylinders F2 and F3 is attached to the rig base with the help of joint 11 in the plane of blade fragment longitudinal section, while another end is attached to the traverse fixed at the top part of blade fragment with the help of joint 9.

The general view of the fatigue test rig with helicopter rotor blade fragment installed is shown in Figs. 4, 5 and 6. Fig. 5 presents a diagram of AE measuring equipment installation for the fatigue tests of helicopter blade fragment.

3. Results and Discussion

AE signals were recorded using Vallen System [5, 6]. The piezoelectric transducer of AE signals was stuck to the tested blade fragment in the zone of artificially introduced (simulated) "starved spot" (see Figs. 5 and 6). The signal from AE transducer was pre-amplified using a pre-amplifier (see Fig. 5) and then sent to the signal recording and processing system of Vallen System. During the tests, the changes of total N_{AE} and AE signal intensity N_{AE} were recorded. To synchronize AE pulses with the load applied to the analog-to-digital converter (ADC) Lcard L-783, the load signal was sent from the tension dynamometer of channel F1 via a matching device. The above-mentioned
synchronization allowed to analyse the changes in the intensity of acoustic emission signals in each load cycle and to control the changes in AE signals during the rig operation in different modes.

The loading of blade fragment was performed at different frequencies. For loading blocks No.1 - No.4, No.5, No.6 - No.10, the frequency of loading was 1.5 Hz, 2 Hz and 2.5 Hz respectively.

Fig. 4 Diagram of helicopter blade fragment loading

Fig. 5 General view of the test rig: 1 – hydraulic cylinder simulating blade bending; 2, 3 – hydraulic cylinders simulating the effect of centrifugal forces with torsion; 4 – piezoelectric transducer of AE signals; 5 – pre-amplifier of AE signals

Fig. 6 View of the fragment of rotor blade in the zone of artificially created "starved spot": 1 – "starved spot" simulation zone; 2 – piezoelectric transducer of AE signals

Fig. 7 Changes of total $N_{AE}$ during loading and AE signal intensity $\tilde{N}_{AE}$ in the load cycle as a result of force $F_1$
The analysis of the results of AE measurements presented in a graphical form (Fig. 7) confirmed the possibility of the quantitative evaluation of failures appearing in a rotor blade. The significant growth of total AE $N_{AE}$ during loading and the relevant change of AE signal intensity $N_{AE}$ in the load cycle correspond to the points of failure initiation in the CM. In particular, after the completion of tests and visual optical inspection, the failures of the adhesive joint of metal protective gasket A, separation of the core from the spar B and skin C were revealed (see Fig. 2).

4. Conclusion

As a result of analysing the nature of helicopter rotor blade operating failures, it was found that failures occur in the areas of the adhesive failure of adhesive joint.

The appearance of "starved spot" zones is caused by unfavourable changes in the physicochemical properties of adhesive film.

During operation, the separation of blade metal caps and separation of the core from the spar or skin is also observed on rotor blades made of CM.

The analysis of the results of AE measurements confirmed the possibility of the quantitative evaluation of rotor blade failures.

It is proposed to monitor the condition of CM in a full-scale model using the AE method both at the post-production stage and at the stage of operation during the overhaul period.

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References

Simulation Model for Optimizing the Parameters of Passengers Handling Process at Airports

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Abstract

In air transport, the majority of systems designed for passengers and baggage handling has the character of a multiphase system. Air traffic intensity requirements (passenger numbers) vary throughout the day, week, and year. When changing the conditions and requirements of practice, we need to determine the optimum capacity of these airport subsystems, properly dimensioning the subsystem capacity for each stage of passenger and baggage handling process. Individual airports aim to minimize passenger waiting times and their handling in order to seek a balance between passenger waiting times and costs associated with the achievement of this condition. The aim of the article is to optimize the passenger and baggage handling process at the selected airport using a simulation model.

KEY WORDS: model, simulation, check-in, Rockwell Arena, optimization

1. Introduction

Increasing demand for air transport causes congestion and various delays, which are becoming an increasingly common part of normal airport operations. Uncertainties associated with these problems make it difficult for airports, airlines and air traffic service providers to manage air traffic. Among other things, capacity congestion at airports also leads to significant financial and environmental inefficiencies. There are many problems and risks in the design and operation of complex transport systems. The complexity of problem evaluation, or the large number of variations, does not give the designer or manager a choice of optimal solution using classic tools. Given the uncertainty of the development and requirements of transport, time pressure, limited funding and the unavailability of modern tools, it is difficult to talk about overall system optimization. Therefore, it is very convenient to use high-tech techniques and technologies to help us solve such problems. These include computer modeling and simulation [1].

A lot of organizations and businesses deal with this issue applied to air transport. As a representative example, there are two cases. The Civil Engineering Department of Surabaya, Indonesia, has been investigating the congestion of services at the airport terminal, depending on the time when the process is being carried out. Flow data was collected at time intervals divided into time blocks dependent on the average operator time. The best time for such a division is 10 minutes, because IATA's passenger arrival distribution is based on 10 minute time intervals.

The method adopted in this research does not take into account the variability of service time. The variables that have been included in the calculation for the number of resources are service time, arrival curves, service line typology, and equipment costs. Optimization of this model is based on minimizing total costs of the system. Expected costs are the cost of space, operating costs and inconvenience costs that the passenger survived when the waiting time exceeded the allowable limit. By integrating space costs, it was possible to optimize the size of the terminal. The second example is a solution designed at Carleton University in Ontario, Canada, where a linear programming model has been designed to minimize the total working time at the check-in desks, ensuring a satisfactory level of customer service. The output of this simulation shows a significant improvement in performance by providing shorter line lengths, reducing waiting time, and increasing the percentage of satisfied customers [2, 6, 7].

The area of modeling, simulation and 3D visualization of simulation results is a broad-spectrum area applied in various fields of research even in air transport. It enables to acquire new knowledge effectively without incurring large financial and personnel costs and without the necessary risk in case of incorrect parameterization of the application directly into the running process during operation.

2. Problem Description and Data Collection

Our primary goal was to optimize the passengers ground handling system at Fryderik Chopin Airport in Warsaw on Wizzair flights based on available operational information. Based on the findings, it was necessary to define the key parameters and factors that affect the process of passengers ground handling. Subsequently, to create a process-based simulation model and to perform an initial simulation of the process problem state, based on which we could optimize the entire process of the ground handling system in order to improve management and operation efficiency of the process. In order to meet these objectives, it was necessary to define the mathematical model of the queuing system in addition to the efficient processing of input data and to use the simulation of the given processes for the needs of subsequent optimization. Fryderik Chopin Airport in Warsaw is Poland's largest airport and is one of the 50 busiest
airports in Europe (Fig. 1). In 2017, it was the most frequented airport from the group of V4 countries. The number of passengers handled and the fact that all types of transport operate at this airport as well as the fact that it offers short-haul domestic and international short-haul networking and subsequent long-distance and intercontinental flights and low-cost flights, make this airport a suitable object for research and optimization of the passengers and baggage ground handling process using the queueing theory.

Warsaw Airport has one terminal, which was built after the airport was reconstructed by connecting two original terminals. This terminal is thus composed of two parts, the north and the south one. There are 5 check-in zones throughout the terminal. The southern part of the terminal is the older terminal and has 2 check-in zones (A and B). The more modern, northern part of the terminal includes check-in zones C, D and E. Thanks to this terminal, Warsaw Airport's capacity is up to 25 million passengers. Chopin Airport operates approximately 300 flights a day and over 50 airlines operate at this airport. The most widespread airline operating at this airport is LOT Polish Airlines, which holds up to 40% of all traffic. The second most widespread company at the airport is the low cost Wizzair, whose traffic is rapidly increasing [3].

To optimize the passengers and baggage ground handling process, it was necessary to obtain data and information on the handling process of passengers at the airport as well as data on the number of passengers per line. For the collection of this data we have chosen low-cost flights of Wizzair. There are 9 check-in desks opened for the Wizzair’s flights. The following tables (Table) show the numbers of passengers for the selected lines of this company on normal business days and weekends.

<table>
<thead>
<tr>
<th>Time odleту</th>
<th>Flight Number</th>
<th>Destination</th>
<th>PAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>5:55</td>
<td>W6 1321</td>
<td>Birmingham</td>
<td>229</td>
</tr>
<tr>
<td>6:00</td>
<td>W6 1301</td>
<td>Londýn</td>
<td>236</td>
</tr>
<tr>
<td>6:05</td>
<td>W6 1431</td>
<td>Bergamo</td>
<td>224</td>
</tr>
<tr>
<td>6:05</td>
<td>W6 1339</td>
<td>Bari</td>
<td>155</td>
</tr>
<tr>
<td>6:25</td>
<td>W6 2468</td>
<td>Budapešť</td>
<td>177</td>
</tr>
<tr>
<td>6:50</td>
<td>W6 1505</td>
<td>Goteborg</td>
<td>178</td>
</tr>
<tr>
<td>7:15</td>
<td>W6 1591</td>
<td>Agadir</td>
<td>138</td>
</tr>
<tr>
<td>8:55</td>
<td>W6 1575</td>
<td>Kutaisi</td>
<td>174</td>
</tr>
<tr>
<td>9:55</td>
<td>W6 1501</td>
<td>Štokholm</td>
<td>177</td>
</tr>
</tbody>
</table>

For the purposes of characterizing the mathematical model we used the busiest hour of these days, ie the time when most flights are handled. In both of the days examined, this is the time between six and seven o'clock in the morning, as shown in Table 1. Additional data that was necessary to determine the accuracy of the simulation was the average time spent by the passenger at the check-in desk, how many passengers really come to the check-in desk, how many people travel with luggage and also how many people are subject for more detailed physical checks. In the case of Wizzair, the average time spent is slightly lower than for other companies, as many passengers travel without luggage. Such passengers then spend little time at check-in or do not appear at the check-in counter and go straight to the security check. The average time per passenger was one minute, with about 50% of the passengers coming to the trip. Similarly, on average 50% of passengers have luggage that they have to register at the trip counter. It is common practice in security control that approximately every other passenger is subject to more detailed physical checks.

3. Simulation Model of the Problem and Simulation

Before the simulation itself, it was necessary to create a simulation model based on the mathematical model of
mass operation to optimize the parameters of ground handling of passengers and luggage. By simulation we do not get a direct optimal solution; by simulation we can examine the impact of the decision on the simulation model and give us the possibility of effective decision making. We used Rockwell Arena software from Rockwell Automation, which was developed for simulation in all areas of human activity, to create this simulation model and simulate it. It is used in areas such as the food industry, engineering, aerospace, manufacturing, supply businesses, government and military, retail, healthcare, call centers, logistics, transportation, and customer service. Regardless of the industry, Arena enables companies to solve any business problems in a fast and cost-effective way [4-7].

After finding out all the necessary operational data and limitations, we could proceed to create a simulation model. In its creation, we have maintained the best practices in creating architectures of common two-phase mass-handling models. Since data on security controls and baggage handling may be distorted due to the fact that it is not possible to determine exactly how many lines are devoted to one company flights, the simulation will take place in the ground handling passenger subsystem, assuming that half of all passengers would come to the check-in desk and based on the results of this simulation, we will propose changes to the simulation model of the system if all the passengers arrived at the check-in desk. Nine check-in desks have been entered into the system, which are in operation and service for Wizzair flights. Input data were used to specify how often passengers arrive at the check-in desk and the number of requests, i.e. how many passengers need to come to the check-in desk. The next block addresses the way from the entrance to the check-in desks, and what time it takes passengers to pass from the entrance to the airport check-in desks.

The time of handling one passenger is entered in the features of the check-in desks. Next, we defined the time of the way from the check-in desks to the output stage, which is in terms of the system the entry into the security check. The resulting simulation model architecture shows Fig. 2.

After assembling the architecture we could proceed directly to the simulation so it was necessary to insert data that we want to work with. Based on the data collected we defined the time of handling one passenger for 1 minute, and the length of the way from the entrance to the check-in desks and from check-in desks to the security control for 2 minutes. This data remained fixed throughout the simulation and did not change. Variable data in our case related to passenger input flow, the difference between the arrival of passengers to the check-in desk and the number of passengers requiring service at the given time. In the first case, we chose about half of the daily peak traffic at Fryderik Chopin Airport on Wizzair flights, in which case passengers arrive at approximately 7.5 second intervals. From the simulation output data, we can read that the average waiting time at the check-in desks ranges from 2 to 3 minutes and the maximum waiting time was generated on the check-in desk number 5, almost up to 10 minutes. The most passengers (59 passengers) in this simulation were handled at the check-in desk number 4 and 6. The simulation results are shown in Figs. 3 and 4.

Fig. 2 Passengers handling model by Rockwell Arena

After assembling the architecture we could proceed directly to the simulation so it was necessary to insert data that we want to work with. Based on the data collected we defined the time of handling one passenger for 1 minute, and the length of the way from the entrance to the check-in desks and from check-in desks to the security control for 2 minutes. This data remained fixed throughout the simulation and did not change. Variable data in our case related to passenger input flow, the difference between the arrival of passengers to the check-in desk and the number of passengers requiring service at the given time. In the first case, we chose about half of the daily peak traffic at Fryderik Chopin Airport on Wizzair flights, in which case passengers arrive at approximately 7.5 second intervals. From the simulation output data, we can read that the average waiting time at the check-in desks ranges from 2 to 3 minutes and the maximum waiting time was generated on the check-in desk number 5, almost up to 10 minutes. The most passengers (59 passengers) in this simulation were handled at the check-in desk number 4 and 6. The simulation results are shown in Figs. 3 and 4.

Fig. 3 Waiting times at check-in desks
Fig. 4 Number of PAX handled at individual check-in desk
The following simulation was used to determine the maximum number of passengers that can be arrive to the check-in desk so that ground handling of passengers can be carried out smoothly and without delay. With unchanged features from the previous simulation, we found that such a model could accept a total of approximately 600 passengers who would enter the system at 6-second intervals. In practice, this means that approximately 62% of all passengers can arrive at check-in at a daily weekly peak for passenger ground handling service. In this simulation, the average waiting time was again about the same, and the maximum waiting time jumped above 10 minutes in two cases. In this case, the most passengers (78 passengers) were handled at the check-in desk number 4. The simulation results are shown in Figs. 5 and 6.

![Fig. 5 Waiting times at check-in desks at the largest possible burden](image)

![Fig. 6 Number of PAX handled at individual check-in desks at the largest possible burden](image)

In the situation that all passengers who fly Wizzair's flights at the busiest hour at the airport would have to arrive at the check-in desks, the simulation was carried out with a critical failure due to the overload of the simulated system model. The software has already made a mistake after 179 passengers in such a simulation, due to too few passenger arrivals. In practice, in the process of passengers handling, Wizzair automatically assumes that nearly 40% of passengers will use a different form of check-in service than at the check-in desks. Based on these new experiences, we decided to review and optimize the model in order to ensure that it will work on the assumption that all passengers traveling on a peak day will arrive to the check-in desks. Adding multiple check-in desks as well as increasing the time to handle passengers may appear to be suitable alternatives to changing parameters, which means that the check-in desks would be open earlier for Wizzair flights. It was found by gradual screening and simulation that in order to serve all passengers traveling by Wizzair on a daily peak, the passenger handling process had to be started 30 minutes earlier, thus increasing the arrival time of the requests. At the same time, it is necessary to open three extra desks. The passenger arrival interval was thus 5.6 seconds.

![Fig. 7 Optimized passenger handling scheme at Rockwell Arena](image)

After simulating such a model, we could see that the waiting time is considerably higher. The average waiting time is approximately 3.5 seconds, with a maximum waiting time of up to 18 minutes at check-in desk number 7 (Fig. 7). Most passengers have gone through the check-in desk number 9 (a total of 92 passengers). The simulation results are shown in Figs. 8 and 9.
4. Conclusion

The facts found during the individual simulations of the Wizzair passenger handling process have substantially altered our vision of the operation of the passenger handling system at Fryderik Chopin Airport in Warsaw during daily and weekend peaks defined by the previous assumptions. In the first model, it has been clearly demonstrated that the process of passengers handling is smooth, provided that not all passengers travel with luggage. Since the airport only opens nine check-in desks for Wizzair flights, we can assume that they have this number of passengers so that the check-in desks are not overloaded and automatically assume other forms of passenger check-in (online check-in, self check-in terminals etc.). By simulation, we found that the highest number of passengers that can arrive to the check-in desks and the system will run smoothly is approximately 600 passengers in one hour. In a simulation attempt, when all passengers at the busiest hour of the airport arrive to the check-in desks, the system will experience congestion and downtime and delays in operation will result in increased handling agent error rates and increased nervousness and discomfort during the passengers handling process of the given flight. It is interesting to note that Wizzair increases the risk of delays by doing so.

Therefore, it was necessary to develop a proposal for optimization changes to the ground handling model if all passengers had to come to the check-in desks. Such a model counts on the fact that passengers on given flights would be able to come to the facility 30 minutes earlier, thereby increasing the theoretical average passenger arrival intervals and relieving the system. At the same time, it would also be necessary to open three more check-in desks. After changing these parameters, we can say that the ground handling system for the busiest traffic at Fryderik Chopin Airport for Wizzair flights is optimized, despite the high waiting times of passengers. In practice, in this simulation, we can also optimize other cases of ground handling at other airports, as the system is the same everywhere, and parameters that change, such as the number of passengers, arrival intervals, or check-in time can be changed quickly and easily.

References

Cost Decision Trees in International Military Logistics

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Abstract

Logistics in the globalization era is characterized by a high level of complexity of subsystems and processes occurring in them. Develops in stages ranging from increasing the international activity of enterprises, through the processes of creating global dependencies between the economies of individual countries, to the processes of intensification of economic, political and cultural relations of a supranational nature [1]. A special role in modern logistics is played by effective decisions taken at various levels by the individual or in a collective way, using support systems derived from a quantitative approach, qualitative support for analyzes and axiomatic-based sciences [2]. This article is an attempt to articulate the issue of making decisions based on the inevitability of decision scenarios leading to the so-called "Decision games".

KEY WORDS: international military logistics, decision trees, logistic costs, scenario analysis

1. Scenario Analysis Using a Decision Trees

Implementation of the assumed objectives in the international approach requires knowledge of the conditions limiting the assumed functions of the objectives (separated from the bundle of goals). From the point of view of heuristic, you can consider the so-called heuristic models, which in addition to optimization and simulation models are an effective tool for forecasting and implementing complex logistics processes (including transport). In many cases, the heuristic analysis methodology requires IT support resulting from mathematical simulation, benchmarking or good ex post practices [3, 4]. In international logistics it is possible to use scenario analysis developed on the basis of decision variants. Therefore, it is possible to use decision theory in the construction of decision trees based on the probabilities of individual scenarios and transport costs. Transport costs seem to be a particular problem, which in the article presented in the article determine logistics decisions. The assumed thesis is based on the statement that logistic decisions in the field of transport services for military entities should result from a deep cost analysis based on scenario analysis methodology, i.e. no costs should result from ineffective decisions, but rather ex ante decisions should be preceded by cost analysis of options scenarios.

2. Heuristics of Scenario Methods

The scenario method is one of the heuristic methods of decision making. The ability to detect (Greek heurisko) new facts and find connections between facts, especially using hypotheses, is based on the assumption that events (in the future) can not be predicted with certainty. It is therefore necessary to foresee and develop various scenarios for the development of the current situation, and for each variant to develop a way of behaving in case it turns out to be real. In the event of failure resulting from the implementation of the most likely option, alternative solutions are used.

In the modeling of logistic processes, which are influenced by strong turbulent factors, attention should be paid to the approach that functions successfully in the management sciences (eg quality) of the so-called process mapping, which is a mapping of existing objects and relations between them. The key to developing the process model is observation with observance of perceived relationships and regularity, which is important, with particular emphasis on knowledge resulting from practical activities in a variable spectrum of aspects. In creating a process model (integrated processes) it is necessary to define preliminary criteria (general assumptions) and outline the directions of actions (goals) for the needs of scenarios in the decision-making model. Among the many criteria taken into account in the work dominates the problem of transport costs related to the simulation of the transport process associated with legislative and legal reasons for logistic responses outside the country and the right selection of infrastructure elements (existing and possible to create - in accordance with the location theory) [5].

The notion of probability is the key issue in building a decision-making model. In the classic theory of von Naumann and Morgenstern, the probability was introduced into the theory from outside as part of the decision analyzing apparatus. The struggle with paradoxes has shown that one must first show how the decision maker attaches probabilities to the possibilities he considers.

There are several philosophical approaches to probability. Generally, they can be divided into objective ones, referring to such properties of the world, as the frequency of events of a certain type or dispositional property of events,
and subjectivist, referring to the property of beliefs whose contents are possible states of affairs. Both approaches to probabilities have advantages and disadvantages, but rather applications in which they perform better or worse. In searching for the basis of human subjectivity, it is natural to turn to the properties of beliefs. However, in this respect, there is a significant difference between the epistemological concept and the subjectivist conception in the proper sense. According to the epistemological concept, the probability is the same as the degree of justification for the right belief [6].

3. Epistemology of Relevance in Logistics

The epistemological approach raises two problems difficult to solve, because of which they have turned towards subjectivism. The first problem concerns the calculation of the degree of belief. In this matter there are a number of purely logical ideas, referring to the degree of embedding beliefs among other beliefs, the relationship of belief in the set of beliefs (determining its relative strength), a relation of relevance is needed.

In most cases, the term relevance is defined by the concept of probability. It seems that one can talk about probability even when stating some uncertainty, we only collect the data used to determine its measure. This does not mean that such uncertainty has no measure; in fact, something is assumed about it, for example, that it is not very close to 1 or very close to 0 [7].

The subjectivist theory of decision formulates the conditions for the rational construction of a certain set of beliefs about possible states of things. The probability here is the uncertainty of the mind included in a rational system of uncertain judgments, which, after being ordered, turn into judgments about uncertainty (subjective estimates of uncertainty). L. Savage proved that rationally ordered preferences are consistent with subjective probabilistic judgments, in which the concept of probability is consistent with the universally accepted axiom of A. Kolmogorov for the theory of probability. Thus, he created the basis for thinking about the human subject as being capable of this type of construction [8].

In the classic theory of decision, the subject is where the theoretician of the decision is - it is not expected that the persons who speak about the theory would actually perform the deliberative activities provided for by this theory, but only that they would behave as if these activities were performed. The problem, then, is to develop the concept of an entity that is constructed when the person actually embodies the norms of rational decision making into his natural mechanism of reflection.

One of the most frequently used unreliable heuristics concerns the probabilistic component of our preferences and consists in ignoring the base probability, i.e. the frequency of occurrence of S in the considered set of states of affairs. The necessity to take this probability into account results from the Bayes rule [9]:

\[
P(A | B) = \frac{P(A) \cdot P(B | A)}{P(B)}.
\]

In order to assess the probability that some event A occurred because an event B occurred, multiply the base (independent) probability of occurrence A (the frequency of its occurrence in the considered population of events) by the conditional probability that B will occur if A occurs and divide by probability, that there will be B with no relation to A, ignoring the basic P (A) and focusing only on P (B|A), which we usually do, we systematically violate this rule. We are prone to this error in the assessment of probability, because P (A) seems irrelevant to us. According to Peterson, Bayes' rule well characterizes the process of acquiring scientific knowledge [10].

4. Premises of Decision Tree Construction in Logistics

The essence of a decision tree is a graphic representation of the structure of elements of the decision process using vertices (nodes) and edges (branches) for the whole so-called learning sample. Moving along the branches of successive elements of the test by nodes in which decisions are made as to the selection of branches is a key action scheme. The criterion of the division performed in a given node is common (same) for all elements of the learning test that are included in this node.

Formally, the decision tree is defined as any consistent directed acyclic graph with a vertex with one incoming edge and an outgoing edge number of 0 or greater than 1. Nodes, branches and tree leaves correspond to: tests performed on attribute values of the examples, possible test results and category labels [11].

According to J. Koronacki, the classification tree is built to allow the classification of future observations, which we do not know to which classes belong. In this case, the conditions of division must take the form of conditions imposed only on the values of the observation vector, and not on (known to the elements of the learning sample) belonging to these classes [12].

From the point of view of the conducted research on the logistic system of international logistic service of military contingents, the effectiveness of the system itself is important, as it is expressed in the expenditure of resources for rational effects of all subsystems and processes taking place within them. The assumption that high costs of logistics services (mainly transport) are determined by the time of property delivery is too much a simplification of the problem and should not justify excessive costs generation and increasing the budget of the Defense Ministry budget to the detriment of the functioning of current operations. The justification of this type of activity leads to the duplication of not quite rational
5. Decision Trees for Selected Scenarios

The issue of military supply chains is based on assumptions resulting from state commitments assumed by the state in terms of participation in operations abroad, and, consequently, in an executive act expressed in the actual movement of specific property and personnel at a given distance [13, 14]. The time spectrum can be divided into phases depending on the development of the situation on the international arena. Regardless of the number of phases, all actions for a specific mission are based on the stage: initiation (commencement of the operation of the mission), maintenance (regular and cyclical transports, constant supply of material resources, staff turnover, and other) and termination of operations (return of people, equipment, financial and material settlement) (Fig. 1).

In the development of the decision tree (T), it is assumed that the set of nodes is marked by NT, and the set of leaves as LT, the set of examples P is limited to one, and the subsets marked as n, for which tn will be a test. In the oval symbols of nodes (as a rule) there are corresponding tests, while rectangular symbols denote their category labels. Test results are marked with the symbol r.

6. Defects Chain – Case Study

Considering the sustainment stage, which is the longest of the mentioned, where the share of costs in the total costs of the mission's functioning over a few years is the highest. The aim of the transport at this stage is to ensure timely deliveries of military equipment and materials (we exclude for the time being the model of personnel transport) for distances over 6000 km for a quota of 2,500 soldiers and civil servicing. Supplying is based on the needs of recipients in strictly defined five classes (being a reflection of previously developed norms).

The lack of sufficient means of transport determines the necessity of outsourcing solutions expressed in the involvement in EU and NATO programs and initiatives differing in the costs of participation, the price of hourly rates, the possibility of free exchange of services and others. The problem is therefore the rational use of available programs and initiatives (complemented by the use of resources from own resources), maximizing the use of cargo space, combining transports in intermodal options and executing additional orders within the Ministry of National Defense to avoid "empty" or "incomplete" flights as part of previously paid hours.

The collected data in the Table results in hourly costs for individual international initiatives of the EU and NATO. It is also known from the conducted research that repeatedly there is no possibility of a transit shipment due to lack of diplomatic consent.

Knowing the technical capabilities of air transport units in the field of transport capabilities, dimensions of hold, range and others, we can work out a scenario based on a decision tree. Individual scenarios are marked with symbols S1, S2, S3. The probabilities of occurrence of events were determined a posteriori based on historical data from 2008-2012.

Using the data contained in the attachment, we can develop several decision trees or one complex (with limited assumptions). One of the decision problems is the transport cost, taking into account the limitations in the use of means of transport depending on the distance (range) and potential diplomatic consent. A simplified decision tree for such a variant is shown in the Fig. 2.

For shipment variants, where delivery time is not a priority, we can use sea transport (low cost and long range) for land transport or S4 scenario to use sea transport to a possible (substantiated port) and then apply a solution in line with scenario S3 and reload the means of supply by air. Determining the potential intermediate (or several) base using the network method allows you to estimate cost variants with a certain probability of an event (based on historical data) and consequently, choose the lowest-cost scenario.
Table

<table>
<thead>
<tr>
<th>Program/Initiative</th>
<th>Type of means of transport</th>
<th>Finance/sources of founding</th>
<th>Aprox. Cost of Transport (USD/h.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>program salis</td>
<td>AN 124-100</td>
<td>national / UE</td>
<td>33900</td>
</tr>
<tr>
<td>program sac</td>
<td>C-17 Globemaster III</td>
<td>national / UE/USA</td>
<td>62000</td>
</tr>
<tr>
<td>buying the measure of the</td>
<td>CASA C-295</td>
<td>national</td>
<td>2000</td>
</tr>
<tr>
<td>new means of transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>buying / acquisition /</td>
<td>Herkules C-130E</td>
<td>national / FMF</td>
<td>3500</td>
</tr>
<tr>
<td>used means of transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>program atares</td>
<td>C-130, AN 124, Airbus A310 and others</td>
<td>national / reciprocal exchange of services</td>
<td>Exchange of services according to the tariff</td>
</tr>
<tr>
<td>program z amc¹</td>
<td>Airbus A400M²</td>
<td>UE</td>
<td>unknown</td>
</tr>
<tr>
<td>program cooperation with</td>
<td>C-17 Globemaster, C-5 Galaxy</td>
<td>USA</td>
<td>76 000/86 000</td>
</tr>
<tr>
<td>usa - acsa</td>
<td>ro-ro, lo-lo</td>
<td>national</td>
<td>145000¹</td>
</tr>
</tbody>
</table>

Assuming the cost criterion and assumed probability (e.g., using a logistic intermediate base), the scenario for which the lowest level of total displacement costs was observed is S3 scenario. In a situation where they are not the only criterion there is a need for solutions based on multicriteria methods. These criteria should consider variants of purchase of means of transport in the context of their long-term use, which is related to economic reasons for depreciation of fixed assets and spreading fixed costs over time (Fig. 3). It is also important to consider the sensitivity of solutions correlated with variants (scenarios).

1 OCEAR (Organisation Conjointe de Cooperation en Materie d’Armament – an organization associating seven European countries.
2 As a possible solution.
3 For a two-way consecutive trip (on the Szczecin-Karachi route).
Based on historical data, it is possible to develop several scenarios for future solutions. The idea of supplying military contingents over the years does not differ significantly from the reference SCOR supply chain model, however, functioning in a highly turbulent environment, a deficit in the means of transport and a strong need of the recipient in meeting the needs in a timely manner (resulting from the specificity of activities) scenario models should include sensitivity analysis and the probability of failure of selected "paths".

High uncertainty regarding the predictability of results (resulting from a shortage of material and transport resources, maladjustment of the rules of conduct to cooperate in the international system) is what distinguishes modern logistics processes occurring in the area of military logistics.

7. Research Methodology - Test of Assumptions Simulation

In the quantitative research methodology, it is important to use the zbiorówR total event sets to search for the function with the highest desired value. For this purpose, it is possible to use the point estimation method, also known as the maximum likelihood method. Suppose we have a function:

\[ f: K \rightarrow R, \text{ where } K \subset R, \quad (2) \]

where \( R \) is a fixed set. We say that this function takes the largest value at \( x \in K \) if:

\[ f(x) \leq f(x), \text{ for each } x \in K. \quad (3) \]

Of course, the largest value can not be determined for all functions, but with some additional assumptions it can be concluded that such a value exists. From a practical point of view, we are interested in determining the point \( x \), in which the function takes the largest value.

A derivative is a very important tool here. The problem is to calculate the derivative and solve the equation:

\[ f'(x) = 0. \quad (4) \]

Very often it happens that our problem written in the form of an equation has exactly one root and that it is easy to check that the largest value can not be accepted at the ends of the range of specificity - in this case it is this solution that is the only point where the function takes the largest value. In the method of highest credibility, it is helpful to use the SOLVER function. Next, it is necessary to calculate the probability with the indication of the value for which the calculated probability is the highest. This methodology is helpful in developing multi-variant scenarios with probability estimation at particular stages of the decision tree.

8. Conclusions

In the scenario analysis, it is important to define the purpose function and specify the limiting conditions. After developing the above, a simulation of theoretical assumptions should be developed to check the assumptions made. Assumptions in the cognitive model (variable) depending on the situation determined by turbulent factors may change and determine the criteria (priorities). At the initiation stage, it can be a delivery time criterion, and in the ending (settlement) and maintenance option - eg transport cost. The development of the test will allow you to make a decision (choose one or several of the total available), eg what type of transport to use with a given weight of cargo meeting the criterion of delivery time or what means of transport can be used to carry out the transport service with the assumed financial resources. This can be done by testing the assumed hypotheses in the positive and negative scenarios (eg increasing the probability of minimizing transport costs as the expected value). The aim of choosing the right scenario is to help you develop auxiliary calculators (usually the need for lack of proper software).

As a result of the conducted research, the thesis was verified as to the necessity of making decisions based on cost analyzes for individual action options. The implementation of international transport processes requires:
- in-depth economic analysis using decision trees;
- knowledge of the basics of probability in probability estimation;
- skills in constructing and modeling decision scenarios;
- knowledge of building decision trees and target trees;
- the need to test simulated assumptions.

Testing hypotheses in a positive and negative approach will allow to maximize the function of the goal in the form of reducing the costs of transport processes, which are the source of the budgets of countries (entities) that implement logistic services on an international basis.

References


Optimization of the Postal Transportation Network in a Rural Area

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Abstract

The main objective of the article is to optimize the postal transportation network in the attraction district of the selected regional node in a rural area. In the introduction and literature review, authors describe the basic concepts of the issues related to postal infrastructure, postal network and the essential concept of graph theory. An analysis of the state of the postal transportation network is also carried out. Further, the article contains characteristics of optimization methods, which are necessary to achieve the main objective of the article. In the results, based on the defined optimization methods, optimization of the postal transportation network is carried out, where the created optimal solutions are compared with the existing state of the postal transportation network in the selected regional district.

KEY WORDS: optimization, postal network, accessibility of postal network, design of postal network

1. Introduction

Nowadays, consumers put high requirements for the transport of mail items. The customers require the carrier of the shipment to secure the safety of transportation and especially, the speed of the shipment. The transport of postal items between points of the network is carried out by means of mobile devices - postal courses. These postal courses, together with the transport routes they use for transportation, create a postal transportation network. The postal transportation network is understood to be the organization and set of stationary devices used by the postal service provider, namely to collect and distribute postal items [8, 20].

The design of a suitable postal transportation network is the most important issue for providing elementary functions of the postal enterprise. A correct technology decision depends on the chosen postal infrastructure model and specific technological methods and processes [21]. The designed model takes into consideration the demands of the outside postal environment and requirements of the high-level automation equipment in the conditions of postal enterprises [4, 27]. By optimizing the postal transportation network, it is possible to minimize the travelled routes, save transportation costs and also contribute to a better environment [1]. Therefore, this article is dedicated to the optimization of the postal transportation network in the district of a selected regional node in the conditions of the national postal service provider - Slovak Post.

2. Analysis

On the basis of essential postal technology terms, it is important to analyze main areas, which influence the whole technological process of the postal items processing [26]. The analysis determines the critical part of the whole optimization process – the identification of the construction variant of the postal transportation network at the regional level and then design the routes for postal courses [9].

The most suitable construction variant of the postal transportation network at the regional level is the circle. In this model, the stationary facilities (post offices) are fed to the regional centre by postal courses which, after leaving the regional centre, are progressively passed through every post offices and finally returned to the regional centre. (Fig. 1) [17].

Fig. 1 Configuration of postal transportation network – circle [17]

There are several methods for solving the problem of design or optimization of postal transportation network at the regional level. The most important are the methods of graph theory [18]. The problems differ in the type of objective function and model of the environment in which they are addressed [6, 22]. Model of environment, in our...
case, is the postal transportation network abstracted by the complete weighted graph \( G = (V, E, c, w) \). \( V \) is the set of vertices representing post offices and possible regional centres locations. \( E \) is the set of edges representing connections between nodes (vertices in our case - post offices). Label \( c(e) \) of edge \( e \in E \) is its length. Weight \( w(v) \) of node \( v \in V \) represents the importance of a node in the addressed system (number of demands, etc.) [12, 19].

Some nodes can serve as centres. These centres can generally have two functions – rescue or supply. The supply function of the centre is characterized by term depot. The depot is, for example, the warehouse of material [15, 20]. Each node of a graph \( G = (V, E, c, w) \) need \( w(v) \) material units per time unit, while the unit costs for supplying the material are proportional to the travel distance. In this case, the location of centres is performed in such a way, that the total transport costs of serving all nodes are minimized. Postal processing and distribution centres (regional centres) thus perform the supply function [16].

Optimal construction of postal courses is the second most important task when we want to optimize postal transportation network. For solving this problem we are using the vehicle routing problem (VRP). VRP is a combinatorial optimization and integer programming problem which asks "What is the optimal set of routes for a fleet of vehicles to traverse in order to deliver to a given set of customers?" [7]. It first appeared in a paper by George Dantzig and John Ramser in 1959 [5], in which the first algorithmic approach was written and was applied to petrol deliveries. The objective of the VRP is to minimize the total route cost. In 1964, Clarke and Wright improved on Dantzig and Ramser's approach using an effective greedy approach called the savings algorithm [3]. The VRP concerns the service of a delivery company (postal provider). How things are delivered from one or more depots (regional centre) which have a given set of home vehicles and operated by a set of drivers who can move on a given road network to a set of customers [10]. It asks for a determination of a set of routes, \( S \), (one route for each vehicle that must start and finish at its own depot) such that all customers' requirements and operational constraints are satisfied and the global transportation cost is minimized. This cost may be monetary, distance or otherwise (for example time) [3, 25].

The road network can be described using a graph (as we mentioned above) where the arcs are roads and vertices are junctions between them. The edges (arcs) may be directed or undirected due to the possible presence of one-way streets or different costs in each direction. Each edge has an associated cost which is generally its length or travel time which may be dependent on vehicle type [18].

We can identify the most commonly used techniques for solving Vehicle Routing Problems, that we can find a five basic classification of the solution techniques - exact approaches, heuristics, constructive methods, 2-phase algorithms and metaheuristics. The best VRP solutions techniques (algorithms) include:

- **Branch and bound** - A branch and bound algorithm uses a divide and conquer strategy to partition the solution space into subproblems and then optimizes individually over each subproblem [14].
- **Heuristic techniques** - Heuristic methods perform a relatively limited exploration of the search space and typically produce good quality solutions within modest computing times.
- **Clarke and Wright** - The Clarke and Wright savings algorithm is one of the most known heuristics for VRP. It was developed on and it applies to problems for which the number of vehicles is not fixed (it is a decision variable), and it works equally well for both directed and undirected problems [3].
- **2-phase algorithms** (route-first, cluster-second) - The problem is decomposed into its two regular components the first is a clustering of vertices into feasible routes and the second is actual route construction, with possible feedback loops between the stages. Route-first, cluster-second methods construct in a first phase a huge Traveling Salesmen Problem tour, disregarding side constraints, and decompose this tour into feasible vehicle routes in a second phase. This idea applies to problems with a free number of vehicles [2].
- **Genetic algorithms** - Genetic algorithms (GA) are very likely to be the most widely known type of metaheuristic algorithms. GAs are computer procedures that employ the mechanics of natural selection and natural genetics to evolve solutions to problems. GA evolves a population of individuals encoded as chromosomes by creating new generations of offspring through an iterative process until some convergence criteria are met. Such criteria might, for instance, refer to a maximum number of generations, the convergence to a homogeneous population composed of similar individuals, or getting an optimal solution. The best chromosome generated is then decoded, providing the corresponding solution [23].
- **Tabu search algorithms** - The basic concept of Tabu Search (TS) is a metaheuristic superimposed on another heuristic. TS explores the solution space by moving at each iteration from a solution \( s \) to the best solution in a subset of its neighbourhood \( N(s) \). The current solution may deteriorate from one iteration to the next. Thus, to avoid cycling, solutions possessing some attributes of recently explored solutions are temporarily declared tabu or forbidden. The duration that an attribute remains tabu is called its tabu-tenure and it can vary over different intervals of time [11].
- **Large neighbourhood search** – LNS metaheuristic methods explore a complex neighbourhood by the use of heuristics. Using large neighbourhoods makes it possible to find better candidate solutions in each iteration and hence traverse a more promising search path [13, 24].

For optimization of the postal transportation network in the attraction district of the

3. Objectives and Methodology

The main objective of this article is to optimize the existing postal network in the attraction district of the
selected regional node in a rural area based on operational analysis methods and graph theory (LNS). The object of our research is the postal transport network within the regional processing centre Dolný Kubín. This regional network consists of three local area nodes Dolný Kubín, Tvrdošín and Námestovo. We will implement the optimization of the existing regional postal network for each of the three nodes separately.

4. Results

The regional processing centre Dolný Kubín manages three local nodes: Dolný Kubín, Tvrdošín and Námestovo. The regional network Dolný Kubín consists of 11 post offices, which are served by a single postal course, whose route can be seen at Fig. 2 and its route cross the nodes 0-5-1-7-9-10-6-3-0-4-8-2-0. The regional network Tvrdošín consists of a group of 10 post offices.

Delivery and distribution of postal items within the regional network Tvrdošín are carried out by two postal courses due to the high time and distance demands. The current route of one postal course points through the nodes 0-2-4-3-9-3-4-0-7-0 and the second postal course through nodes 0-6-1-5-1-8-6-0 (Fig. 3).

The regional network Námestovo has 18 post offices in its attraction district. Delivery and distribution of postal items in the attraction district Námestovo are carried out by means of two postal courses due to the high time and distance demands.

The first post course serves 8 post offices and the second post course serves 9 post offices. The current route of the first mailing course points through nodes 0-9-12-7-16-8-10-5-2-0 and the actual route of the second postal course points through nodes 0-13-11-15-14-17-1-4-6-3-0 (Fig. 4).

For the optimizing the existing postal transportation network in the areas of regional networks Dolný Kubín, Tvrdošín and Námestovo we used an algorithm – Large neighbourhood search. Heuristics based on large neighbourhood search have recently shown outstanding results in solving various transportation and scheduling problems. Large neighbourhood search methods discover a complex neighbourhood by the use of heuristics. Using large neighbourhoods makes it possible to find better candidate solutions in each iteration and hence traverse a more promising search path.

Applying this algorithm at the current versions of the three regional postal distribution networks we can optimize them and then we are able to find better routes of particular postal courses. The results you can see at the next three figures (Figs. 5-7).

The optimized route for the regional network Dolný Kubín has the following directions 0-2-8-4-1-5-7-3-6-9-10-0 (Fig. 5) and the length of the optimized route is 102.25 km.

For the regional network Tvrdošín, we also found outcomes for comparison of both variants. The resulting route for the first postal course goes through the nodes 0-4-3-9-2-7-0 and is 41.21 km long (Fig. 6). In the case of the second postal course, its path goes through the nodes 0-6-1-5-8-0 with a total length of 42.16 km (Fig. 6).
When the regional network Námestovo is optimized, the resulting route for the first postal course leads through nodes 0-2-5-10-16-87-12-9-0, which is 78.8 km and the new and optimized route for the second postal course goes through points 0-17-15-11-13-14-1-4-3-6-0, which is 85.19 km (Fig. 7).

If we count on the current price of fuel for the postal vehicle Volkswagen Crafter, whose average fuel consumption is 9.1 litres per 100 km, while the price of diesel in Dolný Kubín at the petrol station Benzinol is 1.199 € per litre, we can calculate economic effects of optimization (Table).

<table>
<thead>
<tr>
<th>Regional Network</th>
<th>Total distance before optimization (km)</th>
<th>Total distance after optimization (km)</th>
<th>Difference (km)</th>
<th>Cost saving (€/route)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolný Kubín</td>
<td>120.56</td>
<td>102.25</td>
<td>-18.31</td>
<td>4.06</td>
</tr>
<tr>
<td>Tvrdošín</td>
<td>55.12</td>
<td>41.21</td>
<td>-13.91</td>
<td>3.09</td>
</tr>
<tr>
<td>Námestovo</td>
<td>94.47</td>
<td>78.80</td>
<td>-15.67</td>
<td>0.61</td>
</tr>
<tr>
<td>Total</td>
<td>400.82</td>
<td>349.57</td>
<td>-50.51</td>
<td>11.39</td>
</tr>
</tbody>
</table>

If the postal rates carry out these routes twice a day (delivery and collection) of postal items, then the resulting economic benefit of the optimized solution is 22.78 € per day (455.6 € per month).

5. Conclusions

The main goal of the article was to optimize the existing postal transportation network in the selected region. We focused on the regional postal transportation network for regional processing centre Dolný Kubín 1, which also includes the local nodes Námestovo 1 and Tvrdošín 1. Therefore, we also optimized these local centres. For the purposes of optimizing the regional postal network, we used the large neighbourhood search algorithm, which showed the best results when comparing the appropriate algorithms. The results obtained from the optimizations show very interesting results. The total number of kilometres saved by optimization of regional processing centre Dolný Kubín was 24244.8 km per year. According to the current price of fuel and used vehicle fuel consumption we can find that total saves of the optimized solution is 5467.2 € per year.

The benefits of realized optimization are not only saving the cost of postal courses, or minimizing routes, but other possible benefits include time savings, lower occupancy of postal courses and environmental friendliness. We can, therefore, assume that the possibility of optimization of the postal courses will also be found in other postal regional networks in Slovakia or in other countries.

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References


(Dis)connection of High Speed Rails Between Western and Central Europe – Sheer Coincidence, or Inevitable Consequence?

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Abstract

High speed lines are considered to be a sustainable kind of public transportation. They are suitable for distances which are too long for sustainable car using, and too short for plane flights. In Western Europe, these policies have been common since the 1980s. In the post-socialist countries of Central and Eastern Europe, the situation is slightly different. The conventional railway networks were used mainly for freight transportation and kept in a state of stagnation. New connections or fundamental reconstructions were rare. These divergent policies are now playing an important role in fast railway network planning and operating.

This paper focuses on a comparison of approaches in the planning and operating of fast railways in Central European states (e.g. Austria, the Czech Republic, Slovakia, Hungary and Poland). There are significant differences not only among the non-socialist and post-socialist states but also among the post-socialist states themselves. Austria, which is the only non-post-socialist country of those mentioned is fully connected to the European fast railway network, mainly via Germany and Italy. The Czech Republic and Poland have designed national fast railway networks, which are primarily meant to service the largest cities and agglomerations within each country. The building of cross border connections is being considered, but they are only peripheral supplements of the networks. Hungary and Slovakia both decided to prefer fundamental reconstructions of selected spinal railways.

The aim of this paper is to identify the key decisions and approaches in the planning of fast railways in each of those states. The paper also identifies the main points causing the disconnection of fast railways networks between Western and Central Europe.

KEY WORDS: high speed rail, high speed line, Western Europe, Central Europe, post-socialist states, railway services, diversity of conditions, disconnections

1. Introduction

High-speed rail transport systems have been developed in the world for more than 50 years, with the first public high-speed line being opened in 1964 in Japan (the so-called Tokaido line). These systems have also been developed in Europe since the 1980s, with a high-speed line first being opened on this continent in 1981 in France (St. Florentin-Sathonay, as part of the Paris-Lyon corridor). Since then, Europe's high-speed rail networks have grown considerably, and nowadays this rail transport element is operated in a number of other countries, reaching a total of 7,795 km in the EU in 2014. The longest national systems are in operation in Spain, France, Germany and Italy. In addition to the length of the lines themselves, the transport performance realized on them is also growing, which in 2014 reached more than 110 billion passenger-kilometers in EU countries. For more details on European high-speed lines and about traffic on them see [1].

On the one hand, the position of high-speed rail on the transport market is defined by their competitive position towards medium and long-distance road and air transport. On routes of up to 500 km, this rail segment can be seen as their environmentally friendly option [2-4]. On the other hand, high-speed rail can also be seen as a complement to air travel, on long-distance intercontinental routes, which can be operated by feeder routes, i.e. routes that drive demand for long-haul flights in the most important hubs [5, 6].

High-speed rail is not always developed everywhere according to a unified concept. Its arrangement is quite significantly changing both in time and in space, i.e. between different states and regions of the world. Mostly, the indicated differences are created as a result of a number of geographical, economic, social, but also political, institutional and organizational factors (for example, see [7] or [4]). From a purely operational point of view, [8] distinguish four different concepts for high-speed rail transport, specifically French, Spanish, German and Japanese.

2. High-Speed Rail Network Construction Framework in the EU. The Objective and Methodology of Analysis

High-speed rail transport is being developed in the EU as part of the Trans-European Transport Networks (TEN-T) system, which includes, in addition to the railway component, roadways, inland waterways, airports, ports and associated infrastructure [9]. The goal of its construction is to create capacity principal routes allowing intermodal transportation. The TEN-T concept was adopted for the first time in the EU in 1996, the backbone of the current TEN-T network last updated in 2013 is a total of 9 priority axes that run across the EU [10]. If we look at railways within the
TEN-T network in more detail, it can be said that their subsystem consists of two sub-components as well as different components, both the Trans-European high speed rail network (TEN-R) [11] and the Trans-European conventional rail network. TEN-R includes 7 corridors in which high speed lines should be primarily implemented. According to EU rules [12] these are:

- ‘specially built high-speed lines equipped for speeds generally equal to or greater than 250 km/h;
- specially upgraded high-speed lines equipped for speeds of the order of 200 km/h;
- specially upgraded high-speed lines which have special features as a result of topographical, relief or town-planning constraints, on which the speed must be adapted to each case.’

“Trans-European conventional rail network then includes all the other lines for passenger transportation, freight transportation, mixed traffic (both passenger and freight), hubs connected with these lines, lines connecting the components mentioned above and traffic management, tracking, and navigation systems as well” [13]. The conventional rail network is defined as a total of 9 corridors, corresponding to the current priority axes of TEN-T.

This legislation provides the framework for the creation of a unified network of European (high-speed) railways. However, interconnections between individual states or individual projects are dealt with separately, taking into account national needs and priorities. An important reality is the fact that the TEN-R (High Speed Lines Network) network was defined in the first half of the 1990s, and this corresponds to its spatial scope covering mainly only the territory of the then EU-15. Only 2 of 7 corridors are considered with a little overlap into the current EU-28 territory, this is only Corridor 6 Lyon - Budapest (via Trieste and Ljubljana and with possible extension towards the Ukrainian border via Hungary) and Corridor 7 Paris - Bratislava (via Strasbourg, Munich and Vienna, also nicknamed the “Main Line for Europe” [14]). This list has not been updated since its inception, so it does not reflect the fundamental territorial expansion of the EU after 2004, gradually by 13 new Member States in Central and Eastern Europe. Thus, in our opinion, the TEN-R network is not preparing for the deeper rail integration of the new and old EU Member States [10].

In Central European countries, which were part of the Eastern-bloc, ideas for the construction of new railway lines appeared mainly in the 1970s. The aim of these plans, however, was primarily to ensure the transport of cargo and to ease the congested rail network [8, 15]. In the vast majority of cases, these projects took the form of partial relocations, connectors and other structures to increase the operational capacity of existing networks. Moreover, all these projects were purely national in nature. Only one project implemented in Poland responded to the concept of high-speed rail: the CMK track (see below). Projects for the modernization of the railway network, often strongly inspired by the French high-speed trains, planned in these states after the change of political-economic orientation in the 1990s, also had a primarily national character [8, 16, 17]. In our opinion, the varying genesis of the idea of high-speed railways in Western and Central Europe, conditioned, inter alia, by historical and political conditions (the formation of the TEN-R network versus national modernization projects), means that the countries of Central Europe (apart from Austria) are not even connected with the Western European high-speed network, or with each other1.

This article analyzes the approaches to high-speed rails or as the case may be long-distance passenger trains applied in the five countries of Central Europe - the states of the so-called Visegrad Four, i.e. Czech Republic, Slovakia, Poland and Hungary and supplemented by Austria2. The selection of these states is due not only to their cultural similarity and geographical proximity and, with the exception of Poland, also a similar territorial and population size, but also to the sharing of a substantial part of the events of modern history (belonging to the territory of Austria-Hungary, the emergence of independent modern states after the First World War, the socialist era in the second half of the 20th century as well as the political-economic transformation in the 1990s leading to later accession to the EU). From the point of view of rail transport, the fact that during the existence of Austria-Hungary the construction of a significant part of the existing railway network took place in these countries is an interesting link between them. It is also interesting to note that, with the exception of the northern half of Poland, a strong radial orientation to Vienna and Budapest can still be seen in the tracking of railway lines in this area. However, despite these obvious common features, each of these countries is pursuing a different approach to the issue of high-speed rail, both in the recent past and in the outlook of the future. Despite many similarities, each of these countries is developing its own concept of the future development of high-speed rails.

The aim of the article is to introduce the concepts with which the fastest rail connections in the Czech Republic, Slovakia, Poland, Hungary and Austria are planned. The concept of each state is analyzed and set in a geographical context. The article focuses mainly on the tracing of transport corridors (i.e. the position of the transport corridor in relation to the settlement structure and the socio-economic structure of the state), the relationship to the existing rail network (new high-speed rail routes, the upgrading of existing sections, the combined model) and the existing or anticipated operating concept (exclusively passenger transport, combination with freight transport, only long-distance transport, combination with suburban transport, etc.). The results are commented on and evaluated in relation to the European transport network and cross-border connections.

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1 In recent years, there have been initiatives to link Central European countries through a high-speed rail (e.g. the May 2019 Visegrad Four countries’ intention [18], or the idea of a hyperloop [19]), however, only time will tell how sustainable these intentions will prove to be.

2 Germany as a close neighbor is not included in the comparison due to its different role within Europe and the European transport network. In fact, the German transport network is fully integrated into the Western European and EU transport systems and, in line with this, there is also the construction and reconstruction of high-speed lines [20].
3. High-Speed Rail Transport in Austria

Austria is the only country from the listed countries that already has high-speed rail services in its normal operation. The network has been built gradually since the late 1980s and early 1990s, and the nationally most important line connecting the two largest cities, Vienna and Linz, is now almost completed. The Austrian high-speed rail network is built mainly for 250 km h⁻¹, and in demanding mountain areas there is a reduction to around 200 km h⁻¹ in places [21].

The Austrian high-speed rail network can be divided into three segments.

1) Vienna - Linz - Munich. The most important railway direction of the state, connecting the cities of Vienna, Linz and Salzburg, with an overlap to Germany and other Western European countries. This line is basically of pan-European importance as it is part of the pan-European route Main Line for Europe, TEN-T core network railway corridor No. 8 and TEN-R corridor No. 7. The basic concept was to build a continuous four track line between Vienna and Linz, which in many sections meant the construction of a completely new line, designated the "New Western Railway", named "Neue Westbahn", which refers to the original Vienna-Linz line, labeled as "Westbahn", "Western Railway"). Another goal was the 1-2-3 system, which is the time it takes to drive from Vienna to Linz. 1 hour, to Salzburg in 2 hours and to Munich in 3 hours. The section between Vienna and Linz is already practically complete, with reconstruction between Linz and Salzburg taking place [22].

2) Munich - Salzburg - Innsbruck - New Brenner Tunnel - Italy. The importance of this connection lies primarily in linking Germany and Italy across the Alps. The so-called New Lower Inn Valley railway is part of the TEN-T core network railway corridor No. 1 and TEN-R corridor No. 1. At present, the Brenner base tunnel is being built, which is expected to significantly reduce travel on this route. The track is predominantly completed in the surface sections, the tunnel opening is expected around 2025 [23].

3) Vienna – Graz – Klagenfurt. Track with high national and international importance. The track concept is a combination of the previous two. Like the Neue Westbahn, one of the goals is a faster connection between Vienna, Austria's third largest city of Graz and the Carinthian capital Klagenfurt. This is achieved by the construction of the new Semmering base tunnel and the brand new Koralm Bahn (Koralm Railway) between Graz and Klagenfurt. In the second plan, this line is intended to enable crossing the Alps, especially by freight trains between Poland, the Czech Republic, Austria and Italy as the track is part of the TEN-T core network railway corridor No. 4. The entire connection should be operational by 2022 [24].

The basic operating concept of high-speed lines in Austria is the operation of several layers of passenger trains, in particular:

1) very fast long-distance services serving only the most important centers;
2) fast long-distance services serving other centers of an inter-regional character;
3) medium-speed long-distance links serving selected centers (centers not served by the above categories, significant nodes);
4) medium-speed combined links, moving part of the high-speed infrastructure such as long-haul trains and subsequently conventional infrastructure such as regional to suburban trains;
5) slow suburban trains, but only in selected sections of the day.

The Austrian high-speed lines are, with some exceptions, designed for combined transport, thus also enabling the operation of freight trains.

4. High-Speed Rail Transport in the Czech Republic

At present, the Czech Republic has no public route with the possibility of operating at 200 km.h⁻¹ or higher. The backbone lines, which are part of the TEN-T corridors (TEN-T core network corridors No. 4 and 5), are conventional lines and are gradually being upgraded to a maximum speed of 160 km h⁻¹ [25]. Due to the long-time horizon of modernization, there are noticeable differences in the concept of the "backbone corridor track" on the network. Initially, the preference for the original track was considered. The original routes in the lowlands and valleys allow for speeds of around 160 km.h⁻¹ without demanding relocations (e.g. Prague - Pardubice, Zábřeh - Přerov, Brno - Břeclav, Břeclav - Bohumín). However, historical routes in the valleys (Brno - Svitavy, Prague - Ústí nad Labem) were reconstructed without relocation, but for lower speeds, often less than 100 km.h⁻¹. In the second phase, relocations were used more often to facilitate faster passage through the terrain (Česká Třebová - Zábřeh na Moravě, Beroun - Plzeň). In the third and final stage up to now, it is practically a new double track, only slightly using the original single track (Benešov - České Budějovice, prepared for Brno - Přerov).

The basic operating concept of the backbone lines in the Czech Republic is the combined operation of passenger and freight trains. In terms of passenger trains, these are mainly layers:

1) long-distance passenger trains stopping only in major agglomerations and nodes;
2) long-distance passenger trains also stopping at major regional centers and hubs;
3) medium-speed combined links, driving part of the route (often in suburban areas) such as long-haul trains and in more remote areas as multi-stop regional trains;
4) slow regional trains with lots of stops
5) slow suburban trains with plenty of stops and as short as possible especially at peak times (only in large cities).

In the agglomerations of large cities (especially Prague, Brno, Ostrava), there are problems with a lack of track
capacity due to dense suburban traffic [26, 27].

Initial reflections on the high-speed rail network appeared in the Czech Republic in the 1970s, and the primary motivation for these considerations was to relieve the congested network at that time. This idea reappears in the 1990s, when the proposed network, almost entirely independent of the conventional rail network, is in the form of a "railroad aircraft", to be built for speeds of around 300 km.h⁻¹ and have only three stops in Prague, Brno and Ostrava [8]. After 2005, studies are being prepared that consider a more appropriate "German" type concept, i.e. a speed of about 200 km.h⁻¹ using selected parts of a modernized conventional network. After 2010, this network began to be referred to as “Rychlá spojení” ("Fast Links") and includes both newly built lines exclusively for high-speed traffic and upgraded existing conventional lines serving as connecting links or extensions to high-speed trains [28].

The network of fast connections in the Czech Republic is radial with a central hub in Prague (Fig. 1). The basis of the network is the new backbone line Prague - Brno - Ostrava, continuing eastwards to the Upper Silesian conurbation in Poland. This line is to become an alternative to the existing “northern” connection Prague - Pardubice - Olomouc - Ostrava and will enable the interconnection of the capital, the second (Brno) and the third (Ostrava) largest city of the state (including the extensive Ostrava agglomeration) and other regional centers. Other branches of fast connections are Prague - Ústí nad Labem - Dresden (with a possible turning to the Most area) Prague - Liberec and Prague - Hradec Králové (both with the potential to extend to Wrocław) and Prague - Plzeň (- Bavaria). A quick connection to Vienna and Bratislava is planned from Brno.

Neither the technical specifications nor the operating models of the new network are yet to be clarified. Although three less exposed sections (a new eastern exit from Prague, a southern exit from Brno and the section Přerov - Ostrava) are being prepared for construction, directional guidance of the Prague - Brno line is currently being dealt with the most. From the operational point of view, a model will probably be used, where long-distance trains between Prague and Brno without stopping will be supplemented by trains stopping at several regional terminals and trains that will ride on the new line from conventional railway lines. This concept, which aims to cut the travel time between Prague and Brno to 60 minutes for the fastest travel time trains (now about 150 minutes), is very similar to the Austrian Neue Westbahn concept [28]. However, according to Czech Ministry of Transportation, the technical specifications of lines shall be similar to France [29].

The concept of fast connections is primarily focused on domestic rail transport. With the exception of the Prague-Dresden connection, which is particularly interested in the Czech and Saxon governments, cross-border connections are more likely to be considered than actually tested. The extension of the Ostrava branch to Poland will depend on the Polish conception of lines of a similar nature, which is still very different now (see below). In addition, the interconnection of Prague and Wrocław (either via Liberec or via Hradec Králové) is perceived as hypothetical, although it could be connected to the Polish high-speed network in question. Another important unknown for the Czech Republic is the strategically important interconnection of Prague and Munich, which has the potential to significantly improve the current connection of the Czech Republic to the transport network of the so-called Blue Banana, a key urban core of the EU.

5. High-Speed Rail Transport in Poland

In the 1960s and 1970s, there was a need in Poland to overcome the congestion of conventional lines, mainly by freight transport. Centralna Magistrala Kolejowa (The Central Main Line, CMK), one of the largest constructions of this project, has been in existence since the late 1970s connecting the Warsaw and Upper Silesian agglomerations, including the metropolitan region of Krakow, Poland's second largest city. Several passenger express trains started to drive this
way from the 1980s onwards, and the track was gradually upgraded to higher speeds (from 2017 to 200 km.h⁻¹, only on part Grodzisk Mazowiecki – Idzikowice). In addition to national trains between central and southern Poland, there are also international connections to the Czech Republic, Austria, Slovakia and Hungary. The track is part of the TEN-T core network corridor No. 5 [15, 16].

From a geographical point of view, the track links exclusively to both target areas and is therefore routed as directly as possible, regardless of the locations in its vicinity. The entire section between Grodzisk Mazowiecki and Zawierce was planned without public stops, but traffic terminals on the line are gradually being opened (e.g. Opoczno Południe, Włoszczowa Połnoc). These terminals are of rather regional significance, as there is no seat of nationwide significance near the track (the largest settlement in the neighborhood, Opoczno, has only over 21,000 inhabitants).

In addition to this line, the connecting line of Warsaw-Gdańsk, a city that is part of the so-called Tri-city which is an agglomeration around Gdańsk, Gdynia and Sopot is also adapted to higher speed operation in Poland. This is a conventional railway line adapted for speeds of up to 200 km.h⁻¹. The reconstruction of the track was the result of many years of thinking about the combination of these two agglomerations. For some time, the extension of CMK to the north and the creation of a western bypass of Warsaw were being considered [16].

In addition to the reconstruction of the existing network, Poland is planning a new network of high-speed lines. The project is labeled “Linia kolej dużych prędkości Y” (High speed rail line Y) according to the shape of the network which is similar to the letter Y (Fig. 2) [30]. The new independent track for speeds of up to 350 km.h⁻¹ is supposed to have the character of the French TGV and is to connect Warsaw, Łódź, Wrocław and Poznań, i.e. large cities not yet connected to the CMK Line and the Warsaw - Gdańsk line. This project, like the network in the Czech Republic, primarily has a national character, however, the possible extension of both western branches to the Czech Republic and Germany is being considered. Line Y was to be built from 2020 and opened by 2030. There should also be a link between the Y and CMK Line [16, 30].

In the future, high-speed rail transport in Poland should therefore take the form of the French model, which will include an existing conventional network of different speeds (with regard to the CMK and Warszawa-Gdańsk route, including 200 km.h⁻¹) and the newly built, largely autonomous network for the speed of 350 km.h⁻¹. The development of a high-speed network in the form of new lines is planned for areas where rail connections from the metropolis are less suitable. From a geographical point of view, the country will be effectively connected in both the north-south and west-east directions. Although the backbone track in the west-east direction was also considered in the early 1990s, with a potential to link Berlin and Moscow, no high-speed line projects are now being considered east of Warsaw [31].

6. High-Speed Rail Transport in Slovakia and Hungary

Slovakia and Hungary now have the least sophisticated and at the same time the least specific plans for the construction of high-speed rail lines compared to all the states thus far evaluated. In Slovakia in the second half of the
1990s, a study of a high-speed railway line for a planned speed of 350 km h⁻¹ was created to connect Bratislava and Košice south (i.e. through Nitra, Zvolen and Rimavská Sobota) [17]. The aim was to create a full-fledged alternative to the so-called northern route (through Trenčín, Žilina and Poprad) and to strengthen the importance of the cities in southern Slovakia. These cities (with the exception of Nitra) are already part of the so-called southern route, which was built up to the 1950s, but this route frequently uses the original railway network and does not meet the parameters of a backbone arterial line. However, due to the structure of settlement in southern Slovakia, such a high-speed line is highly questionable. In the period before 2010, a project for the interconnection of Vienna and Bratislava by high-speed railway was also considered in Slovakia (project TEN-T 17) [32]. This line was supposed to be an extension of the previously discussed Main line for Europe [14] but the construction plan was abandoned on the basis of the economic balance sheet [33].

Instead of building new lines for high-speed traffic, Slovakia has therefore decided to undertake a major reconstruction of the backbone line, the above-mentioned northern route Bratislava - Trenčín - Žilina – Košice (Fig. 3). The goal of the reconstruction, which has been underway since the mid-2000s, is to create a track with a speed of 160 km h⁻¹ and to minimize speed drops [17, 34]. Gradually the whole line, which is the busiest line in Slovakia, should be reconstructed. Although the final reconstruction will not meet the conditions for high-speed operation, it should fundamentally speed up the connection of the most important Slovak cities. The track is also part of the TEN-T core network corridor No. 8. Interestingly, a similarly extensive modernization is not being considered in the case of the existing line connecting Slovakia with the territory of the Czech Republic with Hungary (route Břeclav – Bratislava – Štúrovo - Budapest).

Fig. 3 Scheme of backbone railway lines in Slovakia [35]

Backbone railway lines are also being reconstructed in Hungary, mostly at a speed of 160 km h⁻¹. Recently, there have been some thoughts about the creation of new high-speed lines. It should be two, probably separate, routes, one of which should be facing south to Belgrade [36-38] and the other southeast to east to Bucharest, Romania [37]. The nature of these intentions is not much known at the present time. The Budapest-Belgrade line, built with financial help of China as a part of wider planned connection from Greece to Hungary, is to be an upgrade of temporal lines with a maximum speed of around only 160 km h⁻¹ [38]. That means this line, despite its label, should not be included among high speed rails [12].

However, the space between Vienna, Bratislava and Budapest can be very important for (international) rail transport. It is a space with a high concentration of inhabitants and activities, whose distances are too short for air transport. In addition, three of the TEN-T core network corridors are crossing the territory, intersecting in Budapest: No. 5 (Germany – Hungary – Greece), no. 8 (France – Slovakia/Hungary – Romania/Bulgaria) and No. 9 (Spain - Italy - Slovenia - Croatia - Hungary), so the construction of fast railways could be a good solution. The problem, however, is that at present, international rail transport is not a national priority in this area, see the situation discussed above in Slovakia and Hungary.

7. Conclusions

High speed rails in western parts of the European Union already play a major role in the modal split in personal, and partly in freight transport. Only in this part of Europe is this specific part of the transport infrastructure built, not only on a national scale, but also with a substantial international dimension. At the same time, the construction of lines in this area is carried out according to stabilized plans and concepts. At the EU level, their territorial anchorage is represented mainly by the TEN-R network. The problem is that this network has been defined in the second half of the
1990s and therefore does not reflect at all the fundamental enlargement of the EU after 2000, with a total of 13 new Member States, mainly from Central and Eastern Europe, gradually joining the EU [10]. At the same time, these states are still planning to build high-speed rail and apply their own, uncoordinated approaches, in which they often prefer their own national territorial priorities. This hypothesis was confirmed by analysis of the situation in five Central European countries, i.e. in the Czech Republic, Slovakia, Poland, Hungary and Austria, the results of which are presented in this article.

The high-speed rail situation in Central European countries is therefore diverse and can be characterized as follows: in Austria, high-speed lines are gradually being built as an integral part of the network with an international dimension, while in the Czech Republic and Poland high speed lines are being planned as a complementary part of the network with a now weakened international dimension, and only the reconstruction of the main parts of the conventional network without high speed lines is in progress in Slovakia and Hungary. The deeper transport integration of the EU-28 territory is not taking place at least for the time being, and the geopolitical division of Europe from the second half of the 20th century remains unchanged - at least within the fast rail networks.

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Analysis and Evaluation of the Transport Services Outsourcing

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Abstract

Taking advantage of external subcontractors is used in various areas of the company's operations, including transport. The concept of outsourcing is associated with risk, but it also brings benefits, therefore its implementation must be preceded by a thorough analysis of the possible solutions.

In the study presented in this article, the analysis and evaluation of the implementation of the outsourcing concept of transport services was made using a production company that has its own fleet of vehicles which fully meets the company's needs, as an example. Several variants were presented and the best was selected based on the calculations made.

KEY WORDS: transport services, demand analysis, outsourcing, seasonality of transport

1. Introduction

The demand for transport services is shaped by economic, legal, social or climatic factors as well as demand generated in the sectors served by the transport sector [1, 8]. They often work in a systematic manner, causing changes observed in short, medium and long time intervals [2, 5]. Clear fluctuations, their repeatability and cyclicality allow companies to adapt to the market expectations and satisfy buyers' requirements [4]. It is important to extract the most important variables depending on the needs of the study. Support is provided by statistical and mathematical tools and methods commonly used in literature. Most often they are based on the stochastic processes models [2, 3], examining the impact of various important factors on the change of the dependent variable over time [8, 7]. They allow to describe the nature of the process, and based on this, formulate business management guidelines.

An example of such an analysis is presented in this article.

In addition, the study drew attention to the problem affecting many companies which, while focused on their main activity, the accompanying processes treat superficially or do not analyze them at all, not recognizing the hidden in them potential, when the obtained results could have significantly improve their functioning [4, 9].

2. Subject of the Study

The study concerns transport tasks carried out in the period from January 2016 till March 2019 at a production enterprise, in which the distribution is based on its own rolling stock. The specificity of the company's activity means that the greatest accumulation of transport tasks concerns winter months, especially from November till March (Fig. 1). The size of the fleet owned is adjusted to the demand recorded in this period and ensures the completion of all transport tasks.

![Fig. 1 Transport tasks carried out in the examined period](image-url)

The car fleet owned comprises 23 semi-trailer trucks. It was assumed that a single vehicle is able to travel a maximum of 10,000 kilometers per month, which allows to cover 230,000 km each month. The fleet is relatively new because the average age of the vehicle is 6.5 years and fully secures the transport needs taking into account the seasonality of transport, shown in Figs. 1 and 2.
Fig. 2 Average transport needs in the individual months

The average values of the kilometers covered during a month clearly differ from each other (Fig. 2). The largest indications relate to the winter months, especially January and December. The summer months are the least loaded. The measures of basic descriptive statistics for individual months are presented in Table 1.

Table 1

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<tr>
<td>January</td>
<td>225.912</td>
<td>226.340</td>
<td>221.013</td>
<td>229.956</td>
<td>4.30</td>
<td>1.91</td>
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<td>March</td>
<td>192.451</td>
<td>192.734</td>
<td>190.991</td>
<td>193.344</td>
<td>1.03</td>
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</tr>
<tr>
<td>April</td>
<td>173.845</td>
<td>172.427</td>
<td>170.022</td>
<td>180.503</td>
<td>4.75</td>
<td>2.73</td>
</tr>
<tr>
<td>May</td>
<td>166.653</td>
<td>167.315</td>
<td>160.404</td>
<td>172.239</td>
<td>5.95</td>
<td>3.57</td>
</tr>
<tr>
<td>June</td>
<td>158.275</td>
<td>156.077</td>
<td>153.802</td>
<td>164.946</td>
<td>5.89</td>
<td>3.72</td>
</tr>
<tr>
<td>July</td>
<td>151.891</td>
<td>150.558</td>
<td>150.288</td>
<td>154.826</td>
<td>2.55</td>
<td>1.68</td>
</tr>
<tr>
<td>Aug.</td>
<td>150.378</td>
<td>150.687</td>
<td>149.744</td>
<td>150.702</td>
<td>0.55</td>
<td>0.37</td>
</tr>
<tr>
<td>September</td>
<td>155.670</td>
<td>157.580</td>
<td>151.419</td>
<td>158.011</td>
<td>3.69</td>
<td>2.37</td>
</tr>
<tr>
<td>October</td>
<td>167.050</td>
<td>166.049</td>
<td>165.666</td>
<td>169.435</td>
<td>2.07</td>
<td>1.24</td>
</tr>
<tr>
<td>November</td>
<td>174.066</td>
<td>172.888</td>
<td>172.532</td>
<td>176.777</td>
<td>2.35</td>
<td>1.35</td>
</tr>
<tr>
<td>December</td>
<td>189.053</td>
<td>189.826</td>
<td>187.203</td>
<td>190.128</td>
<td>1.61</td>
<td>0.85</td>
</tr>
<tr>
<td>January</td>
<td>208.905</td>
<td>209.211</td>
<td>206.162</td>
<td>211.343</td>
<td>2.60</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Low variation coefficient in the individual groups indicates high stability of tasks, which is an important information in the aspect of transport management. The average is definitely different. Its maximum value is 225.912 thousand km, and the minimum 150.337 thousand km. This results in a very uneven loading of the rolling stock. In the summer months the usage is not full, while in winter cars are used to the limit of their capabilities. This influenced the decision to consider allocating transport services to an external company. An analysis of such a solution was made.

For the purpose of the calculations a permanent maintenance cost of one vehicle was assumed at PLN 120,000. It consists of vehicle insurance, road tax, fixed costs resulting from the employment of drivers as well as workshop service, administration, etc. The variable cost has been calculated at 1.92 PLN per kilometer of mileage. The size of the transport needs of the enterprise, measured by the total number of kilometers traveled, is over 6 934 thousand km in the period under study. The market price of road transport of goods by means of high-tonnage vehicles with a capacity of 24 tons, as of the day of analysis ranged from PLN 3 to 4 per so-called "Load kilometre". The rate of 3.50 PLN has been accepted for the calculations. Three options outlined below have been considered and compared.

3. Analysis of Transport Options

3.1. Haulage Using Own Transport Means

The monthly transport capacity of the company is 230,000 km, which fully meets its needs, which reach a maximum of 229 thousand km. The capacity reserve remaining in the most-loaded period, however, is not significant and amounts to only one thousand kilometers, which is particularly risky in the face of increased demand for transport. In the remaining months, there remains a large unused surplus, shown in Figure 3, which lists the transport capabilities of the company with the demand and the existing surplus.

The analysis carried out showed that the total transport costs incurred by the company during the analyzed period amounted to 22.700 605. Detailed calculations are presented in Table 2.
According to the calculations presented, the average monthly costs are around PLN 600 thousand. The overestimated value of the last examined period (January-March 2019) results from the fact that the survey covered only the period of highest demand for transport. It is worth emphasizing the growing number of total kilometers traveled each year suggesting that the vehicle fleet owned may soon be insufficient.

### 3.2. Passing Over the Transport Tasks to an External Company

Hiring an external company is associated with a risk primarily in terms of timeliness and quality of transport. It also requires close cooperation with the subcontractor. However, it has several benefits [6]. First of all, it enables to relieve the company from its accompanying activities and focusing on the core business. In each case, the decision must be preceded by a detailed cost analysis and risk assessment.

In the surveyed enterprise, the costs of outsourcing transport services in the analyzed period would amount to PLN 24,271,272, which means an increase of PLN 1,570,666 as compared to the costs if using own transport. Thus, on average, each month the company would have to additionally incur expenses larger by PLN 40,273. Detailed calculations are presented in the Table 3.

### 3.3. Partial Outsourcing of Transport Services

The high costs of outsourcing transport services to an external company do not negate the decision to outsource.
In the case of such high variability of the transport needs, it is worth considering a concept combining both the advantages of outsourcing and own transport, i.e. partial outsourcing. It was considered to outsource only a part of the transport to the external company. Two options for rolling stock reduction were assumed and compared. The first variant was adjusted to the average value of completed transport (about 170,000 km) and 17 vehicles were established. The total cost of such a proposal was 20,823,671 PLN, which allows to achieve savings at the level of 1,876,934 PLN per month. The detailed figures are presented in Table 4.

Table 4
Listing of the costs of partial transport outsourcing - 17 own vehicles

<table>
<thead>
<tr>
<th>Costs</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>I-III 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport potential [km]</td>
<td>2,040,000</td>
<td>2,040,000</td>
<td>2,040,000</td>
<td>510,000</td>
</tr>
<tr>
<td>Number of vehicles [items]</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Transport needs [km]</td>
<td>2,087,050</td>
<td>2,117,866</td>
<td>2,132,459</td>
<td>510,000</td>
</tr>
<tr>
<td>Own variable costs / year [PLN]</td>
<td>4,039,200</td>
<td>4,039,200</td>
<td>4,039,200</td>
<td>1,009,800</td>
</tr>
<tr>
<td>Variable foreign costs / year [PLN]</td>
<td>16,467,55</td>
<td>27,253,18</td>
<td>32,360,64</td>
<td>30,545,77</td>
</tr>
<tr>
<td>Fixed costs / year [PLN]</td>
<td>20,400,000</td>
<td>20,400,000</td>
<td>20,400,000</td>
<td>510,000</td>
</tr>
<tr>
<td>Total costs [PLN]</td>
<td>6,243,876</td>
<td>6,351,732</td>
<td>6,402,806</td>
<td>1,825,258</td>
</tr>
<tr>
<td>Total costs / month [PLN]</td>
<td>520,322,96</td>
<td>529,310,99</td>
<td>533,567,2</td>
<td>608,419,29</td>
</tr>
</tbody>
</table>

The second option was to leave 15 vehicles that would ensure meeting of the minimum transport needs recorded over three years (149 thousand km). The costs of such a solution amounted to PLN 21,229,271, which gives savings in the analyzed period in relation to the total transport using own transport means at the level of 1,471,334 and therefore about 37,726 PLN a month, with the reduction of the rolling stock by 6 vehicles. The detailed figures are presented in the Table 5.

Table 5
Listing of the costs of transport partial outsourcing - 15 own vehicles

<table>
<thead>
<tr>
<th>Costs</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>I-III 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport potential [km]</td>
<td>1,800,000</td>
<td>1,800,000</td>
<td>1,800,000</td>
<td>450,000</td>
</tr>
<tr>
<td>Number of vehicles</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Transport needs [km]</td>
<td>2,087,050</td>
<td>2,117,866</td>
<td>2,132,459</td>
<td>510,000</td>
</tr>
<tr>
<td>Own variable costs / year [PLN]</td>
<td>3,564,000</td>
<td>3,564,000</td>
<td>3,564,000</td>
<td>891,000</td>
</tr>
<tr>
<td>External variable costs / year [PLN]</td>
<td>10,046,755</td>
<td>11,125,318</td>
<td>11,636,064</td>
<td>51,545,75</td>
</tr>
<tr>
<td>Fixed costs / year [PLN]</td>
<td>18,000,000</td>
<td>18,000,000</td>
<td>18,000,000</td>
<td>450,000</td>
</tr>
<tr>
<td>Total costs [PLN]</td>
<td>6,368,676</td>
<td>6,476,532</td>
<td>6,527,606</td>
<td>1,856,458</td>
</tr>
<tr>
<td>Total costs / month [PLN]</td>
<td>530,722.96</td>
<td>539,710.99</td>
<td>543,967.20</td>
<td>618,819.25</td>
</tr>
</tbody>
</table>

Comparing the results obtained (Table 6) and non-financial benefits resulting from the implementation of outsourcing indicate that the reduction of the fleet at the enterprise and the separation of some transport needs to an external company is economically justified and should only bring benefits in the company's operations.

Table 6
Listing of all transport options during the period being considered

<table>
<thead>
<tr>
<th>Costs</th>
<th>Total by own</th>
<th>For the average</th>
<th>For the minimum</th>
<th>Total by external</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport needs in the period being</td>
<td>693,464,89</td>
<td>693,464,89</td>
<td>693,464,89</td>
<td>693,464,89</td>
</tr>
<tr>
<td>Number of vehicles</td>
<td>23</td>
<td>17</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Transport potential/month [km]</td>
<td>230,000</td>
<td>170,000</td>
<td>150,000</td>
<td>0</td>
</tr>
<tr>
<td>Transport potential for the period</td>
<td>897,000</td>
<td>663,000</td>
<td>585,000</td>
<td>0</td>
</tr>
<tr>
<td>External transport [km]</td>
<td>0</td>
<td>304,649</td>
<td>1,084,649</td>
<td>693,464,89</td>
</tr>
<tr>
<td>Variable costs, own transport/period</td>
<td>13,730,605</td>
<td>13,127,400</td>
<td>11,583,000</td>
<td>0</td>
</tr>
<tr>
<td>Fixed costs own transport/period</td>
<td>8,970,000</td>
<td>6,630,000</td>
<td>5,850,000</td>
<td>0</td>
</tr>
<tr>
<td>Variable costs external transport/</td>
<td>0</td>
<td>10,662,71,488</td>
<td>37,962,71,488</td>
<td>24,271,27,49</td>
</tr>
<tr>
<td>Total costs, own transport [PLN]</td>
<td>22,700,605</td>
<td>19,757,400</td>
<td>17,433,000</td>
<td>0</td>
</tr>
<tr>
<td>Total costs external transport [PLN]</td>
<td>0</td>
<td>1,066,271</td>
<td>3,796,271</td>
<td>24,271,271</td>
</tr>
<tr>
<td>TOTAL COST [PLN]</td>
<td>22,700,605</td>
<td>20,823,671</td>
<td>21,229,271</td>
<td>24,271,271</td>
</tr>
<tr>
<td>Savings [PLN]</td>
<td>0</td>
<td>1,876,934</td>
<td>1,471,334</td>
<td>-1,570,666</td>
</tr>
</tbody>
</table>
4. Conclusion

The analysis presented in the article indicates that the strategies in the company should be constantly monitored and adapted to the changing needs and requirements of the market. The solutions originally adopted may turn out to be insufficient in the face of dynamically changing conditions. Then, specialized external companies can become support in the implementation of tasks, allowing enterprises to focus more on the main activity, by taking some of the burden on themselves. This solution brings many benefits, both financial and organizational. Giving selected processes to an external company may also result in an increase in their quality and timeliness, but requires cooperation with a contractor and shaping relationships within the supply chain.

References

Operation Security Plan for Transport and Energy European Critical Infrastructures

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Abstract

Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection concentrates on the transport and energy sectors. In accordance with this document the primary and final responsibility for protection of the European critical infrastructures falls on the Member States and the owners/operators of these infrastructures who are obliged to implement operation security plan. Although the operation security plan is a basic legal tool in addressing the protection of a critical infrastructure element, the above mentioned Council Directive provides only very brief description of its minimum content.

The aim of this paper is to present the more detailed and sophisticated general model of operation security plan usable in both sectors of the European critical infrastructure that can be used by the owners/operators. It describes the process of operation security plan development based on the system approach to solution of all issues related to the security. The importance of ensuring the critical infrastructure protection is highlighted also by the Global Risk Report 2019 published by the World Economic Forum where the risk of „breakdown of critical infrastructure and networks“ was included among top 10 risks both in terms of impact and interconnections.

KEY WORDS: critical infrastructure, operation security plan, risk, vulnerability

1. Introduction

Critical infrastructure protection has obtained great importance worldwide. Based on current security risks and the threats, the need to define and protect critical infrastructure as an infrastructure whose disruption or destruction, for any reason, would cause the threat or breach of the political and economic running of the state or threat to life and health of the population, have arose in developed countries. The protection and defence of critical infrastructure elements has become a priority concern for the European Union, national executives, national territorial governance bodies as well as private legal entities managing critical infrastructure elements. The objective of protecting and defending critical infrastructure elements is to ensure the functionality, integrity and continuity of element activity in order to prevent, deter or mitigate the threat of its disruption or destruction [1].

2. Transport and Energy – European Critical Infrastructure Sectors

Following the attacks of international terrorism in the United States of America, Spain and the United Kingdom, the need to protect and defend critical infrastructure at national and international levels has increased significantly. That is why individual states and gradually international organizations have created institutional, legislative and organizational conditions for ensuring the protection and defence of critical infrastructure which is strategically important for the functioning of the state and whose loss could lead to a threat to people's lives, to irreversible, negative economic and social impacts on society and population [2]. In particular, a number of documents were developed at the European Union level in years 2004-2008, addressing prevention, preparedness and response to threats to critical infrastructure. The most important documents are as follows:

- Green Paper on a European Programme for critical infrastructure protection [3].
- Communication from the Commission on a European Programme for critical infrastructure protection [4].

Council Directive 2008/114/ES establishes a process for the identification and designation of European Critical Infrastructures (ECIs) and represents the first stage in relation to the phased approach to identification and designation of ECI. It focuses on the energy and transport sectors, taking into account the possibility of including additional sectors, depending on the impact assessment of this Directive. Identifying and designating ECIs on the basis of a common approach, which would also allow a joint assessment of security requirements, with the acceptance of individual sector specifications, is considered important. Under this Directive it is expected [5]:

- Establishment of an Operator Security Plan (OSP) which includes identifying important equipment, risk assessment, identifying and selecting counter-measures or procedures.
- Designating a Security Liaison Officer for communication and cooperation with competent authorities.
- Identifying the risks, threats, vulnerabilities in each sector that are shared with the responsible authorities as
part of more effective security management.
This document highlights the need for communication, coordination and cooperation at all levels, as well as the creation of European critical infrastructure protection contact points.

3. Operator Security Plans for Transport and Energy Assets as Key Critical Infrastructure Sectors

Operator security plans are a tool for increasing the security of critical infrastructure elements. Security measures implemented on the basis of processed OSP contribute both to the reduction of vulnerability and increasing the resilience of a critical infrastructure element as well as the entire society since failure of a critical infrastructure element may result in a threat to health, property or life of the population as well as to the essential functions of the state. The importance of ensuring the critical infrastructure protection is highlighted also by the Global Risk Report 2019 published by the World Economic Forum where the risk of „breakdown of critical infrastructure and networks“ was included among top 10 risks both in terms of impact and interconnections [6].

The basic structure of the OSP which is briefly described in Annex II of Council Directive 2008/114 / EC, includes:
- Identification of important devices.
- Risk analysis based on the main threat scenarios, vulnerabilities and possible consequences.
- Identifying and selecting security measures that either have a permanent character or apply graduated security measures depending on the level of risk and threats.

From the above-mentioned OSP development process follows that this is a very brief and general description which is not aimed at systematically applying the principles of designing the security of critical infrastructure elements. As far as the Slovak Republic is concerned, there is currently no generally binding regulation or a technical standard that would comprehensively address the issue of security plans for critical infrastructure objects. Therefore, the aim of this paper is to present the more detailed and sophisticated general model of operation security plan usable in both sectors of the European critical infrastructure that can be used by the owners/operators.

Development of a general OSP model can be based on the purpose for which the security plan is developed. This purpose is to create such security environment in which all negative effects on the protected object are minimized. Thus, the security plan focuses on risk management that affects the security of a critical infrastructure protected object. It is therefore possible to base the design and implementation of the security plan on the principles and general guidance on risk management. The comprehensive description of the principles, framework and process of risk management is currently defined in ISO 31000: 2018 - Risk Management.

A similar approach to critical infrastructure protection, based on the Risk Management Framework, is also applied in the United States of America within the Transportation Systems Sector-Specific Plan and Energy Sector-Specific Plan [7, 8].

Applying risk management principles under ISO 31000: 2018 to develop and implement operator security plans for critical infrastructure objects in the transport and energy sector requires adaptation of policies, practices and established practices in the sectors concerned to ensure and maintain the security of the protected element. It is therefore the introduction of individual steps of the risk management process into the element protection environment, where the process is used as a tool to create a secure environment [9].

The process of operator security plan development, based on risk management process, presents a set of coordinated and purposeful activities aimed at ensuring the security of a protected object. Based on the ISO 31000: 2018 standard, the operator security plan can be processed in structure and content as shown in Figure 1. The core of the OSP process is to determine the context, risk assessment that involves identifying, analysing and evaluating risks and risk treatment. In this context, the content of each stage of the OSP development process is as follows:

4. Critical Infrastructure Element Context

The risk assessment process is preceded by the stage of establishing the context of critical infrastructure element. In terms of security risk management, this means:
- Provide basic information about the element: general information about the operator of the element (name, registered office, name of the statutory representative ...), characteristics of the own object (purpose, dislocation, GPS coordinates, ...).
- Analyse external security environment: urbanistic characteristics of the environment, social and criminological factors, state of general security.
- Analyse internal security environment: management and organizational structure, policies and security objectives, occupational health and safety, asset inventory - identification of key assets (critical nodes).
- Identify the conditions determining the need for protection, e.g. legislation, insurance conditions, professional standards and standards, value of protected interest and etc.
- Adopt criteria for risk assessment - criteria applied in evaluation of risk significance.
5. Risk Identification

Risk identification is the process of determining the sources of risks and their causes [10]. For each key asset in the protected area, all possible risks need to be identified. In the process of identifying the risks of the object and protected areas, it is also necessary to carry out a physical inspection of the building, its surroundings and protected areas. The possible content of the identification is shown in Table 1. It includes a negative event (threat), a threat carrier which can be a social unit (individual, group, social group, etc.), a realistic scenario of the impact of the threat on important key asset functions, threat assessment (point method, qualitative, expert), vulnerability assessment (quantitative, qualitative, semi-quantitative) [11].

Table

<table>
<thead>
<tr>
<th>Risk assessment process within development of Operation Security Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk identification</td>
</tr>
<tr>
<td>Neg Event – Threat (E)</td>
</tr>
<tr>
<td>$E_1$</td>
</tr>
<tr>
<td>...</td>
</tr>
<tr>
<td>$E_n$</td>
</tr>
</tbody>
</table>

6. Risk Analysis

The risk analysis identifies the probability of the occurrence and severity of the impact of individual risks that may cause damage or failure of the key equipment. (see Table). The risk value can be determined quantitatively, qualitatively or semi-quantitatively.

7. Risk Evaluation

The security risk assessment includes a comparison of the risk size identified in the analysis process with the risk criteria identified in the context-building process. This is a decision-making process that uses one or more criteria for deciding on the priority of the final number of identified and evaluated security risks.

8. Risk Treatment

The security risk treatment is a process whereby the established security measures can be improved or new ones can be created and implemented. Risk treatment focuses on those risks that have been assessed as acceptable with monitoring and sub-measures or unacceptable which must be minimized by protective measures. The ways of the risk treatment need not necessarily be mutually exclusive or may not be appropriate in all circumstances. It should also be borne in mind that risk treatment can form new risks or modify existing risks [12, 13].
An important step is the re-evaluation and updating of operation security plans which must be carried out on a regular basis, or on an ad hoc basis.

9. Conclusions

The core of the operator security plan processing process is the assessment of security risks which includes identifying security risks, determining their size and selecting the risks that must be covered by security measures taking into account their size or severity. The effectiveness of security risk assessment is influenced by the quantity and quality of knowledge about the facts that describe the protected critical infrastructure element and the factors of security environment. From the point of view of the choice of security risk assessment methods, qualitative methods appear to be optimal as they do not require a lot of statistical data but use logical links between the factors that influence the emergence of risk. Critical infrastructure operators as well as critical infrastructure administration must pay constant attention to critical infrastructure protection and continually develop its methods and include the latest trends and knowledge in this area.

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References

Kinematic Characteristics of Zipline

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Abstract

This paper provides an analysis of the influence parameters, relevant model forming, and the procedure for determining kinematic quantities of person traveling along a tightened rope, so-called zipline. Theoretical background is consisted of two parts. The first one that includes static analysis based on catenary theory, and second that takes into account inertial forces, movement resistance, air resistance, wind effect, the position of the person during lowering, etc, on which basis it is possible to determine all necessary kinematic quantities which are essential for defining the so-called “driving characteristic” of zipline. The analysis are made by computer simulations for concrete conditions of zipline whose installation was planned on Fruška Gora, Serbia. In the simulations, the size of significant parameters such as person’s weight, rolling resistance, air resistance, wind, rope tension, lowering position, etc. were varied. Analysis results are given through diagrams that shows the person’s speed characteristics in dependence of time or travelled distance.

KEY WORDS: zipline, catenary, motion resistance, wind velocity

1. Introduction

The term “zipline” represents a system of tightened steel rope by which the person is carried by high speed travelling trolley. The trolley and person are moving under the influence of their own weight. The main aim is causing increased excitement, so-called adrenaline sport. They expanded over the past two decades, with construction in various locations such as hilly areas, parks, lakes, bridges, the city cores, etc. Fig. 1 shows an example of zipline built in the city core.

From usage and safety viewpoint, the most interesting kinematic parameters are maximum speed and acceleration, travelling time, range and speed at the end of the section (speed at limiter). The most significant size that influences those parameters is the inclination angle ($\beta$). For inclination angle larger than $10^\circ$, high speeds are achieved at the section, but also at the entry of lower station which is a significant problem for safe stopping of the person. In cases of inclination angles lower than $5^\circ$, there is a problem with arriving to the lower station, especially in cases of unfavorable wind direction or changes of the area exposed to the air flow (body position, spreading of hands, etc) during movement. For such cases, there is often a need for “pulling out” the person from the section.

Fig. 2 shows a schematic representation of zipline with main notions.

2. Theoretical Background for Analysis

Line describing the position of the elastic flexible thread, freely suspended between two supports located on the horizontal ($l$) and vertical ($h$) distance and loaded with its own weight, is known as catenary. The catenary equation is obtained in a well-known form:

$$y = C \cdot \text{ch} \left( \frac{x}{C} \right),$$  \hspace{1cm} (1)
where \( C = \frac{H}{q} \) - catenary parameter; \( H \) - horizontal component of the rope force; \( q \) – own weight of rope.

The difference of forces between any two points of rope can be determined by expression:

\[
\Delta S = S_B - S_A = q \left( y_A - y_B \right) = q \cdot h .
\]

Catenary theory provides accurate solutions, but as the use of hyperbolic functions is relatively complicated for engineering practice, the catenary is replaced by the appropriate parabola. Fig. 3 shows the possibility of replacing the catenary with a parabola. Errors in the size of the deflections made by this approximation are \( 2 \pm 3\% \). Accuracy can be increased by introducing a correction coefficient \( (k) \).

**Fig. 3 Parabola method 1**

**Fig. 4 Rope loaded with own weight and the concentrated load** [1, 2]

Parabola method obtains an equation:

\[
y = \frac{q \cdot x \cdot (1-x)}{2 \cdot H \cdot \cos \beta} \cdot k + x \cdot \tan \beta ,
\]

where \( k = 1 + \frac{\cos^2 \beta}{p} \left[ \frac{1}{p} \left( x^2 - l \cdot x + \frac{l^2}{2} \right) - 2 \cdot (l - 2x) \cdot \tan \beta \right] \) - correction coefficient and \( p = \frac{H}{q} \cdot \cos \beta \) - parabola parameter.

**Fig. 4 shows a case of steel rope, whose supports are at different heights, loaded with its own weight and concentrated loads. The equation of the trajectory of person can be represented as:**

\[
y = x \cdot \tan \beta + f_x ,
\]

where the deflection at a distance \( x_D \) at which the load is acting is represented as:

\[
f_D = \frac{x_D}{l \cdot H} \left[ Q \cdot \left( l - x_D \right) + \frac{q \cdot Q}{\cos \beta} \cdot \frac{l}{2} \right]
\]

The ropes can be fixed with both-sided anchorage (Fig. 5, a) or by anchoring one end and the tensioning with weight at other (Fig. 5, b).

**Fig. 5 Change of rope tension for: a - both sided anchored rope; b - rope tensioned with weight**

Both-sided anchored rope represents statically indeterminated system. This case is easy to realize, so it is often used for short ziplines (so-called „from tree to tree“). Case of rope that is anchored at one end and tensioned with weight at other, is generally more favorable because the rope forces aren’t changing much, there is no significant impact of the temperature and elasticity of the rope, but the solution requires more space on the pillar and the system is more expensive. Figure 5 shows the difference in the rope force change for three characteristic load positions. This paper will present the analysis for the case of a system where the rope is anchored at one end and tensioned with weight at other.
3. Relevant Model Forming

According to 1, 3 and 4 the influence of rope oscillation in vertical plane can be neglected in case of “shallow” terrain and a system where the rope is anchored at one end and tensioned with weight at other, as well as the centrifugal force due to the curvature of the path and the influence of the load swinging. In accordance to that, the relevant computational model shown on Fig. 8, can be represented as concentrated mass moving along the trajectory determined for static conditions, 5. The air resistance and rolling resistance are acting on the concentrated mass while moving. The direction of resistances is always opposite to the direction of movement. Every wheel that is rolling along deformable surface has a resistance component due the friction in wheel bearings and due to deformation of contact surfaces. Wheel that is rolling along the rope has additional resistance component due the rope stiffness. Unlike the perfectly flexible rope, the real rope will not take the position of the tangents behind and in front of the wheel (Fig. 6), which can be seen as a “wrinkling” of rope in front of the wheel.

![Fig. 6 Model of wheel rolling along steel rope](image)

Movement resistance of wheel that is rolling along steel rope can be determined by the expression:

$$ F_\mu = \mu \cdot \sum G = \left( \mu_0 \cdot \frac{d}{D} + 2 \cdot \frac{f}{D} \right) \sum G, $$

where $\mu$ - total resistance coefficient; $\mu_0$ - bearing friction coefficient; $d$ – bearing diameter; $D$ – wheel diameter; $f$ – lever arm of rolling torque; $\sum G$ - sum of vertical forces.

As the person traveling on zipline typically generates high speed, the air resistance has a significant impact on all driving parameters. The air resistance is calculated according to 6:

$$ F_w = c_w \cdot A \cdot \frac{\rho \cdot (v \pm v_v)^n}{2}, $$

where $c_w$ - drag coefficient; $A$ – frontal area; $\rho$ – air density; $v$ – person velocity; $v_v$ - component of wind velocity in the direction of movement; $n$ – dimensionless exponent depending on velocity 6.

![Fig. 7 Different cases of flow](image)

As the air density changes relatively small for some standard conditions, and the velocity is more often expressed in km/h than in m/s, formula (4) can be written in the form:

$$ F_w = 0.0473 \cdot c_w \cdot A \cdot v^2, $$

whereby the velocity ($v$) is expressed in km/h, the specific air density is taken as $\rho = 1.225$ kg/m$^3$, medium air humidity as $w = 60\%$ and medium air temperature as $t = 15^\circ$C.
Approximate values of the drag coefficient \((c_w)\) are obtained experimentally, and according to 7:

- standing person \(~0.78\);
- cyclist in an upright position \(0.53\div0.69\);
- cyclist in bent position \(~0.4\).

Based on the above mentioned, the relevant zipline calculation model is shown on Fig. 8.

**Fig. 8 Computational model**

### 4. Computer Simulations

The results of the analysis for a concrete example of zipline are represented within this point. The geometry of the route, with horizontal distance between the pillars 1263 m, drop of 126 m, and the inclination angle of \(\beta = 5.7^\circ\) is shown in Fig. 9.

**Fig. 9 Parameters of concrete zipline**

The selection of the rope type and its diameter, as well as the foreseen tensile rope force, are detailed elaborated in 8. The simulation results will be shown for the steel rope of Warrington 6x19+IWRC construction with diameter of 16 mm.

Determination of motion parameters was performed using computer simulations in the *MSC Adams* program package. As shown on Figure 9, the system has been modeled as a concentrated mass that moves along a given trajectory defined by equation (1).

The simulations were conducted for a weight of 80 kg. Areas exposed to air are depending on the persons size and the body position, which can be sitting, half-sitting or lying. Areas exposed to air flow for lowering in various position are approximately determined like:

- \(0.4\) m\(^2\) for sitting position;
- \(0.3\) m\(^2\) for half-sitting position;
- \(0.2\) m\(^2\) for lying position.

The values of drag coefficient depending on the lowering position are:

- \(c_w = 0.7\) for sitting position;
- \(c_w = 0.6\) for half-sitting position;
- \(c_w = 0.5\) for lying position.

The values of those parameters were varied during the simulations, as well as tensile rope force in range from 20 kN to 50 kN. Presentation of characteristic results as function of varied influential parameters are shown below.

The impacts of the different lowering positions are given for the case of 80 kg person.

The diagrams shown on Figures 10 and 11 are representing the simulation results for two tensile rope forces, where it is notable that, for given conditions and any tensile rope force, the seating position can’t be applied. However, half-sitting and lying positions must be carefully analyzed, because these positions are significantly more “sensitive” to changes in movement, e.g. spreading of the hands (larger surface). It can be noticed that persons are stopping at significant distance from lower station for tensile rope force of 20 kN.
5. Conclusions

For quality design, production and safe use of zipline, it is necessary to perform a detailed analysis of persons kinematic parameters in dependence from a range of influential sizes such as person’s weight, tensile rope force, inclination angle, position during lowering, wheel resistance, wind, etc. It is possible to make an optimal selection of zipline elements (rope, wheels, tensile rope force, position during lowering) by forming an adequate computational model with simulations and variation of influential sizes and determine the so-called “driving” characteristics for concretely conditions.

Air resistance can be reduced by reducing the area exposed to flow or by correct selection of the person’s position during lowering. Half-sitting and lying lowering positions can ensure the arrival of persons to the lower station even for small inclination angle, whereby it is necessary to determine the arrival speed and selection of appropriate equipment for safe stopping.

References

Theoretical Study of the Conditions of Combined Action of Materials of Old and New Concrete in the Repair and Restoration of the Structures of Transport Facilities

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Abstract

When carrying out repair work on the restoration of reinforced concrete structures of transport facilities, the technical requirements for repair compounds are determined by a number of factors, namely: adhesion and chemical compatibility of materials, compatibility with linear expansion coefficient, technology repair, cost of material, etc. Very often, the combined action of the materials of the old and the new concrete is not considered at all, although the durability and quality of the repair work depends on it. Estimation of factors that influence on structural compatibility of old and new concrete is performed in this paper. Attempt of review and choice of tools of finite element analysis with the help of which may be modeled combined action of multiplexer concrete designs is also performed.

KEY WORDS: compatibility, combined action, repair of concrete structures, stress, shear, method of finite-element analysis, mathematical modeling

1. Introduction

Analysis of existing technologies for repair and restoration of reinforced concrete structures showed that, despite the many years of experience in the use of reinforced concrete in construction, the issue of repair of structures made of concrete and reinforced concrete remains open and insufficiently researched. It should be noted that, as a rule, decision-making on repairs, restoration and replacement of structures is mainly carried out on the basis of inspection of structures. Such expertise in most cases results in adoption of unreasonable solutions to replace defective structures with the new ones. This leads to increased cost of repair and restoration work.

The experience in construction of heavy-duty concrete structures has raised a number of problems that resulted in involvement of modern information technologies. The conducted researches with the use of the latest information technologies and in particular mathematical modeling led to the development of a complex system for rehabilitation of reinforced concrete structures. The block diagram of the developed system is presented in Fig. 1.

---

Fig. 1 Block diagram of the complex system for rehabilitation of reinforced concrete structures
The efficiency of the proposed system depends essentially on filling the database of man-made structures. At present, the customers of the restoration of man-made structures do not understand the importance and necessity of creating mathematical models of structures that can have a significant economic effect at all stages of the structure operation.

The development of the system is associated with the creation of mathematical models of both typical and original designs of man-made structures and the account of defects in structures during the analysis of the bearing capacity of the investigated structure.

As a result of the research, practical data on the implementation of both individual units and the entire system are obtained. When designing and refining mathematical models of a number of structures, the structure design errors were identified due to the imperfection and limitations of existing methods for calculating the structural strength. It is also necessary to mention the lack of a regulatory framework for the repair of reinforced concrete structures with the use of modern materials and technologies.

At the next stage, the system involves the completion of various constructional and technological solutions for repairs and the use of modern repair materials based on the results of computational experiments on the developed models. Another important task during the repair work on the restoration of reinforced concrete structures is the definition of technical requirements for repair compositions and the creation of the model that will reflect the combined action of the repair material and the existing structure.

2. Research

When carrying out repair work on the restoration of reinforced concrete structures, the technical requirements for repair compositions are determined by a number of factors, namely: adhesion and chemical compatibility of materials, compatibility by the thermal linear expansion coefficient, technology of repair, cost of materials, etc. [1-3]. Very often the combined action of materials of old and new concrete during repair and restoration is not considered at all [4, 5]. Under the combined action we mean the compatibility of materials by such a parameter as mechanical strength.

For the research, a mathematical model was developed. The design scheme for testing a laboratory sample to study the combined action of materials of old and new concrete is presented in Fig. 2.

![Fig. 2 Design scheme for testing a laboratory sample](image)

The geometric and finite element models of the sample are developed in the finite element program pre-processor. Fig. 2 shows the finite-element model of a two-layer sample.

![Fig. 3 Finite element model with loads and boundary conditions](image)
The boundary conditions are taken in the form of negation along the line (indicated by a dotted line) of the displacements along the Y axis and the symmetry conditions on the axes X and Z, respectively, as shown in Fig. 3.

The first stage of the study provided the choice of the method for modeling the conditions of interaction of the old and new concrete layers when adding the load. A comparative analysis of various conditions for the interaction of the new and old concrete layers was carried out using a computational experiment.

To simulate the conditions of interactions of the old and new concrete layers we tested a linking element. The linking element combines in parallel the properties of the elastic shear, damping and the series-connected gap. The mass may be associated with one or both central nodal points. The element has one degree of freedom in each node or a central shear, rotation, pressure and temperature. The mass, elasticity, shear, damper and / or clearance can be removed from the element. The linking element is shown in Fig. 4.

The element is determined by two nodes, two elastic constants $K_1$ and $K_2$ (N/m), damping coefficient $C$ (N×c/m), mass $M$ (N×c²/m), gap size $GAP$ (m or radian) and friction force (slide restriction) $FSLIDE$ (N).

To analyze the conditions of contact interaction of layers of the two-layer concrete sample, we used the surface-to-surface contact elements. The analysis of the stress-strain state of the two-layer samples from materials of new and old concrete was carried out. We studied the conditions of combined action of materials with setting of the contact interaction conditions and the linking elements in the contact layer. The Figs. 5 and 6 present the analysis results. The dotted line represents the initial state of the unloaded sample. The displacements are increased by 2000 times for illustration purposes. The displacements normal to the contact surface for the condition of the contact interaction are equal to:

- maximum: $-0,431 \times 10^{-5}$ m;
- minimum: $0,166 \times 10^{-5}$ m;

and for linking elements:

- maximum: $-0,434 \times 10^{-5}$ m;
- minimum: $0,165 \times 10^{-5}$ m.

Normal stresses for the condition of contact interaction are:

- maximum compression: $-0,165 \times 10^{7}$ Pa;
- maximum tension: $398792$ Pa;

and for linking elements:

- maximum compression: $-0,165 \times 10^{7}$ Pa;
- maximum tension: $365427$ Pa.

The comparative analysis of the stress-strain state of the two-layer samples showed both qualitative and quantitative convergence of the calculation results when setting the conditions of contact interaction (with friction coefficient equal to zero) and interaction of the layers through the linking element.

To simulate different conditions of the shear strength of the contact layer of the two-layer sample, the conditions for contact interaction between the layers were set with different values of the friction coefficient ($\mu u = 0; 0,3; 0,7$).

![Fig. 5 Field of displacements (m), normal to the contact surface: a - conditions of contact interaction; b - linking elements](image-url)
Table 1 shows the numerical values of the combined action parameters: displacements normal to the contact surface, stresses, and intensity of stresses, both in the entire sample, and in its individual layers.

Table 1

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<td>Min</td>
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<td>Normal stresses, MPa</td>
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<td>Bottom layer</td>
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<tr>
<td>Intensity of stresses, MPa</td>
<td>Contact layer</td>
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<td>Bottom layer</td>
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Fig. 7 shows a qualitative change in the field of the intensity of stresses, depending on the coefficient of friction between the layers.
- maximum: $0.167 \cdot 10^{-5}$ m;
- minimum: $-587 \cdot 10^{-5}$ m.

Modification of the modulus of elasticity of the repair layer under different conditions of contact interaction of materials leads to significantly different results of the combined action of these materials [6, 7].

To adequately model the conditions for contact interaction of multilayered concrete samples using the finite element method, it is necessary to use an element that would work well for compression and shear and, moreover, would allow to model the bond gap between the nodes it connects (that is, between the layers) when it reaches the overstresses. The condition of the contact interaction between the concrete layers allows to adequately model the compression and shear strength (by setting the friction coefficient), but does not allow to model the separation / detachment, since it does not provide any connections between the surfaces of the contact. The linking element, in its turn, works only in one direction (does not work in shear) and as the studies showed (comparison with the contact task), it works adequately. The linking element allows modeling the bond gap when reaching a certain stress level. Thus, neither the contact element nor the linking element fully satisfies our requirements for solving the set task. One of the solutions to this problem is to modify the most similar element or to develop a new element with given characteristics based on existing ones. When determining the strength properties of the repair composition, it is also necessary to take into account the sign and the amount of deformation to the surface under repair (which in most cases is not performed to date), which in turn depends on the geometry and the magnitude of the loads acting thereon.

Modification of the modulus of elasticity of the repair layer under different conditions of contact interaction of materials leads to significantly different results of the combined action of these materials. To adequately model the conditions for contact interaction of multilayered concrete samples using the finite element method, it is necessary to use an element that would work well for compression and shear and, moreover, would allow to model the bond gap between the nodes it connects (that is, between the layers) when it reaches the overstresses. The condition of the contact interaction between the concrete layers allows to adequately model the compression and shear strength (by setting the friction coefficient), but does not allow to model the separation / detachment, since it does not provide any connections between the surfaces of the contact. Thus, neither the contact element nor the linking element fully satisfies our requirements for solving the set task.

Fig. 8 Field of displacements (m) normal to the contact surface: a - set contact layer; b - set condition of contact interaction; c - set linking elements

One of the solutions to this problem is to modify the most similar element or to develop a new element with given characteristics based on existing ones. When determining the strength properties of the repair composition, it is also necessary to take into account the sign and the amount of surface deformation of the structure under repair (which in most cases is not performed to date), which in turn depends on the geometry and the magnitude of the loads acting thereon.

3. Conclusions

The conducted researches with the use of the latest information technologies, in particular mathematical modeling, led to the development of a complex system for rehabilitation of reinforced concrete man-made structures.

The main task of the developed system is to ensure the objectivity and efficiency of decision-making for repair and reconstruction of reinforced concrete structures. For this purpose, based on the created and corrected models, it is proposed to carry out in the first stage a refined assessment of the residual bearing capacity of defective structures and the identification of the most dangerous zones of structures requiring special control.

The application of the proposed system and the methodology for modeling the interaction of the repair layer with the construction in the practice of repair and restoration of reinforced concrete structures can significantly reduce the cost of repairs due to rational choice of materials and effective technological solutions [4-6]. The use of such a system in leading organizations controlling a large number of facilities will increase the efficiency and reduce the cost of repair and maintenance works on man-made structures during their maintenance.
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